Town of Sandwich
Comprehensive Water Resources Management Plan

Needs Assessment

March 2012

Prepared for the
Town of Sandwich
by

WRIGHT-PIERCE
Engineering a Better Environment

Sandwich, Massachusetts
Comprehensive Water Resources Management Plan

Needs Assessment

March 2012

Prepared By:

Wright-Pierce
40 Shattuck Road, Suite 305
Andover, MA 01810

TOWN OF SANDWICH

COMPREHENSIVE WATER RESOURCES MANAGEMENT PLAN:

NEEDS ASSESSMENT REPORT

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A.	Evaluation of Freshwater Ponds
B.	Executive Summaries of Relevant Mass. Estuaries Project Technical Reports

Section 1

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SECTION 1

INTRODUCTION

A community generally undertakes a Comprehensive Water Resources Management Plan (CWRMP) to address some, or all, of the following issues:

- Public health concerns
- Protection of groundwater and drinking water resources
- Reduction of nutrient loading to surface waters
- Support of sustainable economic development
- Addressing aesthetic and convenience concerns attributable to wastewater issues

The current focus on Cape Cod has been on nutrient removal, particularly nitrogen which has been causing eutrophication of its coastal embayments. This issue has been driven by the widespread reliance on on-site septic systems, coupled with significant population growth Cape-wide during which period Sandwich has grown almost 870% -- from approximately 2,000 people in 1960 to approximately 21,800 people today (2010 Census). Eutrophication of coastal embayments can be reversed, and efforts are underway across Cape Cod to do so. All of the 15 communities on Cape Cod are at some point in the wastewater planning process, each with a particular focus on nitrogen/nutrient removal. Sandwich has begun its own efforts, which will culminate in approximately three years with a comprehensive plan to address the Town's portions of these nutrients and their impacts both locally and regionally.

This CWRMP will also address Sandwich's water resource protection needs more broadly for each of the other topics listed above.

- Clearly economic development is of major driver, with a recent focus on the South Sandwich Village Center. The key item which is restraining economic development in the South Sandwich Village Center is a solution to wastewater management issues..
- Historic villages like Sandwich were developed long before wastewater was a concern. One only needs to walk through the historic village and along Route 6A to see examples

of mounded septic systems, and indications of high ground water that need to be addressed.

- The contamination plumes migrating from the Massachusetts Military Reservation or the closed septage lagoons need to be considered as possible threats to groundwater, drinking water and surface water.
- Finally, there is significant interest in, and potential efficiencies from, the Town participating in a watershed-based or regional solution to address its wastewater management needs. To do so, Sandwich must first have a full understanding of its wastewater management needs. The CWRMP will position the Town to do that.

1.2 HISTORY OF WASTEWATER PLANNING

This is not Sandwich's first wastewater planning effort. The first effort was completed in October 1966, the second in June 1977, the third in September 1981, and the most recent effort in March 1990. Each wastewater planning effort concluded that wastewater collection and facilities were needed to serve specific areas of Town north of Route 6, particularly in the Town Neck and Historic Village Centers. Each time, funding for wastewater infrastructure failed at Town Meeting due to concerns about the costs of the plans (despite having significant grants available) and the fear that wastewater infrastructure would promote significant growth in Town (which occurred anyway).

1.3 CWRMP SCOPE

This latest wastewater planning process began in response to the Massachusetts Estuaries Project in 2005, when the Town began sampling efforts in its two local embayments (Scorton Creek and Sandwich Harbor), and continues with the development of this CWRMP. The CWRMP is a "town-wide", three-year plan that is being conducted in four phases, as follows:

Phase 1: Needs Assessment - identifying the wastewater needs in town

Phase 2: Development and Screening of Alternatives - evaluating solutions to address the identified needs

Phase 3: Select the Preferred Alternative and Finalize CWRMP - developing the recommended plan

Phase 4: Submit the CWRMP for Environmental Agency Review

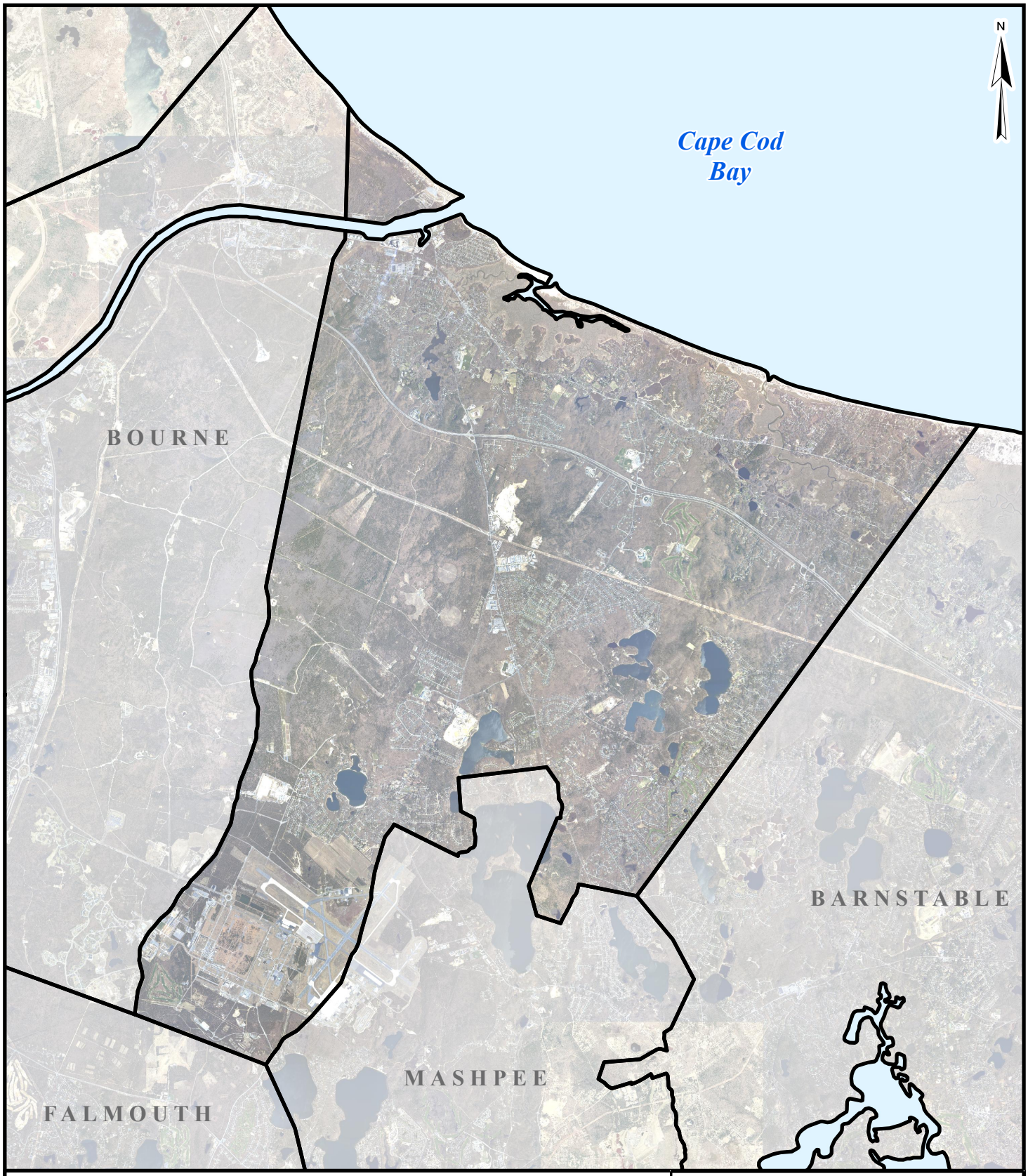
Phase 1, Needs Assessment, began in late 2010. This phase evaluates and identifies the Town's wastewater needs, and culminates with this report. Phases 2 and 3 will occur in 2012 and 2013, and Phase 4 is anticipated to be completed in late 2013 or early 2014. The "town-wide" study area shown on Figure 1-1. The CWRMP is funded in large part by a Natural Resources Damages Fund Grant administered by the Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA) (the so-called "Textron Grant").

1.4 REPORT FORMAT

This Needs Assessment report consists of 5 sections and a number of supporting appendices. Following this Introduction, the report includes these sections:

Section 2:	A summary of existing conditions
Section 3:	Documentation of water resource management needs
Section 4:	A description of expected future conditions
Section 5:	A summary of water resource management needs and the "next steps"

This report uses a variety of technical terms, abbreviations and acronyms. Table 1-1 identifies the most commonly used abbreviations and acronyms.



Source: Base data obtained from MassGIS (2009)

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Sandwich Comprehensive Water Resources Management Plan

Study Area

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TABLE 1-1
LIST OF COMMONLY USED ACRONYMS AND ABBREVIATIONS

ACEC	Area of Critical Environmental Concern
BOH	Board of Health
BOS	Board of Selectmen
CCC	Cape Cod Commission
COT	Citizen Outreach Team
Current	Covering the dates 2007 to 2009, applied to population, wastewater flow or nitrogen load conditions
CWRMP	Comprehensive Water Resources Management Plan
DEIR	Draft Environmental Impact Report
DEP	Department of Environmental Protection (Massachusetts)
DRI	Developments of Regional Impact
EIR	Environmental Impact Report
EENF	Expanded Environmental Notification Form
EOEEA	Executive Office of Energy and Environmental Affairs
ESA	Environmentally Sensitive Area
FEIR	Final Environmental Impact Report
Future	Referring to population, wastewater flows or nitrogen loads, expected at Planning Horizon (2040)
GIS	Geographic Information System
gpd	Gallons Per Day
gpd/sf	Gallons Per Day Per Square Foot
I/A	Innovative and Alternative
I/I	Infiltration and Inflow
kg/day	Kilograms Per Day
lb/yr	Pounds Per Year
MEP	Massachusetts Estuaries Project
MEPA	Massachusetts Environmental Policy Act
mgd	Million Gallons Per Day
mg/l	Milligrams Per Liter
MMR	Massachusetts Military Reservation
NHESP	Natural Heritage and Endangered Species Program
NRCS	Natural Resources Conservation Service
ORW	Outstanding Resource Water
PALS	Pond and Lake Stewards
ppm	Parts Per Million
SEIR	Single Environmental Impact Report
SMAST	School of Marine Science and Technology, University of Massachusetts at Dartmouth
SRF	State Revolving Fund (administered by Massachusetts Department of Environmental Protection)
SWD	Sandwich Water District
TMDL	Total Maximum Daily Load
USEPA	U.S. Environmental Protection Agency
USGS	United States Geologic Survey
WQAC	Water Quality Advisory Committee

Section 2

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SECTION 2

EXISTING CONDITIONS

2.1 BACKGROUND

A number of previous and on-going planning efforts have been referenced and utilized herein. The efforts utilized most frequently or which are most important are summarized below.

2.1.1 Previous Wastewater Planning Efforts

As noted in Section 1, several previous wastewater management planning efforts have been completed by the Town. Information from these efforts has been utilized in the development of this report.

2.1.2 Local Comprehensive Plan

The Town undertook a significant planning effort with its Local Comprehensive Plan (LCP) in 2009. The LCP provides the community with a strategic vision and a detailed plan to achieve that vision. The LCP is intended to serve as the basis in which to make decisions concerning the Town's growth and conservation policies for the next ten years. The LCP planning team performed a detailed evaluation of the following subject matter:

- Land Use and Growth Management;
- Natural Resources;
- Economic Development;
- Transportation and Circulation;
- Public Facilities and Services;
- Housing and Neighborhoods;
- Open Space and Recreation Resources; and
- Historic Preservation.

Much of this work has been referenced in the development of this report. The LCP planning team also developed a vision statement to guide them during the development of the LCP. This

same vision would serve a useful guide during the development of the CWRMP and is shown below.

> *"A sustainable future will support the welfare and lifestyle of residents while preserving and enhancing the environment, providing education and housing, and providing business opportunities through guided economic development. The Town of Sandwich seeks to plan its future so that the historic, community, and cultural character and natural beauty of the community can be sustained for future generations. "*

2.1.3 Stormwater Management Plan

The Town of Sandwich owns a Municipal Separate Storm Sewer System (MS4) that discharges treated and untreated stormwater to surface waters at various locations around the Town. In order to regulate discharges such as these, the Environmental Protection Agency (EPA) requires MS4 communities to obtain a permit for their discharge (NPDES Phase II) and to develop a Stormwater Management Plan. Sandwich completed its initial Stormwater Management Plan in 2004. This plan provides an assessment of Sandwich's water bodies, identifies areas of concern, and Best Management Practices (BMPs) to address those concerns and improve water quality in the community. BMPs have been installed in several areas of town to treat stormwater discharges.

2.1.4 Massachusetts Estuaries Project

The Massachusetts Estuaries Project (MEP) is being conducted jointly by the Massachusetts Department of Environmental Protection (DEP) and the School of Marine Science and Technology (SMAST) at the University of Massachusetts, Dartmouth. The MEP was initiated to identify resolutions to the problems caused by the anthropogenic nutrient loads delivered to the coastal environment. The MEP has developed and implemented a modeling approach to determine critical nutrient thresholds to the environment. This modeling approach includes simulating nutrient inputs, nutrient outputs, natural attenuation and hydrodynamic conditions and calibrating these factors to measured water quality, hydrologic and hydrogeologic conditions. The output of this effort is a MEP "technical report" for each watershed under study.

Following completion of the MEP technical reports, DEP develops a Total Maximum Daily Load (TMDL) Reports and submits it for review and approval by EPA. A TMDL Report establishes the threshold pollutant loads below which water quality impairment are not predicted to occur. These TMDLs (which can be written for any combination of pollutants including nutrients, bacteria, atmospheric pollutants, etc.) are the technical documents on which a management or implementation plan (such as this CWMRP) is based. The TMDL also forms the regulatory basis for potential enforcement actions for lack of progress toward achieving the specified requirements.

Since this modeling approach will serve as the basis for millions of dollars of infrastructure expenditures across Cape Cod, the Cape Cod Water Protection Collaborative (an agency of Barnstable County) sponsored an independent scientific peer review of the MEP work in order to address questions and concerns from the public. The scientific peer review was conducted in November 2011 by a panel of experts in the fields of estuarine water quality modeling, estuarine hydrodynamic modeling, estuarine biology, groundwater modeling, nitrogen transport in the environment, and TMDL policy and implementation. The Peer Review Panel issued a report of its findings in December 2011 which concluded that the MEP modeling approach is scientifically credible, functionally adequate and appropriate for use as the basis for management planning.

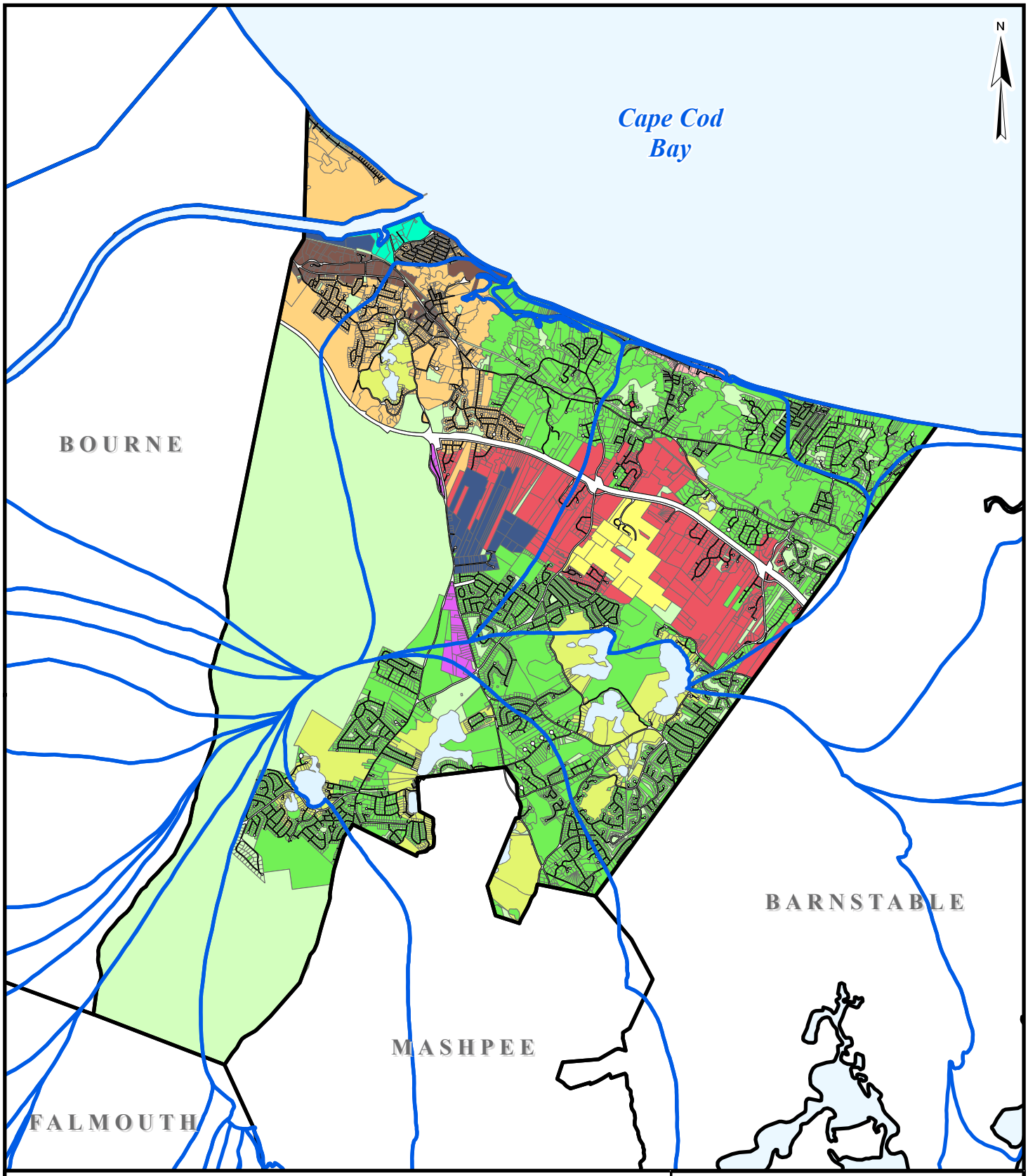
2.2 LAND USE AND DEMOGRAPHICS

Key land use and demographic data are summarized in Table 2-1 based on 2008 GIS data supplied by the Sandwich Assessor's Department. Figure 2-1 shows the 11 zoning districts and Figure 2-2 shows current land uses. The Local Comprehensive Plan divides the community into 15 Strategic Planning Areas based on zoning, parcel lines, land use patterns, topographical features, etc. A detailed description of each area can be found in Section 1 of the LCP. Figure 2-3 shows the 15 planning districts and Table 2-2 summarizes the total acres and total existing building area of each district.

TABLE 2-1
SUMMARY OF LAND USE AND DEMOGRAPHIC DATA

	Watershed										
	Barnstable Harbor	**Canal North**	**Canal South**	**Popp. Bay**	**Sandwich Harbor**	**Sandy Neck**	**Scorton Creek**	**Three Bay**	**Waquoit Bay East**	**Cape Cod Bay**	**Town-wide**
Residential											
Number of Developed Parcels	128	143	782	1,542	1,615	447	2,060	1,235	502	81	8,535
Total Lot Area, acres	123	45	224	1,201	1,477	400	1,990	939	496	61	6,956
Number of Bedrooms	428	367	2,079	4,852	5,285	1,394	6,708	3,905	1,585	220	26,823
Commercial, Industrial and Institutional											
Number of Developed Parcels	--	--	46	16	131	--	61	25	2	2	283
Total Lot Area, acres	--	--	412	420	459	--	224	532	7	1	2,055
Total											
Number of Developed Parcels	128	143	828	1,558	1,746	447	2,121	1,260	504	83	8,818
Total Lot Area, acres	123	45	636	1,621	1,936	400	2,214	1,471	503	62	9,011

Source: Sandwich Local Comprehensive Plan, 2009



Zoning Districts

- Undefined
- 5-1
- BL-1
- BL-2
- Growth
- Industrial
- Marine
- R-1
- R-2
- RIDGE
- SHORE
- SURPRO
- Watershed Boundary

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009) and MassGIS (2009)

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Sandwich Comprehensive Water Resources Management Plan

Zoning Districts

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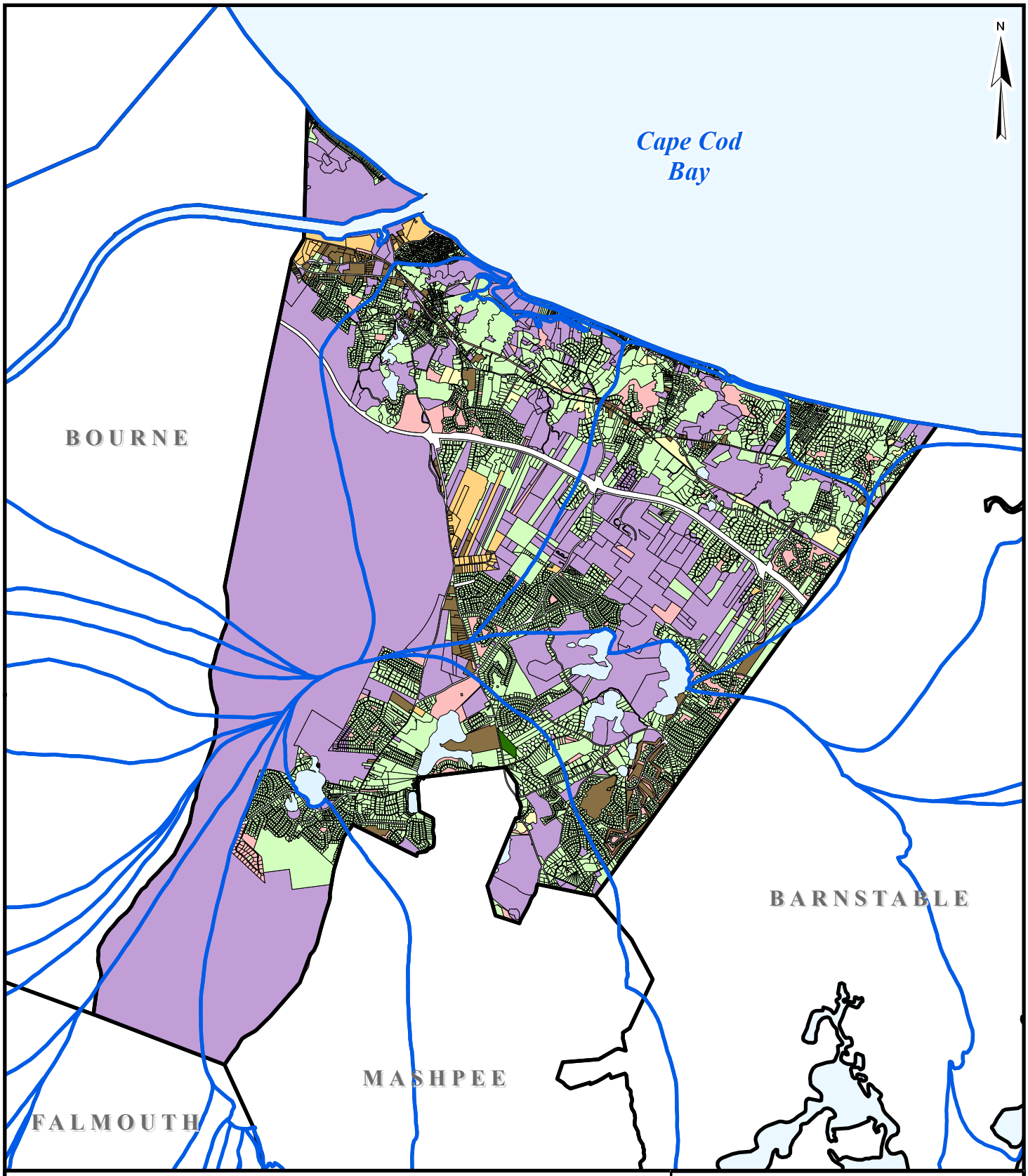

Land Use

- Unassigned
- Residential
- Commercial
- Industrial
- Agricultural
- Recreational
- Public Service
- Watershed Boundary

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009), and MassGIS (2009)

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Sandwich Comprehensive Water Resources Management Plan

Land Use

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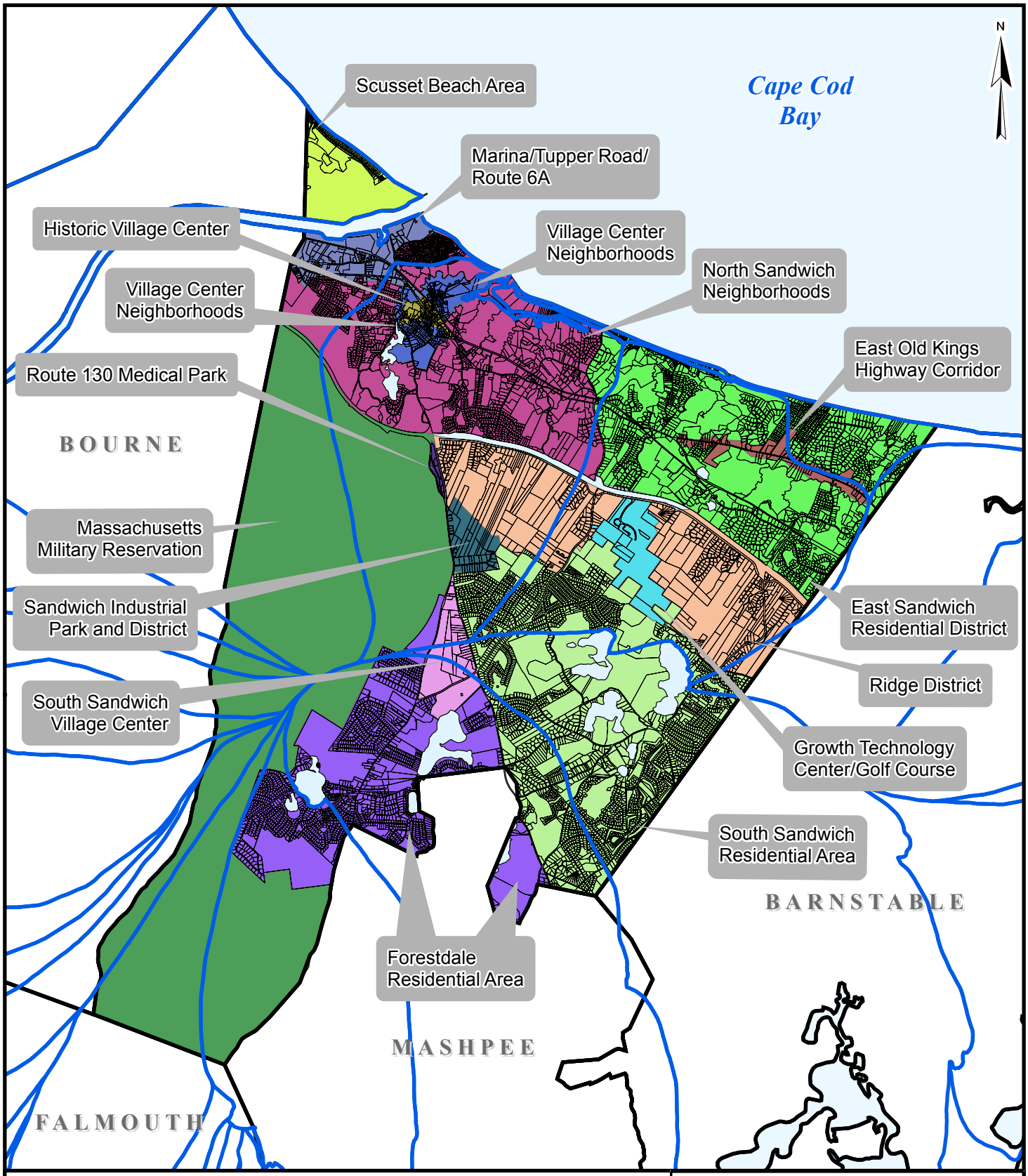

South Sandwich Village Center — Planning District (as denoted in Local Comprehensive Plan, 2009)

Watershed Boundary

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009), and MassGIS (2009)

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Sandwich Comprehensive Water Resources Management Plan
Planning Districts

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TABLE 2-2
SUMMARY OF STRATEGIC PLANNING AREAS

Planning Area Name	Total Acres	% of Total Land Area	Total Existing Building Area (sq.ft.)
East Old Kings Highway Corridor	288	1.1	260,008
East Sandwich Residential District	2,879	11.4	3,241,813
Forestdale Residential Area	2,370	9.4	2,892,395
Growth Technology Center/Golf Course	397	1.6	12,263
Historic Village Center	100	0.4	195,598
Marina/Tupper Road/Route 6A	431	1.7	696,998
Massachusetts Military Reservation	8,438	33.5	1,408,344
North Sandwich Neighborhoods	2,716	10.8	3,303,802
Ridge District	1,939	7.7	934,670
Route 130 Medical Park	62	0.2	16,478
Sandwich Industrial Park and District	444	1.8	488,033
Scusset Beach Area	588	2.3	225,446
South Sandwich Residential Area	3,869	15.4	5,756,404
South Sandwich Village Center	298	1.2	297,229
Village Center Neighborhoods	360	1.4	521,179
Totals:	24,407	100	20,250,660

Source: Local Comprehensive Plan (2009)

Sandwich is a predominantly residential community with a small percentage of parcels dedicated to commercial and industrial zoning. A little over half of Sandwich's land base is dedicated to "public use" (which the state assessors code defines as municipal federal government activities, education, charity and conservation) and includes significant undeveloped acreage. The Commonwealth of Massachusetts is the largest land owner, with most of that land associated with the Massachusetts Military Reservation. Of the remaining area, the majority of Sandwich's developed property falls within the residential zoning districts. Commercial activity is focused in the areas along Route 6A (in the Village Center), along Route 130 (in the South Sandwich Village Center and Sandwich Industrial Park), along Tupper Road and in the Marina District.

Sandwich has a total of approximately 10,500 parcels. Of these, approximately: 8,500 parcels are developed residentially; 300 parcels are used in a commercial, industrial or institutional manner; and the remaining 1,700 parcels are undeveloped. Of the land under public use, a number of those lots have been set aside for conservation and other purposes and are not developable. The land in Town is substantially developed, with just 10% of the total parcels

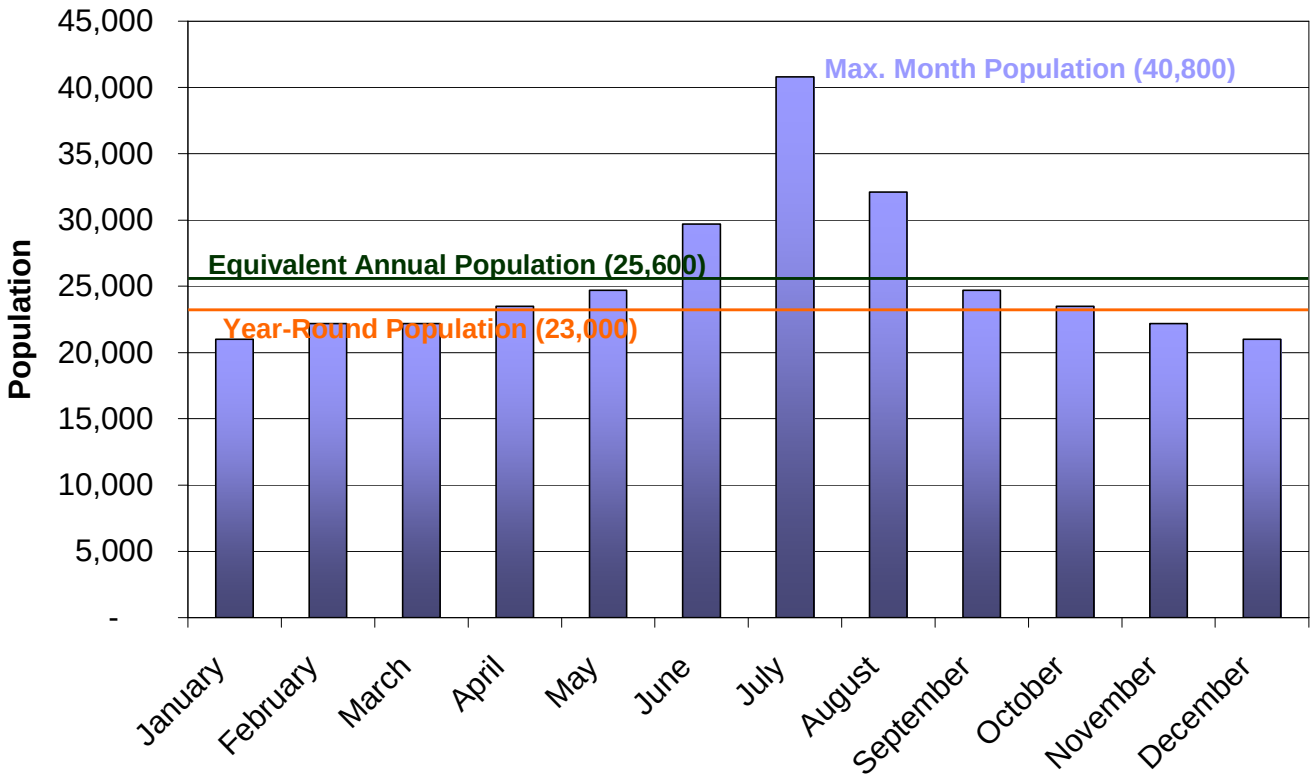
town-wide that are still considered developable.

2.3 CURRENT POPULATION

The Local Comprehensive Plan provided an extrapolation from the 2000 census, estimating Sandwich's year-round population at about 23,000 individuals in 2008. The 2010 Census estimated the year-round population at 21,800 individuals. In order to be consistent with the Local Comprehensive Plan, we will continue to utilize the 23,000 individuals as the "current" population for this project.

For the purposes of wastewater planning, we are interested in "equivalent annual population" as this takes into account seasonal population variation as well as the influence of commercial flows. Based on assessor's information, Sandwich's residential parcels are occupied 85% year-round and 15% seasonally. Using this demographic data and water use information provided by the Water District, we have inferred typical monthly population (as shown on Figure 2-4).

FIGURE 2-4
ESTIMATED MONTHLY VARIATION IN RESIDENT POPULATION



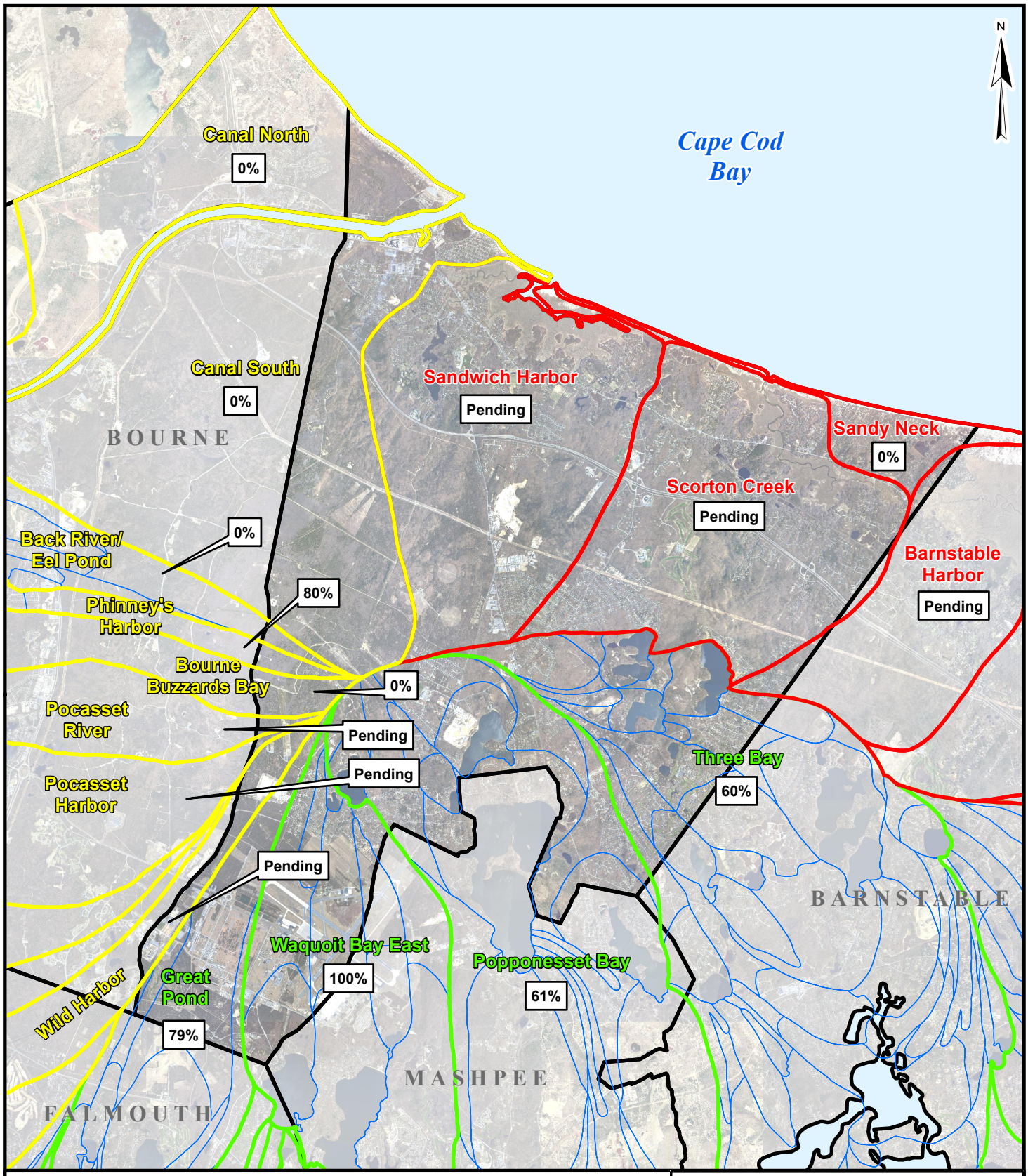
Our estimate of the current equivalent annual population in Sandwich is 25,600 (or 11% greater than the year-round population). In this calculation, a family of 4 spending 3 months of the summer would be equivalent to 1 resident for 12 months.

2.4 WATERSHEDS

All forms of groundwater recharge in the Town of Sandwich flows to one of three general areas: Cape Cod Bay, Nantucket Sound or Buzzard's Bay/ Cape Cod Canal. Within the three major watersheds, there are 15 primary watersheds as summarized below:

- The primary watersheds of Cape Cod Bay drain to the north and include: Sandwich Harbor, Scorton Creek, Sandy Neck, Barnstable Harbor, and a small portion of shore land from which flow enters enters directly into Cape Cod Bay.
- The primary watersheds of Buzzard's Bay/ Cape Cod Canal watersheds drain to the west and include: Canal North, Canal South, Back River/Eel Pond, Phinney's Harbor, Bourne Buzzards Bay, Pocasset River, Pocasset Harbor, and Wild Harbor.
- The primary watersheds of Nantucket Sound drain to the south and include: Great Pond, Waquoit Bay East, Popponesset Bay, and Three Bays.

Each of these primary watersheds can be further broken down into a dozen or more "subwatersheds" which drain to ponds, stream, wetlands, and coastal waters. This subwatershed delineation work is typically done by the Massachusetts Estuary Project (MEP) as a part of the preparation of their technical reports. The subwatershed delineations for the watersheds that have completed MEP technical reports are indicated in blue on Figure 2-5. Moving forward, only 10 of these watersheds will be considered in the CWRMP analyses (i.e. Barnstable Harbor, Canal North, Canal South, Popponesset Bay, Sandwich Harbor, Sandy Neck, Scorton Creek, Three Bay, Waquoit Bay East, and Cape Cod Bay). The other watersheds are excluded because they originate on MMR land over which the Town has no control.



Major Watersheds

- Canal and Buzzard's Bay
- Cape Cod Bay
- Nantucket Sound
- MEP Subwatershed Boundary
- 100% Aggregate Septic Nitrogen Removal Percentage (MEP Reports)

Source: Base data obtained from the Cape Cod Commision (2009) and MassGIS (2009)

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Sandwich Comprehensive Water Resources Management Plan

Major Groundwater Watersheds

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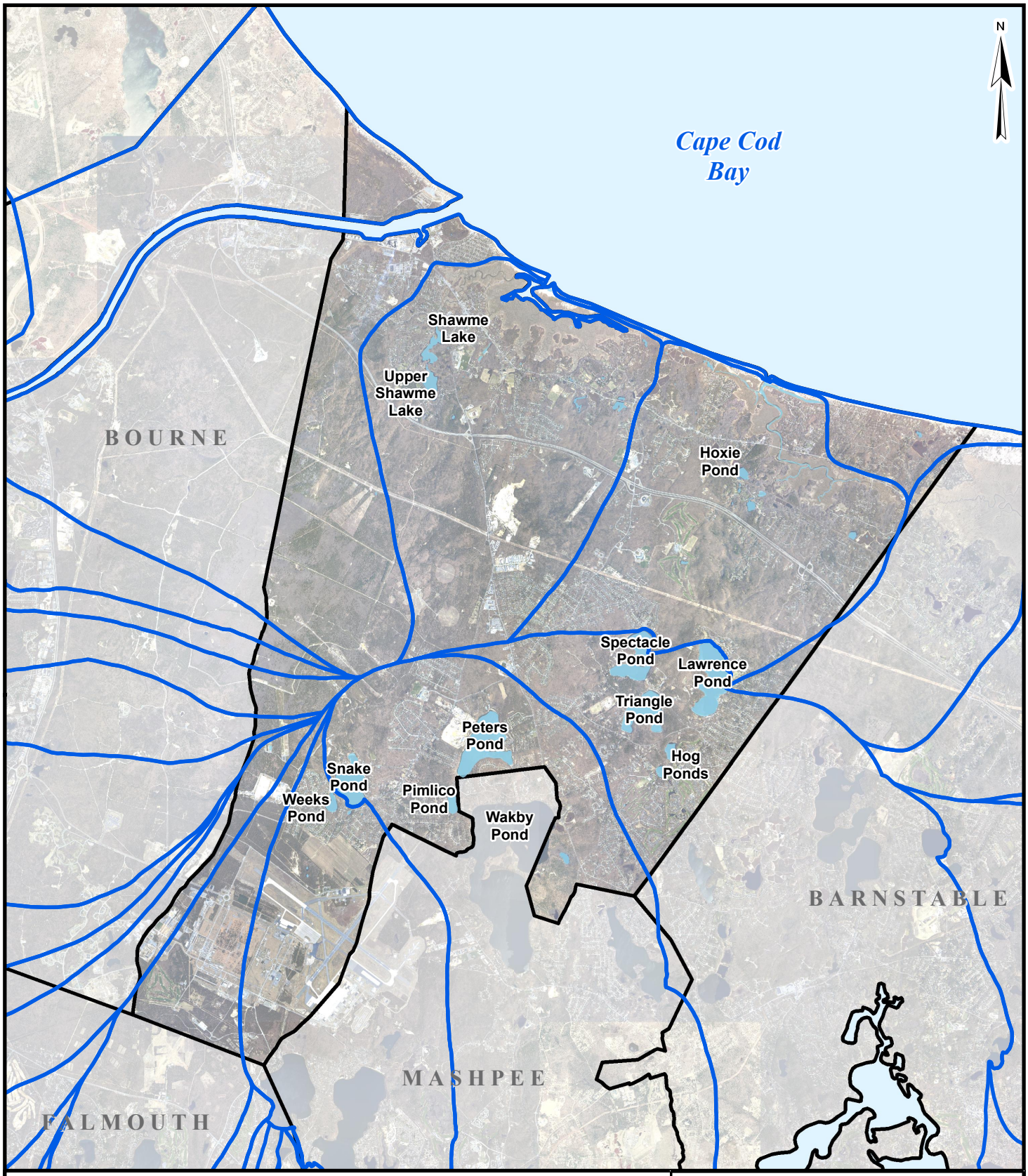
2.5 ENVIRONMENTALLY SENSITIVE AREAS

Environmentally sensitive areas (ESAs) represent significant natural resources in the town. The resources must be recognized when considering existing or potential alternative wastewater management options across town. The following section presents a summary of the ESAs identified for Sandwich based on a review of available Massachusetts Geographic Information System (MassGIS) and Town files, maps, and relevant documents. Information is provided in this section for: 1) Freshwater Ponds; 2) Coastal Embayments; and 3) Protected Areas.

2.5.1 Freshwater Ponds

Sandwich has 63 freshwater ponds. A few of the ponds are impoundments (e.g., Shawme Ponds and Twin Ponds), but most of the ponds are glacial "kettle ponds". While most of these ponds are relatively small in size, there are 6 ponds designated by the Commonwealth as "Great Ponds" (greater than 10 acres), consisting of Wakeby Pond, Lawrence Pond, Peters Pond, Spectacle Pond, Triangle Pond, and Snake Pond. In addition, we have identified an additional 7 ponds which warrant technical review based on water quality concerns identified by the Health Department, because they are of significant size, and/or because they have moderate to dense development along their shorelines. These additional ponds include Hog Ponds (Upper and Lower), Hoxie Pond, Pimlico Pond, Shawme Lake, Upper Shawme Lake, and Weeks Pond. The 11 ponds being evaluated in detail are shown on Figure 2-6. Wakeby Pond was not included in the evaluation because the entire pond and much of its watershed is located in Mashpee. Additional information from the technical review of these freshwater ponds is presented in Section 3.4.

Freshwater ponds are important because they support a broad variety of flora and fauna as well as recreational activities including fishing, boating and swimming. Unhealthy systems threaten species survival, and potentially impede or disrupt the opportunity for recreational activities. In significant amounts, nutrients like phosphorus (carried by stormwater runoff and groundwater flow) can have detrimental affects on the health of freshwater systems.



Watershed Boundary

Principal Freshwater Ponds

Source: Base data obtained from the Cape Cod Commision (2009) and MassGIS (2009, 2010)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

Freshwater Ponds

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2.5.2 Coastal Embayments

Coastal embayments, tidal creeks and inlets are important natural features throughout Cape Cod. The coastal embayments within the town limits of Sandwich are located on the north shoreline along Cape Cod Bay. Activities within Sandwich also impacts coastal embayments in neighboring towns including Bourne, Falmouth, Mashpee and Barnstable. These coastal embayments are natural systems that support a diverse group of species as well as recreational and commercial activities like swimming, boating, fishing, and shellfisheries.

All of the coastal embayments impacted by Sandwich are included in the Massachusetts Estuaries Project. The MEP technical reports will form the basis for the establishment of Total Maximum Daily Loads (TMDLs) for nitrogen. The TMDLs will formally establish the degree of nitrogen reduction required to restore estuarine water quality. According to published MEP technical reports, residential and commercial development on Cape Cod has negatively impacted estuarine water quality. The contaminant of principal concern for coastal embayments is nitrogen which primarily comes from on-site wastewater disposal, lawn fertilization, stormwater disposal, atmospheric deposition and recycling from bottom sediments. Since on-site wastewater disposal is by far the largest controllable source of nitrogen to impaired estuaries; therefore, the TMDLs will constitute a significant driving force for wastewater management.

2.5.3 Protected Areas

Environmentally sensitive areas include "protected areas", which receive additional scrutiny by regulatory agencies. These areas include Areas of Critical Environmental Concern (ACECs), Districts of Critical Planning Concern (DCPCs), wetland resource areas (including vernal pools), shellfishing areas, outstanding resource waters (ORWs), and protected lands. These areas were identified through mapping available from the MassGIS and the Cape Cod Commission and are described below.

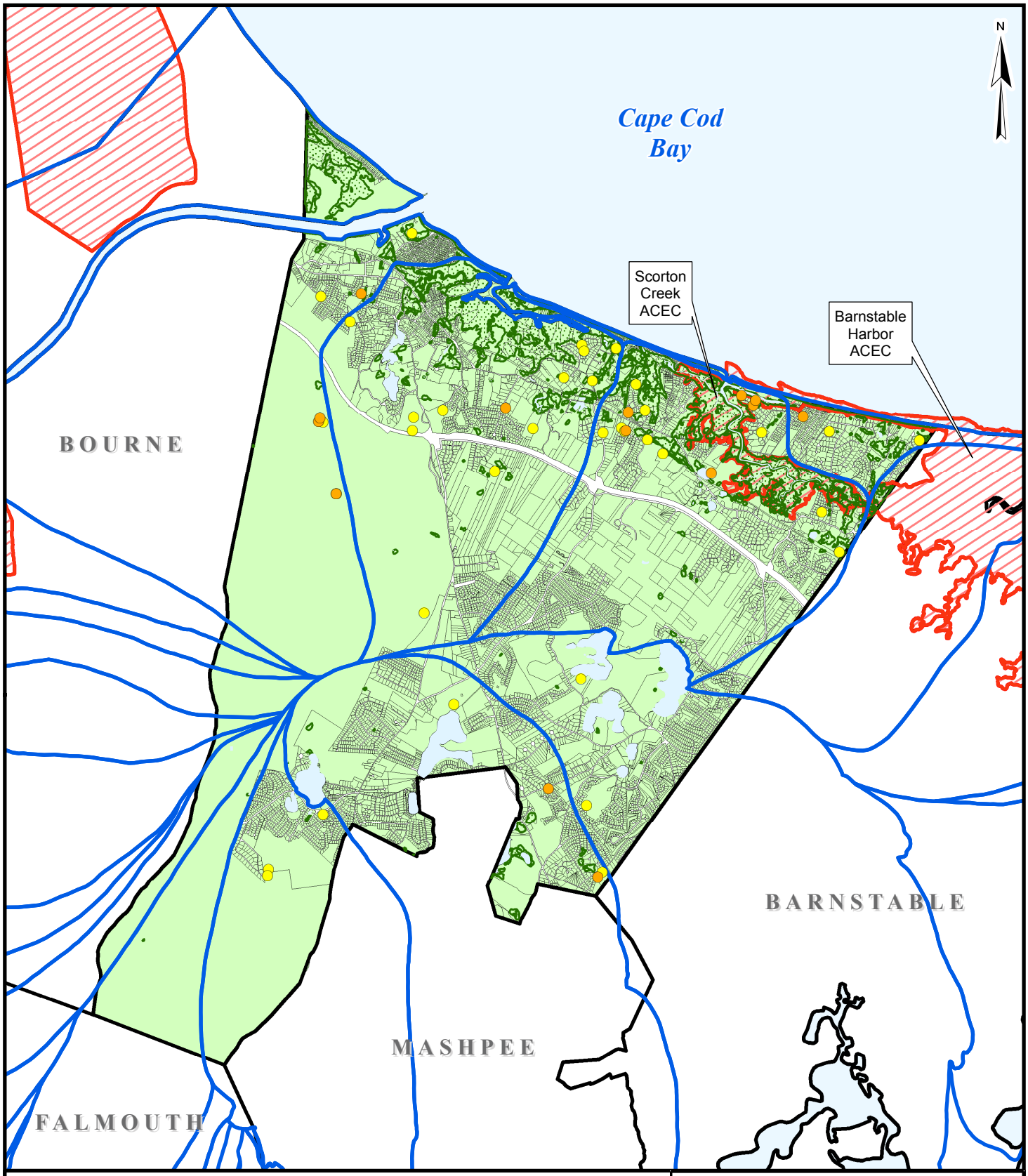
2.5.3.1 Areas of Critical Environmental Concern/ Districts of Critical Planning Concern

ACECs are natural communities that have been nominated and designated for recognition due to the presence of critical resources, wildlife habitat and scenic landscapes, among other features. The Town of Sandwich includes portions of two ACECs: Scorton Creek and Barnstable Harbor (Figure 2-7). While there are no additional rules and regulations that govern activity in an ACEC, they are given a higher level of environmental agency review when development is proposed within the boundary of an ACEC.

DCPCs are designated areas of regional, statewide or national significance that allow a town or a group of towns to adopt special rules and regulations to protect these areas. The "Three Ponds" DCPC (see Figure 2-8) was designated in 1999 and consists of a 692-acre area which encompasses the open water and shorelines of Lawrence Pond, Spectacle Pond and Triangle Pond. In the past, the Town considered designating the Sandwich coastline along Cape Cod Bay as a DCPC (LCP, page 10-9), but no further action has been taken on this topic.

2.5.3.2 Wetland Resource Areas

Wetlands, including marshes, shrub or wooded swamps, wet meadows and bogs, serve a number of vital roles in the natural environment including providing areas of valuable habitat for many species and serving as natural filters and flood management locations. Wetland resource areas in Sandwich also include salt marshes. Vernal pools are temporary pools of water which provide significant seasonal habitat for amphibians during breeding season. According to DEP mapping, the Town of Sandwich has a wide distribution of wetlands and vernal pools (Figure 2-7). Wetlands and vernal pools provide valuable habitat for many species and support recreational activities like bird watching.



Area of Critical Environmental Concern

Fresh and Saltwater Wetland

Watershed Boundary

Certified Vernal Pool

Potential Vernal Pool

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009), and MassGIS (2000, 2009, 2011)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

ACECs, Wetlands, Vernal Pools

PROJ NO: 12217A	DATE: Dec 2011	FIGURE: 2-7

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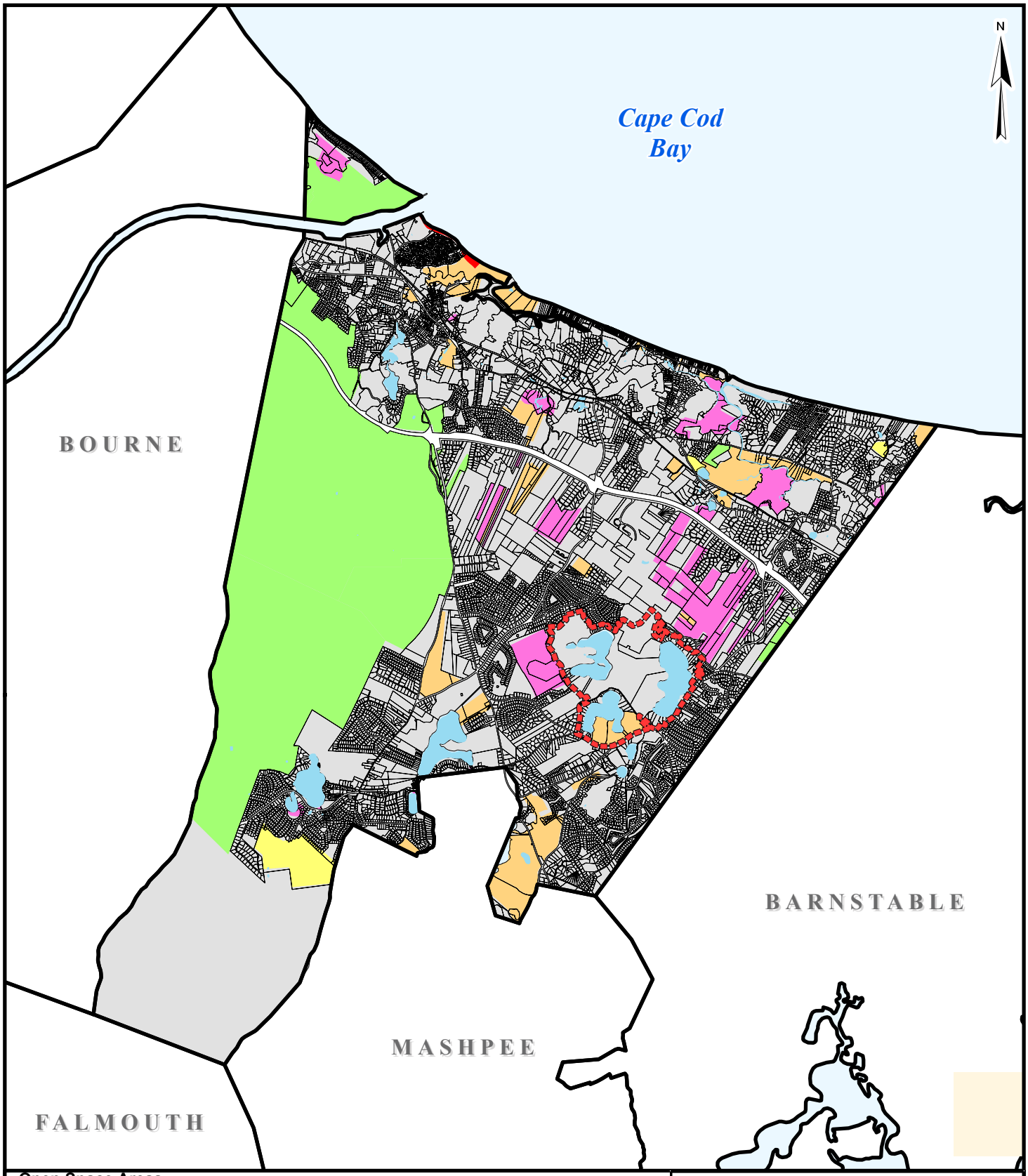

Open Space Areas

- Agriculture
- Recreation and Conservation
- Conservation (non-facility based activities)
- Recreation (facility based activites)
- Unknown
- Non-Open Space
- ThreePonds DCPC

Source: Base data obtained from the Town of Sandwich (2011) and MassGIS (2009, 2011)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

Open Spaces and District of Critical Planning Concern

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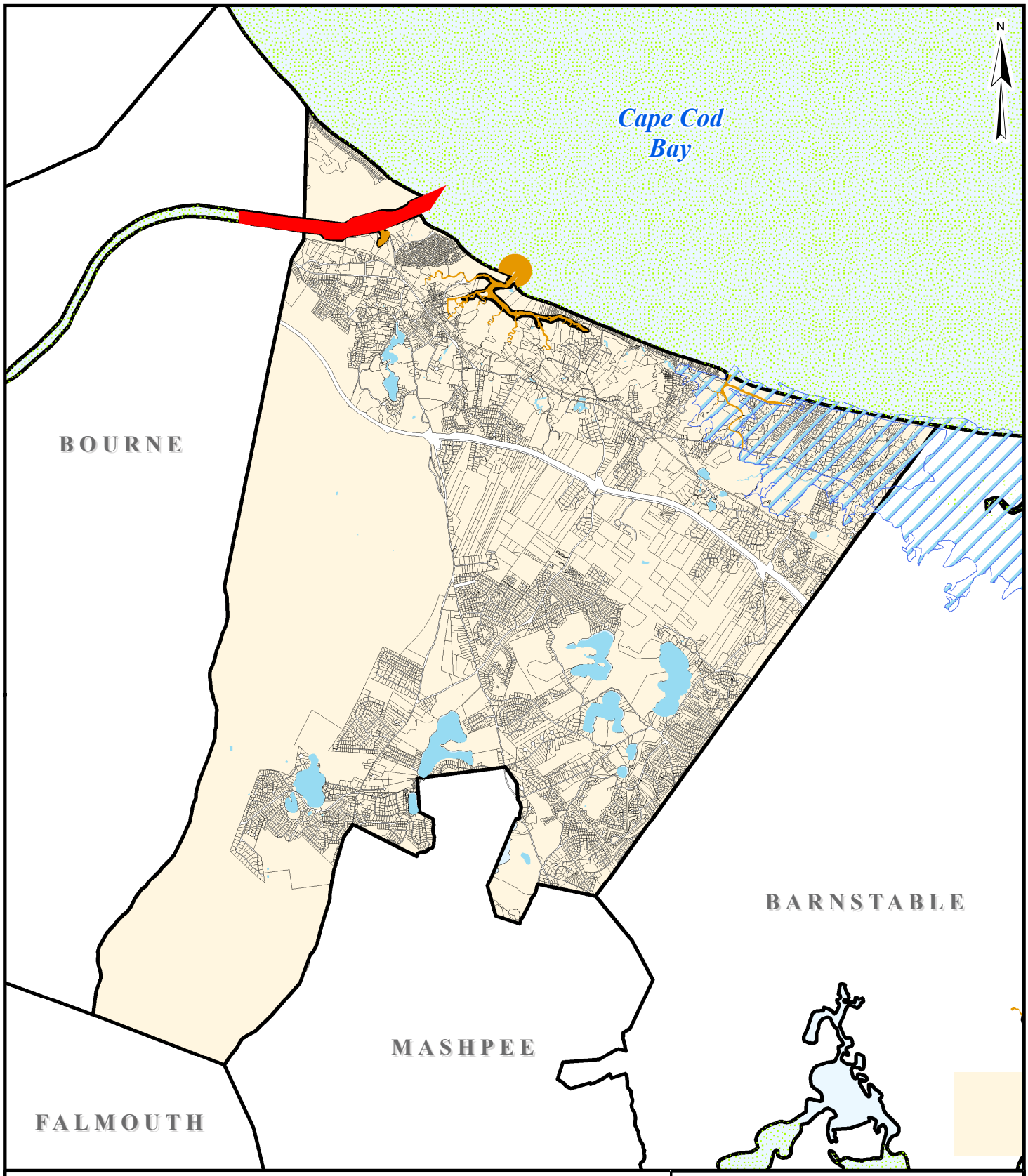
2.5.3.3 Parks, Open Space and Conservation Lands

Currently, over half of Sandwich's land base is categorized as" public use" in assessor's records. Much of that land is under the governance of the Massachusetts Military Reservation (MMR), and most of the remaining land is designated open space or protected lands (Figure 2-8). Some of this land is held as privately-owned open space land, including private land trusts and the Sandwich Conservation Trust (which manages land owned in fee and held in conservation restrictions). Federal and state-owned lands of significance include MMR (a significant portion remains undeveloped), and the Shawme-Crowell State Forest, which is managed by the Massachusetts Department of Conservation and Recreation (DCR).

2.5.3.4 Shellfishing

MassGIS has an available data layer of designated shellfish growing areas (2009) and shellfish suitability areas (2011). This data layer depicts areas of potential shellfish habitat and their respective harvest classification. According to this information, the open waters in Sandwich are classified as “Approved,” which is indicative of general compliance with applicable water quality standards (Figure 2-9). The Canal is a restricted growing zone.

For many years, Sandwich had two significant shell fishing areas -- Scorton Creek (50 acres) and Sandwich Harbor (84 acres). These areas were habitat for blue mussels, soft shelled clams, and quahogs. These beds were closed in 1972 due to pollution and bacterial contamination attributed to stormwater runoff and contamination from septic systems. After more than 30 years of aggressive efforts by the Towns' Departments of Health, Public Works, Natural Resources, and the Massachusetts Division of Marine Fisheries, the Town was granted permission to reopen a significant portion of the Sandwich Harbor estuary in 2009. As of this date, the remainder of the Sandwich Harbor and Scorton Creek shellfish beds remains closed for harvesting. The CWRMP will evaluate whether or how wastewater or Stormwater treatment and disposal practices impact shellfisheries.



Shellfish Suitability

- Blue Mussel
- Ocean Quahog
- Quahog
- Sea Scallop
- Surf Clam

Shellfish Growing Area

- Approved
- Prohibited
- Restricted

Outstanding Resource Waters

Source: Base data obtained from the Town of Sandwich (2011) and MassGIS (2009, 2011)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

Shellfish Suitability

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2.5.3.5 Outstanding Resource Waters

ORWs constitute water bodies or the watershed of a waterbody that are designated for protection under Massachusetts surface water quality standards due to high ecological, recreational, or aesthetic values. ORWs include drainage sub-basins, water supply watersheds, and ACECs. The Scorton Creek, Sandy Neck, and Barnstable Harbor watersheds are mapped as ORWs (Figure 2-9). These resources may warrant additional investigation and/or protection when considering the effects of nitrogen loading, potential wastewater management options across town or existing/proposed stormwater drainage systems throughout town.

2.5.3.6 Floodplains

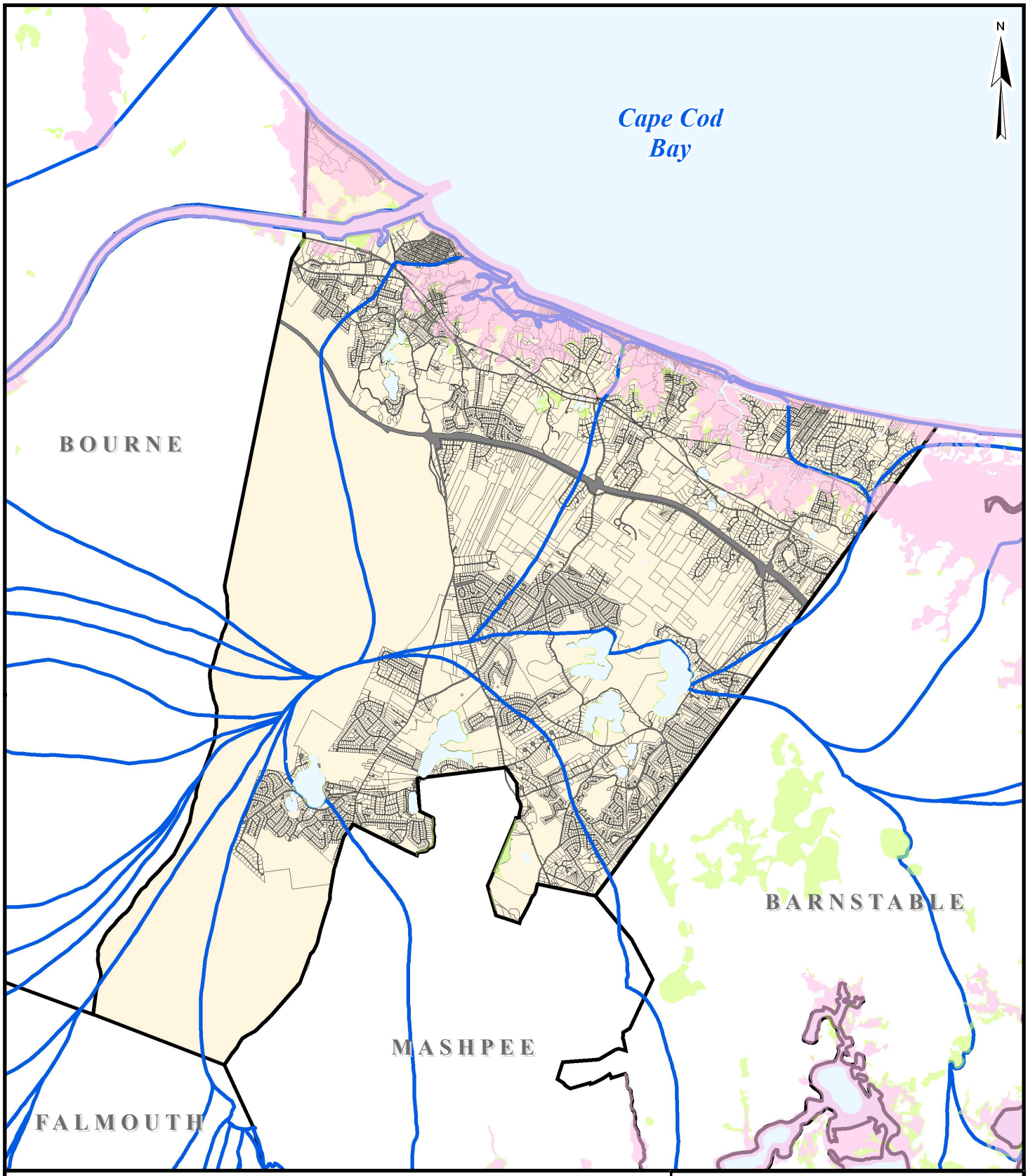
Figure 2-10 shows the extent of lands that are mapped by the Federal Emergency Management Agency (FEMA) as flood hazard areas based on a statistical 100 year and 500 year flood recurrence intervals. The mapped 100-year flood zones exist primarily along the north shore, and follow the low-lying tidal creeks and the mapped 500-year flood zones extend around the perimeter of all major ponds and the upper extents of marine embayments. The extent of floodplains must be taken into consideration in the siting of wastewater infrastructure. FEMA is currently updating the floodplain mapping in Sandwich.

2.5.3.7 Sole Source Aquifer

All of the groundwater on Cape Cod has been designated as a Sole Source Aquifer by the USEPA. Sandwich's water supply comes from the Sagamore Lense groundwater acquifer. Protection of this resource is critical to the sustainability of the town's water supply. Impacts to groundwater quality need to be considered with respect to current and potential future land development and wastewater management perspectives.

2.5.3.8 Habitat of Rare and Endangered Species

Much of the land in Sandwich has been determined to be within Priority Habitat of Rare Species, as documented in the most recent posting of data at MassGIS (2008), see Figure 2-11. The Natural Heritage and Endangered Species Program (NHESP) at Massachusetts Fish and Wildlife is in the process of issuing new priority habitat mapping. Based on existing information,



100-year flood plain

500-year flood plain

Watershed Boundary

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009) FEMA (1997), and MassGIS (2009)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

Floodplains

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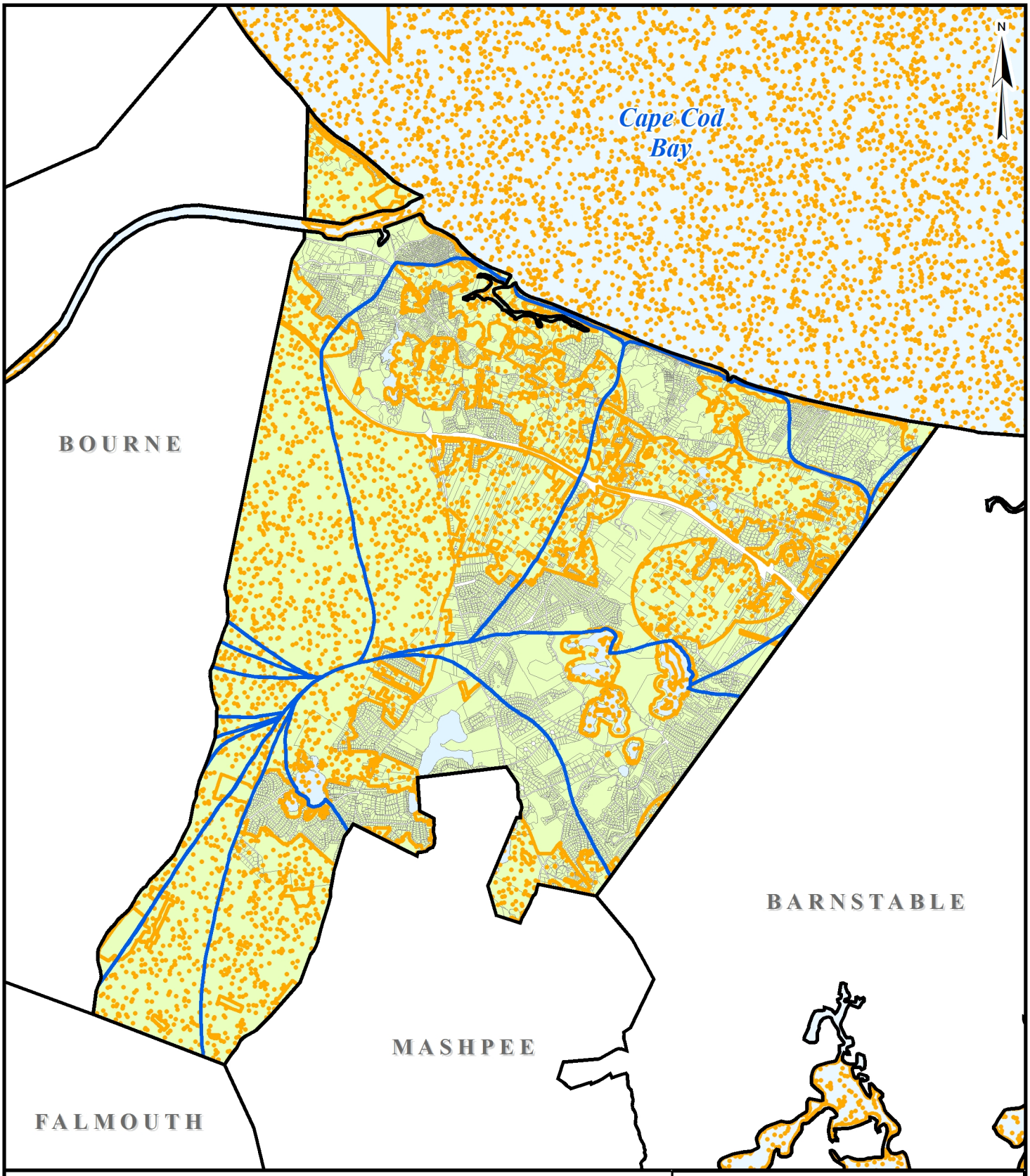

Priority Habitat of Rare Species

Watershed Boundary

Freshwater Pond

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009), and MassGIS (2008, 2009)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

Priority Habitat of Rare Species

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numerous endangered species (e.g., box turtles, dragonflies and plant species) have been identified throughout Sandwich. When the new mapping is issued, it needs to be reviewed to determine if existing or proposed wastewater management practices are or will cause undue impacts on the habitat of rare or endangered species.

2.6 SOILS

Soil conditions are important in selecting sites for treated stormwater disposal, wastewater effluent disposal as well as for sanitary needs screening for Title 5 compliance. The rate at which effluent can percolate through soil directly impacts the size, design, viability and longevity of effluent disposal systems. It also impacts how much "natural treatment" occurs prior to reaching a waterbody. From the standpoint of stormwater and wastewater disposal systems, most of the Cape benefits from sandy soils (i.e. well drained soils). However, the United States Department of Agriculture's Soil Conservation Service characterizes all soils present on Cape Cod as "severe" for the category of septic tank absorption/leaching fields (Soil Survey of Barnstable County MA, March 1993, Table 11) due either to poor percolation or rapid drainage.

Soil suitability determinations begin with soil classifications from the Natural Resources Conservation Service (NRCS). Overall, poorly drained soils are not well-suited for large-scale disposal systems but may be acceptable for siting small or individual on-site disposal systems. It is common for soils rich in peat or loam to support natural wetlands where groundwater remains at or near the surface for part or all of the year. Silt and clay soils can create a perched groundwater condition that impact septic system siting and design. Shallow depth-to-groundwater conditions generally occur along the low-lying land along the north shore. Most commonly, well drained soils are a considerable distance above the groundwater table. When selecting sites for effluent disposal, sites with well-drained soil should take priority over sites that have moderately drained material.

In Sandwich, the majority of soils are well drained and consist of sands and silty sands. Moderately well drained soils are typically loamy sands; poorly drained soils are classified as peat- or muck-based which are predominately associated with wetlands and generally located

near low lying or near shore areas. Figure 2-12 highlights the location of soil type by these three major categories. The approximate land area covered by these types of soil town-wide is listed below.

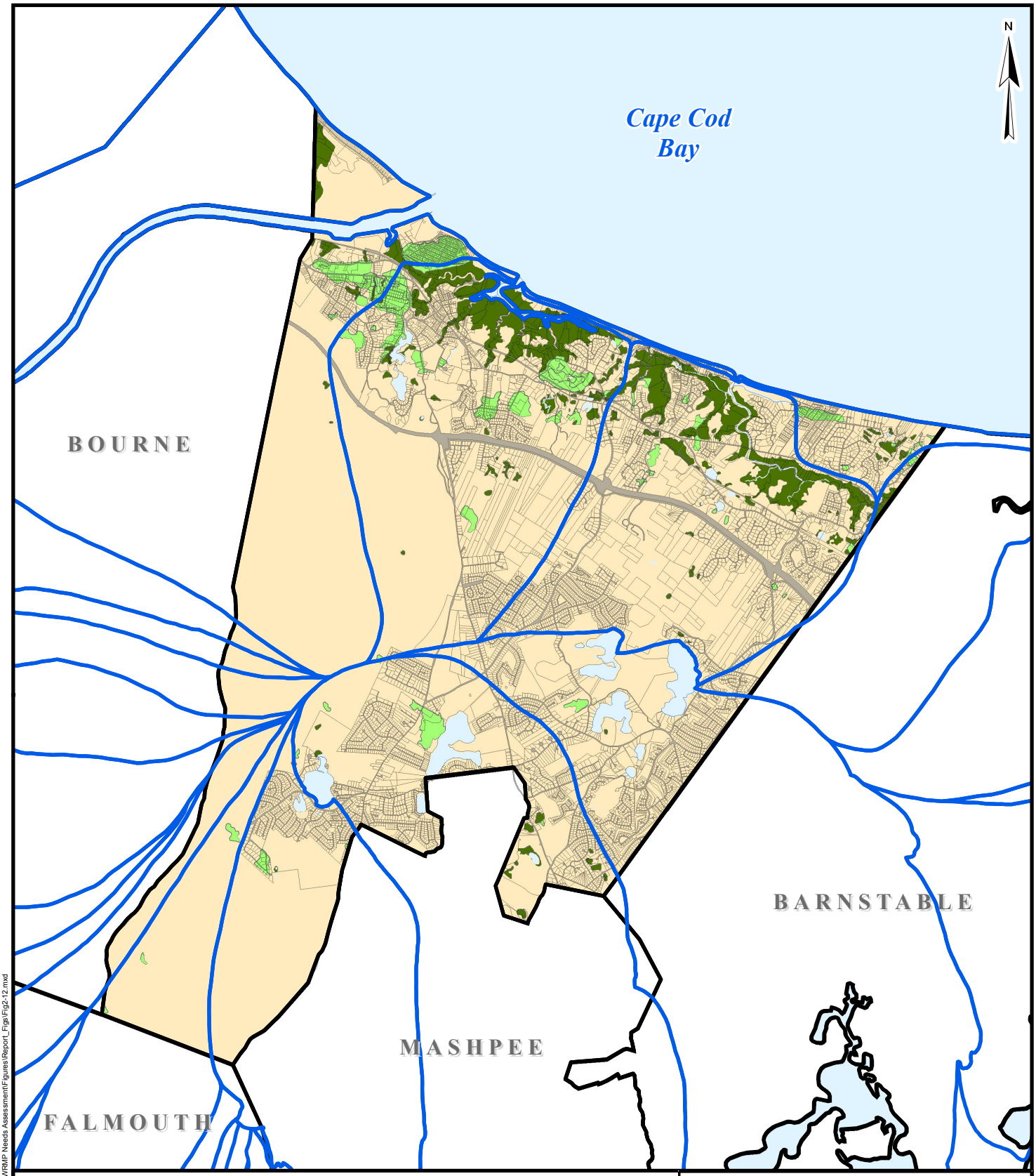
- Well drained soils 90 %
- Moderately well drained soils 5 %
- Poorly drained soils 5 %

Much of the poorly drained soils are located in the Town Neck and Village Center areas.

Note that the NRCS data serves as a starting point for determining soil suitability because it only classifies the top-most soil strata. When looking to quantify effluent disposal capacity at potential effluent disposal site, some level of additional subsurface explorations are always necessary (e.g., test pits, perc tests, soil borings, monitoring wells, infiltrometer testing, load cell testing, etc.). Subsurface investigations need to be targeted to determine items such as seasonal groundwater elevation, classification of deeper soil strata, and vertical and horizontal permeability/conductivity rates.

2.7 GROUNDWATER

Groundwater quality is generally very good in Sandwich. Documented contaminant plumes exist at the site of the former septage lagoons (Sandwich Harbor watershed) as well as on MMR, where multiple jet fuel leaks, multiple oil and hazardous materials releases and historic and on-going wastewater effluent disposal have occurred (primarily in Canal-facing watersheds). Other potential threats have been identified based on land use type at multiple locations throughout Town as shown on Figure 2-13. Overall, groundwater contamination has not impeded the Town's ability to meet public drinking water demands.



Well Drained Soils

Moderately Drained Soils

Poorly Drained Soils

Watershed Boundary

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009) and MassGIS (2009)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

Soil Conditions

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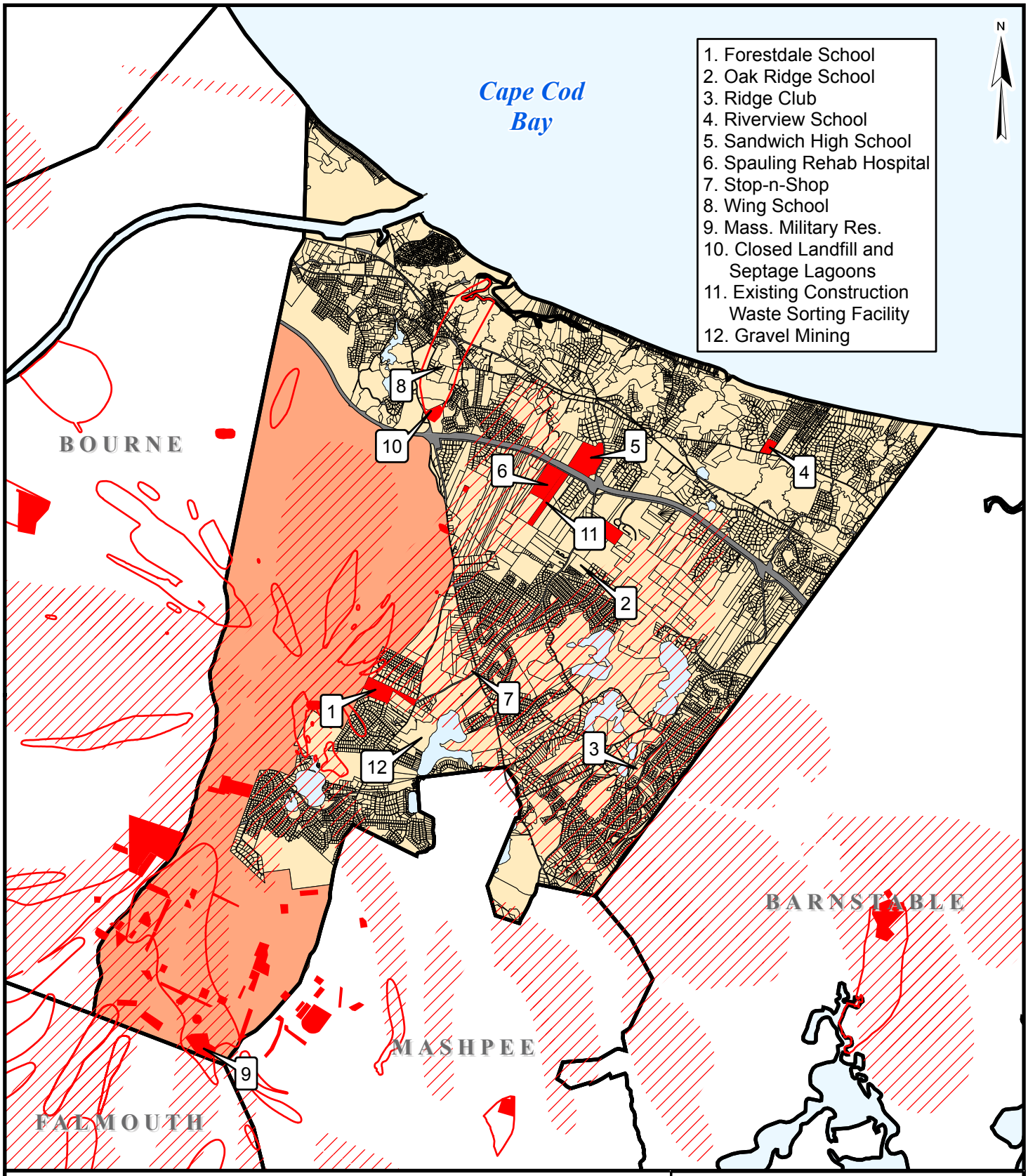

Zone II's

Potential Contamination Plume

Groundwater Threat Site

MMR Land

Source: Base data obtained from the Town of Sandwich (2011) and MassGIS (2009, 2011)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

Groundwater Threats

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2.7.1 Drinking Water Infrastructure

The Sandwich Water District (SWD) has a public water supply system consisting of 11 groundwater wells and approximately 146 miles of water main. The water supply receives treatment for (household plumbing) corrosion control and periodically with small quantities of chlorine. The SWD and the Upper Cape Regional Water Supply Cooperative (UCRWSC) carefully monitor development in the watersheds which contribute to this aquifer. The service area for the SWD is shown in Section 3 on Figure 3-5.

2.7.2 Wastewater Infrastructure

The Town owned and operated a septage disposal facility located on Gully Lane (just off Route 130) from 1981 to 1993. This facility had two unlined septage receiving lagoons and six leaching beds and was permitted for 13,400 gallons per day (gpd). The facility was closed in 1993 by direction of the DEP.

The Town also owns and operates several small wastewater treatment facilities that serve the public schools -- Wing School, Forestdale School, Oak Ridge School, and the Sandwich High School. The facilities are approaching the end of their design life and will require some investment in the upcoming years. The Town does not have a "traditional" publically owned treatment works (POTW) or a collection system.

MMR has a wastewater collection, treatment and disposal system on the base. The collection system is located in Sandwich and Falmouth, the treatment system is located within Sandwich and the disposal system is located in Bourne. MMR and Massachusetts Development Finance Agency have initiated a study to evaluate how to manage the facility and its excess capacity.

There are 3 private wastewater systems located around town; however, the vast majority of residents and businesses in town rely on traditional septic systems and/or cesspools for wastewater management.

The public and private wastewater treatment facilities in Sandwich are identified in Table 2-4 (later in this section.)

2.8 SURFACE WATER

The health of many protected areas can be impacted by surface water quality. Streams, rivers, lakes, ponds, wetlands and vernal pools are affected by natural atmospheric deposition, storm water runoff and groundwater recharge. Nutrients like nitrogen, and chemicals from industrial processes can be carried in the atmosphere and deposited with rain. Nutrients and chemicals can also be present on land and carried to these resources in potentially harmful concentrations from stormwater runoff. While there are no cost-effective man-made solutions to avoiding natural deposition, management of stormwater runoff and groundwater recharge is possible.

2.8.1 Stormwater Infrastructure

The Town's stormwater management systems were generally developed as part of the facilities that they serve (e.g., roads, buildings, subdivisions, etc.). The earliest systems were installed with the simple goal of directing runoff away from the facility. However, modern designs must consider a myriad of regulatory, environmental, construction, maintenance, and legal issues. Not only must today's systems safely convey stormwater to appropriate disposal locations, these systems must also incorporate appropriate treatment elements with the requisite on-going inspection and maintenance. The stormwater infrastructure that is in place today represents the full range of design paradigms employed over time.

Ownership and maintenance responsibilities generally lie with the facilities these systems primarily serve. Within the Town's corporate boundary, there are numerous diverse ownership interests. Federal facilities include those along the Cape Cod Canal (under the Army Corps of Engineers control) and those on the Massachusetts Military Reservation (under federal military control). State facilities include those on the state portions of the MMR, the Shawme Crowell State Forest, the Scusset Beach State Park, the State Fish Hatchery and along state highways such as Routes 6, 6A, and portions of Route 130. Private facilities are located along the 75 miles of private roads and numerous private commercial facilities located throughout Town. Municipal stormwater systems include those along the 148 miles of Town roads and at Town-owned facilities.

The Town of Sandwich operates the municipal stormwater management systems under a permit issued by the EPA National Pollution Discharge Elimination System Municipal Separate Storm Sewer System Program (MS4). As part of this permit, the Town developed a comprehensive Stormwater Management Plan to identify best management practices and reduce potential impacts. It is anticipated that this plan will be updated upon the reissuance of the MS4 permit, currently anticipated for Summer 2012.

Generally, there are three types of stormwater management systems in place in Sandwich:

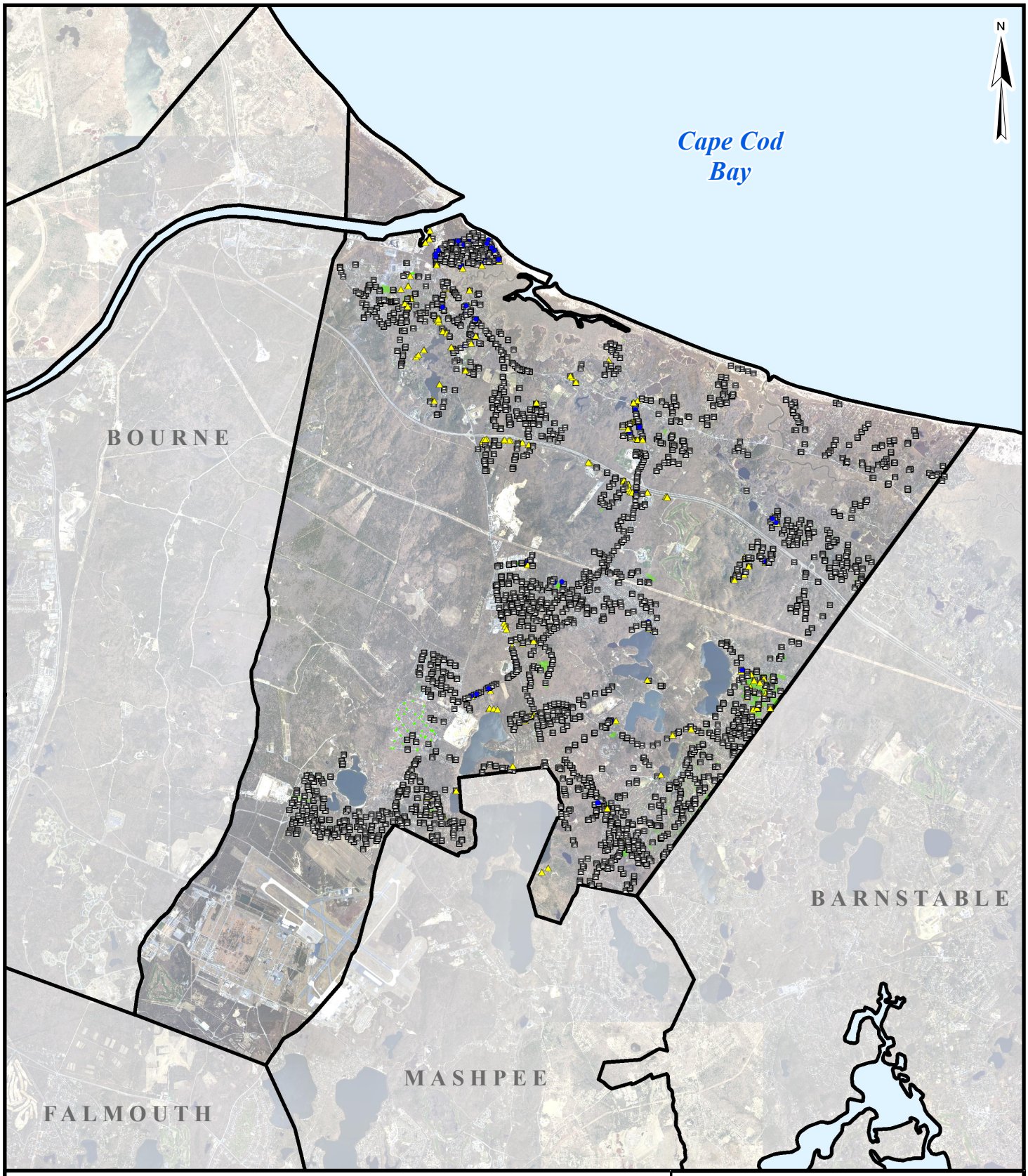
1. ***Informal drainage systems*** include simple open conveyances to adjacent low areas. Common forms of this include diffuse runoff across a vegetated road shoulder or concentrated flow through a paved waterway. These may be found along ancient ways and other roads in rural areas.
2. ***Basic closed drainage systems*** include piped systems with structures such as inlets, catch basins, manholes, and outlets. Residential subdivisions and commercial land development constructed in the 1970's and 1980's also commonly utilized basic subsurface infiltration structures such as leaching catch basins where soils and site conditions would permit. Treatment typically only included basic sumps for coarse particulate removal, and the function of many of these infiltration systems has been compromised. Failed systems are repaired as possible or routed to open infiltration systems. Conveyance-only systems (without infiltration) may be found in older, densely developed parts of Town, and along parts State and County highways.
3. ***Modern stormwater management systems*** include a variety of structural and non-structural elements as detailed in the Massachusetts Department of Environmental Protection's Stormwater Handbook. Generally, systems in this category were developed in the 1990's or later and typically include more extensive treatment processes and open infiltration systems. Subsurface infiltration is generally discouraged due to high failure rates and difficulties with maintenance and replacement. Modern stormwater management systems may be found within recent subdivisions and commercial developments.

Due to the predominance of sandy, permeable soils, most stormwater systems of each type discharge to infiltration galleries with varying degrees of pretreatment. There are some systems, particularly along old roads in low areas that discharge to adjacent surface waters. This was common practice prior to implementation of modern conservation and wetland protection regulations, and unfortunately contributed to the degradation of resource areas. In the late 1980s, the Town began taking steps to address these adverse effects and has been progressively increasing its efforts. Some of these efforts have included retrofitting existing stormwater systems to increase the level of treatment and minimize the pollutant load. The success of the Town's efforts is evidenced by the reclassification of the Sandwich Harbor shellfish growing area from "prohibited" to "conditionally approved". This area had been closed to shellfishing for approximately twenty years. The work that led to the reclassification was a significant achievement carried out with the cooperation of a number of Town departments and State agencies.

Planned Town efforts regarding stormwater include:

- Continuing to pursue opportunities to identify and mitigate significant stormwater-borne pollution sources;
- Updating Town by-laws and Subdivision Rules and Regulations to better promote current stormwater management practices;
- Continuing maintenance of Town stormwater systems, and working with other stormwater system owners to ensure maintenance is performed as needed; and
- Updating the Stormwater Management Plan to comply with the upcoming NPDES MS4 permit.

The extent of the stormwater collection system is shown on Figure 2-14.



Catchbasin

Drain Manhole

Outlet

Drain Pipe

Drain Easement

Source: Base data obtained from the Town of Sandwich (2011) and MassGIS (2009)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

Stormwater Collection System

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2.9 WATER USE AND WASTEWATER FLOWS

The development of GIS (geographic information system) has made the collection, use, and integration of data a much faster and more streamlined process. Cataloging data in a readily-accessible, parcel-specific manner has made the CWRMP process more flexible when estimating wastewater flows during the Needs Assessment phase. The key building blocks are derived from the Assessing Department and the SWD.

There can be variability from year to year in water use that is influenced by weather or economic conditions. One way to reduce that variability is to average multiple years of data. The SWD has approximately 7,000 accounts, and for the purposes of this CWRMP, data have been obtained for the period of 2007 through 2009. The SWD reads water meters on a semi-annual basis, so a total of six readings were used to calculate annual average and average daily water use for each parcel. The 2008 Assessor's database serves as the basis for linking water use data to site location and land use. The total annual water flow data for the 2007 to 2009 data set was compared to the total annual water flow data for the 10 year period from 2000 to 2010 and found to be representative of that time period.

The vast majority of the SWD service area is within the Town of Sandwich, with a few hundred services in Mashpee in the area of Wakeby Pond. Approximately 68% of town-wide water demand is met by the SWD, with the remaining 32% coming from private wells. The parcels on private wells are primarily in the northeastern portion of town.

The Town of Sandwich has 6,646 residential properties that are classified as single family year-round (i.e., excluding seasonal, multi-family, condominium). Of those, 4,606 are served by the SWD with an average water use of 203 gpd. This average was applied to the remaining 2,040 properties that rely on private wells to estimate that single-family, year-round properties use approximately 1,349,000 gpd. This technique was also applied to seasonal, multi-family and condominium type residential properties. Considering all types of residential property, the town-wide water use is estimated at 1,606,000 gpd, or 188 gpd per parcel.

In this report, the term "commercial" is used as "short-hand" for commercial, light industrial and institutional land uses; in essence all land uses except residential, open space and municipal. In Sandwich, this accounts for approximately 300 developed properties. The majority of these properties are served by public water (238 properties) and average 870 gpd. Several of these properties are very high water users, such as the local schools and a handful of industrial properties. The average commercial water use is 800 gpd, when the high water users are excluded. Based on business type as indicated in Town Assessor's data, there does not appear to be any "high water users" on private wells; therefore, we have estimated their water use based on 800 gpd/parcel. In total, commercial water used is estimated at 244,000 gpd. Town-wide, there are about 8,800 developed properties that use approximately 1,850,000 gpd of water.

Since wastewater flows are not measured, they need to be estimated from water use data. The difference between water use and wastewater flows is termed "consumptive use" and represents the water use that does not reach the on-site disposal facility (i.e., lawn irrigation, outdoor showers, etc). Consumptive uses are generally quite low in the winter and reach their peak in the summer months. For this report, consumptive use has been estimated at 10% for residential sources and commercial/industrial/institutional sources on an annual average basis. Figure 2-15 illustrates monthly variations in measured/estimated water use and estimated wastewater flow. This analysis leads to the estimate of current town-wide wastewater flow of approximately 1,667,000, expressed as an annual average. A summary of wastewater flows by use is presented in Table 2-3.

The vast majority of wastewater flow in Sandwich is treated and disposed of in individual on-site septic systems, at approximately 99% of flow town-wide. Some of the wastewater is treated to a higher level in individual treatment systems (often called "I/A" or innovative/alternative systems) or in modular satellite treatment plants (such as the one that serves the Sandwich High School), at just under 1% of flow town-wide. Finally, some wastewater management consists of tight tanks, at less than 1% of flow town-wide.

FIGURE 2-15
SEASONAL VARIABILITY IN WATER USE AND WASTEWATER FLOW

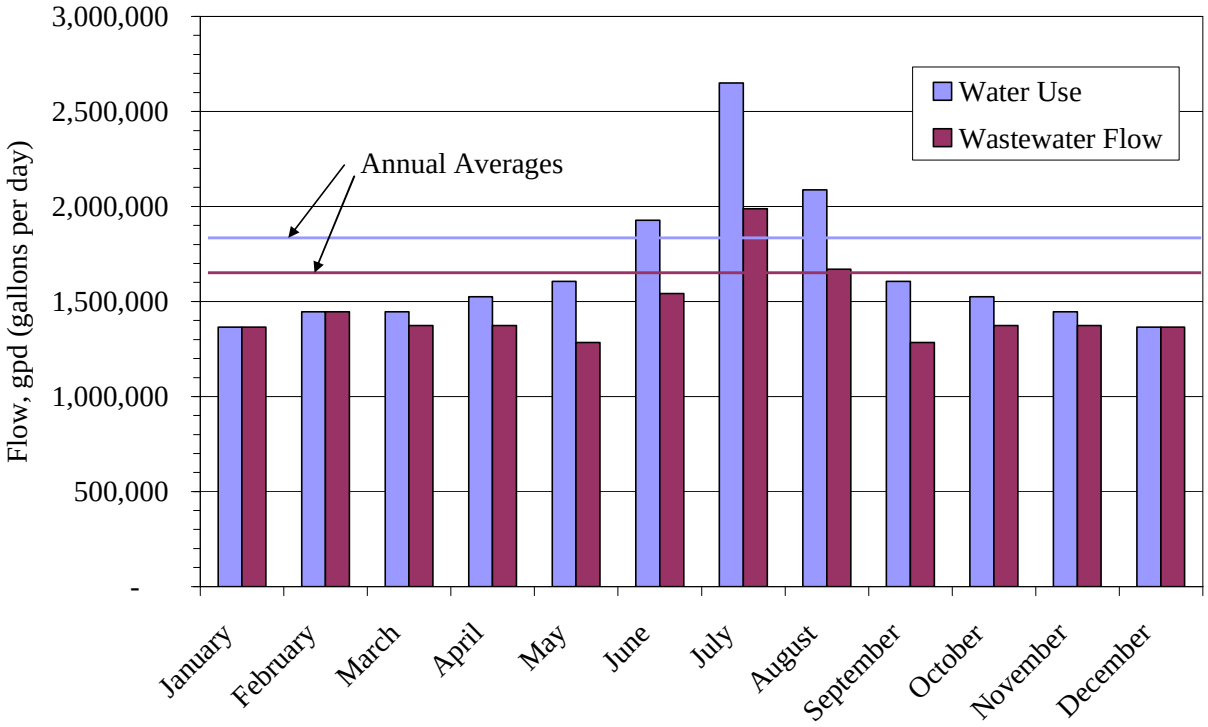

TABLE 2-3
CURRENT WASTEWATER FLOWS

	Total Developed Properties		
Type of Use	**Number of Properties**	**Est. Wastewater Flow, gpd**	
		Average per Property	**Total per Property**
Residential			
Single-Family Homes			
Year-round	6,646	182.7	1,214,200
Seasonal	1,645	110.7	182,100
Condos, Multi-Family	243	202.5	49,200
Commercial	284	780.6	221,700
Town-wide Total	**8,818**	**189**	**1,667,200**

Source: Sandwich Assessing Dept. 2008 data; Sandwich Water District, 2007 to 2009 data.

Table 2-4 catalogs the existing infrastructure that currently provides enhanced wastewater treatment. The location of these facilities can be seen in Figure 2-13 (previous).

TABLE 2-4

EXISTING WASTEWATER INFRASTRUCTURE

Location	Annual Average Wastewater Flow, gpd	Design Average Wastewater Flow, gpd	Type of Treatment
Forestdale School	3,000	20,000	Rotating Biological Contactor
Oak Ridge School	2,500	20,000	Rotating Biological Contactor
Riverview School	8,000	15,000	Amphidrome
Sandwich High School	10,000	31,000	Extended Aeration
Wing School	2,000	12,000	Settling tank, sand filter
Ridge Club	4,500	7,250	Bioclere
Spauling Rehab Hospital	14,000	24,000	Amphidrome
Stop-n-Shop	4,000	12,000	Bioclere with sand filtration
Mass. Military Reservation	160,000[a]	360,000[a]	BNR Oxidation Ditch
Total	**48,000**	**141,000**	

a. flow not included in total flow.

All wastewater treatment and disposal systems, whether large or small, must be sized adequately to handle short-term peak flows (i.e. maximum 2-day flow). From the water pumping records available for 2000 to 2009, the following peaking factors have been estimated for wastewater flows in town:

Maximum month: 1.6 times annual average
Maximum week: 2.0 times annual average
Maximum 2-day: 2.2 times annual average

For the purposes of this report, wastewater flows are being reported by geographic location defined by planning districts and watersheds. Tables 2-5 and 2-6 respectively, show the allocation of current town-wide flows by these categories.

TABLE 2-5

ANNUAL WASTEWATER QUANTITIES BY WATERSHED CURRENT CONDITIONS

Watershed	Total No. of Parcels	Wastewater Flow From Developed Parcels, gpd	Percentage of Total Flow
Barnstable Harbor	147	21,600	1
Canal North	202	17,400	1
Canal South	990	139,500	8
Popponesset Bay	1,762	298,800	18
Sandwich Harbor	2,168	362,200	22
Sandy Neck	641	92,100	6
Scorton Creek	2,402	373,300	22
Three Bay	1,391	264,300	16
Waquoit Bay East	605	89,800	5
Cape Cod Bay	135	8,000	1
Total	**10,443**	**1,667,000**	**100**

TABLE 2-6

ANNUAL WASTEWATER QUANTITIES BY PLANNING DISTRICT CURRENT CONDITIONS

Planning District	Total No. of Parcels	Wastewater Flow from Developed Parcels, gpd	Percentage of Total Flow
East Old Kings Highway Corridor	78	24,900	2
East Sandwich Residential	1,855	263,300	15
Forestdale Residential	1,775	291,100	17
Growth Technology Center/Golf Course	12	200	0
Historic Village Center Route 6A	116	27,600	2
Mass. Military Reservation	30	0	0
North Sandwich Neighborhoods	2,053	264,600	16
Ridge	523	78,600	5
Route 130 Medical Park	6	1,100	0
Sandwich Industrial Park	50	15,700	1
Scussett Beach Area	202	17,400	1
South Sandwich Residential	3,247	560,300	34
South Sandwich Village Center	34	26,600	2
Town Marina-Tupper Rd-Route 6A	178	58,900	3
Village Center Neighborhoods	284	36,900	2
Total	**10,443**	**1,667,000**	**100**

To put these flows in perspective:

- Approximately 40% of the current Town-wide wastewater flow are in known nitrogen-sensitive watersheds (Popponesset Bay, Three Bay, Waquoit Bay);

- Approximately 45% of the current Town-wide wastewater flow are in potential nitrogen-sensitive watersheds with pending MEP technical reports (Sandwich Harbor, Scorton Creek and Barnstable Harbor);

Throughout this report, the wastewater flow estimates presented are based on water use records from the period of 2007 to 2009. These flows are characterized as "current", even though they will represent a time frame prior to the final publication of a completed CWRMP.

2.10 REGULATORY FRAMEWORK

Major elements of the local, regional and state regulatory framework related to wastewater management and water resource protection are summarized below.

2.10.1 Town

Sandwich Zoning Article V creates Water Resource Protection Districts that are coincident with the delineated Zone II areas for Sandwich Water District public supply wells. This article states that wastewater treatment plants are prohibited from a Zone II unless the discharge is located outside of the Zone II, and that for all uses, combined wastewater flow disposed on-site shall not exceed 20,000 gpd.

Sandwich Zoning allows that a wastewater treatment facility may be located only in an Industrial or Marine Zone. That requirement notwithstanding, the treatment facility could otherwise be located in any watershed and/or within a Zone II (with approval from the Town and the Sandwich Water District) as long as the disposal location is outside the Zone II. The treatment facility does not need to be co-located with the disposal facility. Current zoning does

not appear to specifically address where it is allowable to locate effluent disposal if physically separate from treatment.

Sandwich Board of Heath (BOH) Groundwater Protection District Regulations requires additional Board of Health review and obtaining a water quality certificate for developments in this district that potentially use or generate toxic or hazardous substances including petroleum products, sludge or septage, pesticides or herbicides, animal manure, car washes, chemical or bacteriological laboratories, metal plating and other uses.

Sandwich BOH Regulation for the Design, Operation & Maintenance of Small Wastewater Treatment Facilities limits the volume of sewage flow from any project to the in excess of the aggregate volume that would be generated by each lot within the project area based upon the sizing criteria for a septic system , which could have constructed upon it a septic system installed and operated in full compliance with Title 5. This regulation also establishes standards for the design, operation and monitoring of private WWTFs.

Sandwich BOH Nitrates Loading Policy limits the average recharge nitrate concentration of a project to 5 ppm. It is more stringent than the Cape Cod Commission Technical Bulletin 91-001 with respect to: recharge rate (17 inches used instead of 19 inches from TB91-001); flow (no adjustments are made with occupancy, instead full Title 5 flows are used); and concentration (40 mg/l are used for nitrate nitrogen concentration in sewage effluent instead of 35 mg/l).

2.10.2 Department of Environmental Protection

DEP has established a policy that prohibits the issuance of a groundwater discharge permit in a nitrogen-sensitive watershed unless the applicant has already put into effect a project that removes an existing nitrogen load equal to or greater than the load the that proposed project will add to the groundwater. Based on discussions with DEP staff, the nitrogen offset must be in place on or before the start-up of the proposed new WWTF; the applicant cannot merely fund a related study or set money aside for Town use on a future project. A nitrogen-sensitive watershed is one where a draft or final MEP Technical Report indicates that a reduction in

nitrogen load is needed to restore or maintain water quality, even if a TMDL has not yet been issuedhas been issued indicating that a reduction in septic nitrogen load is needed to meet a TMDL. DEP will apply this policy in watersheds where the MEP technical report is only in draft form; a final report or TMDL is not needed. At this time, DEP will not apply this policy in watersheds where no MEP technical report has been issued.

2.10.3 Cape Cod Commission

The Cape Cod Commission's Regional Policy Plan (RPP) has numerous elements related to water resource protection, including:

- A public or private wastewater treatment facility A WWTF and disposal area can not be located in a Zone II unless the facility serves to remediate existing problems (**MPS WR2.3 and WR5.2**)
- Nitrate loading from the project must be below 5 parts per million (ppm) for projects in general and below 1 ppm in potential water supply areas, based on the Commission's Technical Bulletin 91-001. The nitrate loading limit reverts to 5 ppm in a potential water supply area if the Town or the Water District signs off. (**MPS WR2.1 and WR2.6**).
- **MPS WR6.1** prohibits a private WWTF if a feasible public option is expected to be constructed within 3 years.
- All WWTFs must meet a 5 ppm total nitrogen limit, either in the effluent or in the groundwater at the downgradient property line. (**MPS 6.2**).
- **MPS WR6.5** requires that projects with private WWTFs give the municipality the opportunity to take ownership when so desired by the municipality.
- No WWTFs are allowed in ACECs or critical wildlife habitat. (**MPS WR6.6**)
- WWTFs larger than 2,000 gpd must participate in a Operation, Maintenance and Compliance Agreement (OMC Agreement) with the Commission and the local BOH. (**MPS WR6.9**), if the effluent limit is lower than would be included in the typical groundwater discharge permit (10 mg/l).

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Section 3

SECTION 3

WATER RESOURCE PROTECTION NEEDS

3.1 APPROACH

Many communities rely exclusively on private on-site systems for wastewater treatment and disposal. The Commonwealth of Massachusetts sanitary code ("Title 5") provides a thorough regulatory framework for such systems. Under ideal circumstances, on-site systems can provide cost-effective and environmentally-sound wastewater management. Those circumstances include favorable soils, adequate depth to groundwater, reliable and protected water supplies, absence of sensitive downgradient receiving waters, and absence of high-intensity water users. In assessing Sandwich's water resource protection needs, the fundamental question is:

> **"On which properties is the on-site wastewater system an adequate means of providing for sanitation and environmental protection, and on which properties is an improved on-site system needed, or an off-site solution required?"**

One way to answer this question is to identify areas where the above-noted ideal circumstances do not exist. For the purposes of this report, wastewater management needs have been evaluated in the following five categories:

- **Ensuring Sanitary Conditions**--correction or avoidance of unsanitary conditions (that is, public health problems) such as effluent surfacing over a leaching field, inadequate set-back from a private well, or direct discharge of sanitary wastewater to a watercourse.

- **Protecting Private and Public Water Supplies**--preventing contaminants (such as bacteria, viruses, nitrates, pharmaceutical, and personal care products) from reaching private or public drinking water sources.

- **Protecting Surface Waters from Nutrient Enrichment**--reducing nutrients that can cause accelerated degradation of freshwater ponds (typically phosphorus) or estuarine waters (typically nitrogen).

- **Addressing Convenience and Aesthetic Issues**--avoiding unsightly mounded septic systems or individual treatment systems that may be the only way to achieve compliance with Title 5 if off-site options do not exist, or avoiding frequent septage pumping that creates odor and disruption (particularly in the downtown area).

- **Enabling Sustainable Economic Development**--providing wastewater solutions, where necessary, so that wastewater restrictions (such as impermeable soils, shallow groundwater, locations within a Zone II water supply protection area, etc.) are not the limiting factors to economic development envisioned in the Local Comprehensive Plan.

The overall approach for needs assessment is the categorization of all lots in Sandwich according to these five general categories. The specific approach is different for each category, and is presented in the paragraphs that follow. Each category has been evaluated separately, and then the results compiled town-wide to address the fact that some lots fall into more than one category of need. Where improved on-site or off-site disposal is necessary, the reasons must be well documented and defensible.

3.2 SANITARY NEEDS

Correction or avoidance of public health problems (sanitary needs) was addressed by considering the following factors:

- Properties that have required significant variances from Title 5 to install or repair an on-site system and/or properties requiring frequent repairs to an on-site system;
- Properties that use an unusually large amount of potable water per acre of land; and
- Properties near receiving waters where high bacterial counts have been recorded with no other apparent cause.

3.2.1 Title 5 Variances

Methodology

Title 5 is a thorough sanitary code with respect to sanitary issues. If significant variances from Title 5 have been required to allow an on-site system to be constructed or repaired, then there may be benefits to providing that property with other wastewater solutions. The Health Department reviewed its records spanning 10 years: 2001 through 2010. For each variance that was granted, key information was tabulated, such as the name and address of the applicant, and the nature of the variance that was granted. It is important to distinguish between procedural variances and those of environmental significance when evaluating the wastewater needs of a parcel. Points were then assigned to each variance based on the environmental significance of that type of variance. Table 3-1 summarizes an additive points system for assigning a score to each lot based on the type and severity of the variance granted.

Variances that are minor or procedural in nature (e.g., setback from a property line or structure) received a zero-point score. Variances that could significantly impair public or environmental health (e.g., setback to a private water supply) would add 3 to 5 points to a lot's rating. In the case where multiple minor variances have been granted on a single lot, the cumulative impact can be considered, even if each individual variance would be insignificant on its own.

TABLE 3-1
ENVIRONMENTAL SIGNIFICANCE RATING SYSTEM
FOR TITLE 5 VARIANCES

	Nature of Variance	Points
1	**Setback From Wetlands (100 foot local req't)**	
	Setback greater than 50 feet	**1**
	Setback less than 50 feet	**2**
2	**Setback From Well (100 feet required)**	
	Potable Well Setback greater than 75 feet	**1**
	Setback of 50 to 75 feet	**3**
	Setback less than 50 feet	**5**
3	**Setback From Property Lines**	**0**
4	**Setback From Structures**	**0**
5	**Depth to Groundwater (4 feet required)**	
	Depth of 3 to 4 feet	**1**
	Depth less than 3 feet	**2**
6	**Thickness of Underlying Pervious Soil**	
	Thickness of 3 to 4 feet	**1**
	Thickness less than 3 feet	**2**
7	**Depth of Cover Over Disposal System**	
	Depth greater than 3 feet	**0**
	Depth less than 3 feet	**1**
8	**Inadequate Reserve Area**	
	Reserve area less than 50%	**1**
	No reserve area	**2**

To convert this scoring process into a rating system for needs assessment, properties were grouped into one of three categories: little or no environmental significance (0 or 1 point); moderate environmental significance (2 points); and major environmental significance (3 points or more). This additive system provides a consistent and graduated method for identifying individual needs, and is central to this assessment of sanitary needs town-wide. Table 3-2 is a summary of the analysis of approximately 2,300 permits granted between 2001 and 2010.

TABLE 3-2
SUMMARY OF TITLE 5 VARIANCE ANALYSIS

1. **Over 10 years, 2,287 Title 5 permits were issued.**
   116 of those applications required one or more variances.

2. **Determination of Site Suitability--Rating in 5 Categories**
   A. Suitable for current use
   B. Suitable for current use with variances
   C. Suitable for current use with significant variances
   D. Not suited for onsite disposal

3. **What is environmental significance of variances that were granted?**

Score	Rating	# of Permits	% of Permits
0	A	2,210	97
1	B	50	2
2	C	9	<1
3 or more	D	18	1
	Total	2,287	100

4. **Where are properties with variances located?**
   North Shore Embayments 95%
   South Shore Embayments 5%

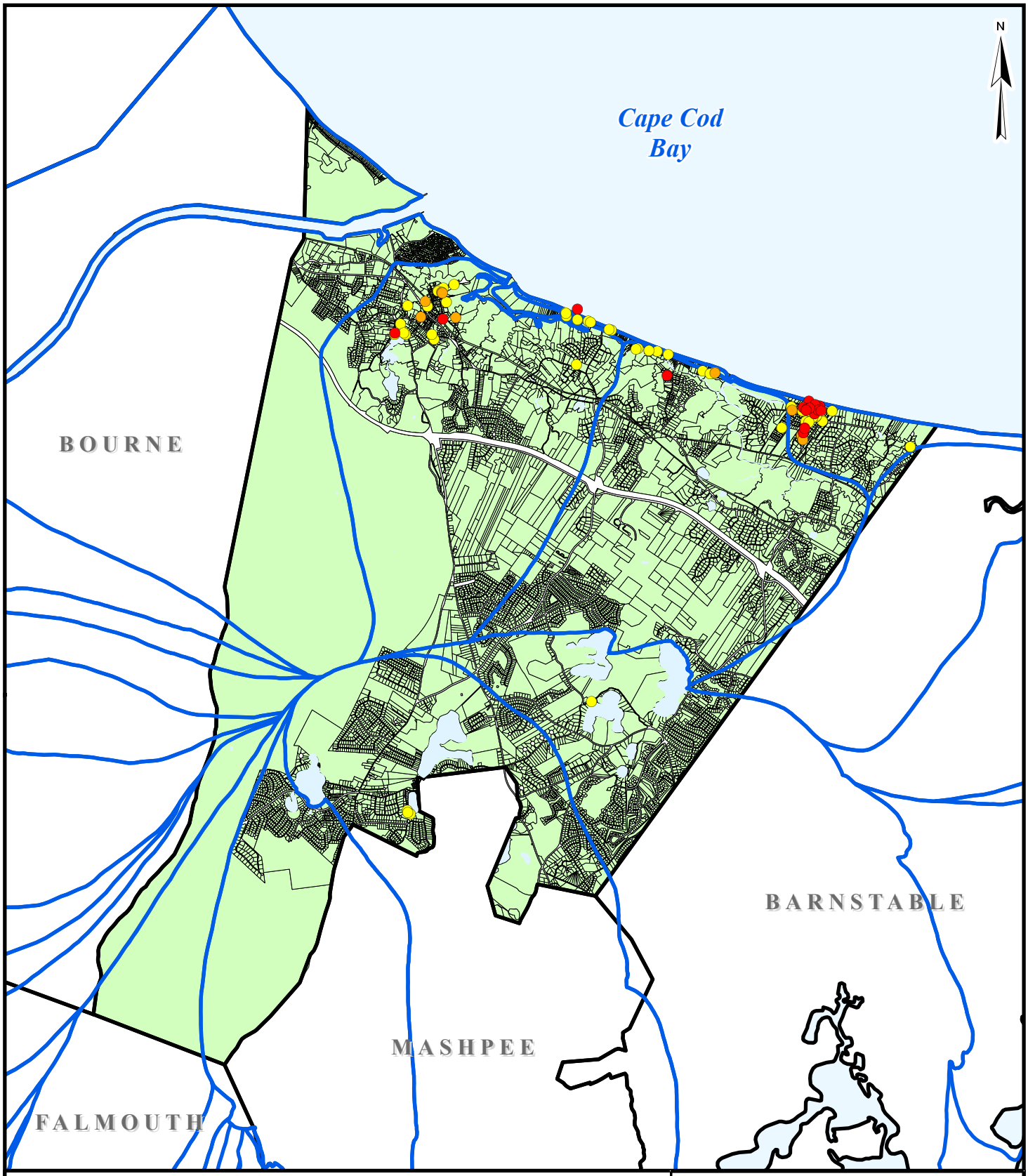
5. **What was the basis for the variance request?**
   Repair/Upgrade 78%
   New Construction 22%

Note: Variance data from 2001 to 2010
Source: Sandwich Health Department

Findings

Table 3-2 describes a rating system for individual lots using categories A through D, where Category A lots are quite acceptable for on-lot wastewater disposal, through Category D lots that are unsuitable. Based on this 10 year record, 97% of the permit requests to the Health Department fall in Category A; 2% fall in Categories B and C, and 1% fall in Category D. The category B, C and D lots are shown in Figure 3-1. The Category D parcels are considered to have a sanitary need. Key findings are as follows:

1. On an annual basis, about 230 requests for new systems or system modifications come before the Health Department. Of the total 2,287 permits granted, 116 (about 5% or roughly 12 applications per year) have required one or more variances.
2. During the period of analysis, 196 variances were granted, an average of about 1.7 variances per applicant.
3. Of the 12 applicants that needed variances in the typical year, only about 3 of them required variances of environmental significance.
4. The types of variances are as follows, in order of frequency
   - ❖ Setback to property lines 34%
   - ❖ Setback to wetlands 25%
   - ❖ Setback to structures 25%
   - ❖ Setback to wells 12%
   - ❖ No reserve area 3%
   - ❖ Depth to groundwater 1%
   - ❖ Thickness of underlying permeable soil <1%
5. On average, 97% of the applications to the Health Department did not require variances, and only 1% required variances of environmental significance. Therefore 99% of the properties in this 10 year sampling can be viewed as having no significant sanitary need, if the 10 year period of record represents town-wide conditions.
6. The properties with variances are clustered along the north shore embayments, as shown on Figure 3-1.
7. Over the period of record, 196 variances were granted, of which 26 (13%) have enough environmental significance to indicate a potential sanitary need for off-site wastewater disposal.
8. A total of 18 properties were granted the 26 environmentally significant variances. Those properties generate about 2,500 gpd of wastewater on an annual average basis.



Title 5 Variances
Lot Suitability Rating

- B
- C
- D
- Watershed Boundary

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009), and MassGIS (2009)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan
Title 5 Variances
2001 - 2010

PROJ NO:	DATE:	FIGURE:
12217A	Dec 2011	3-1

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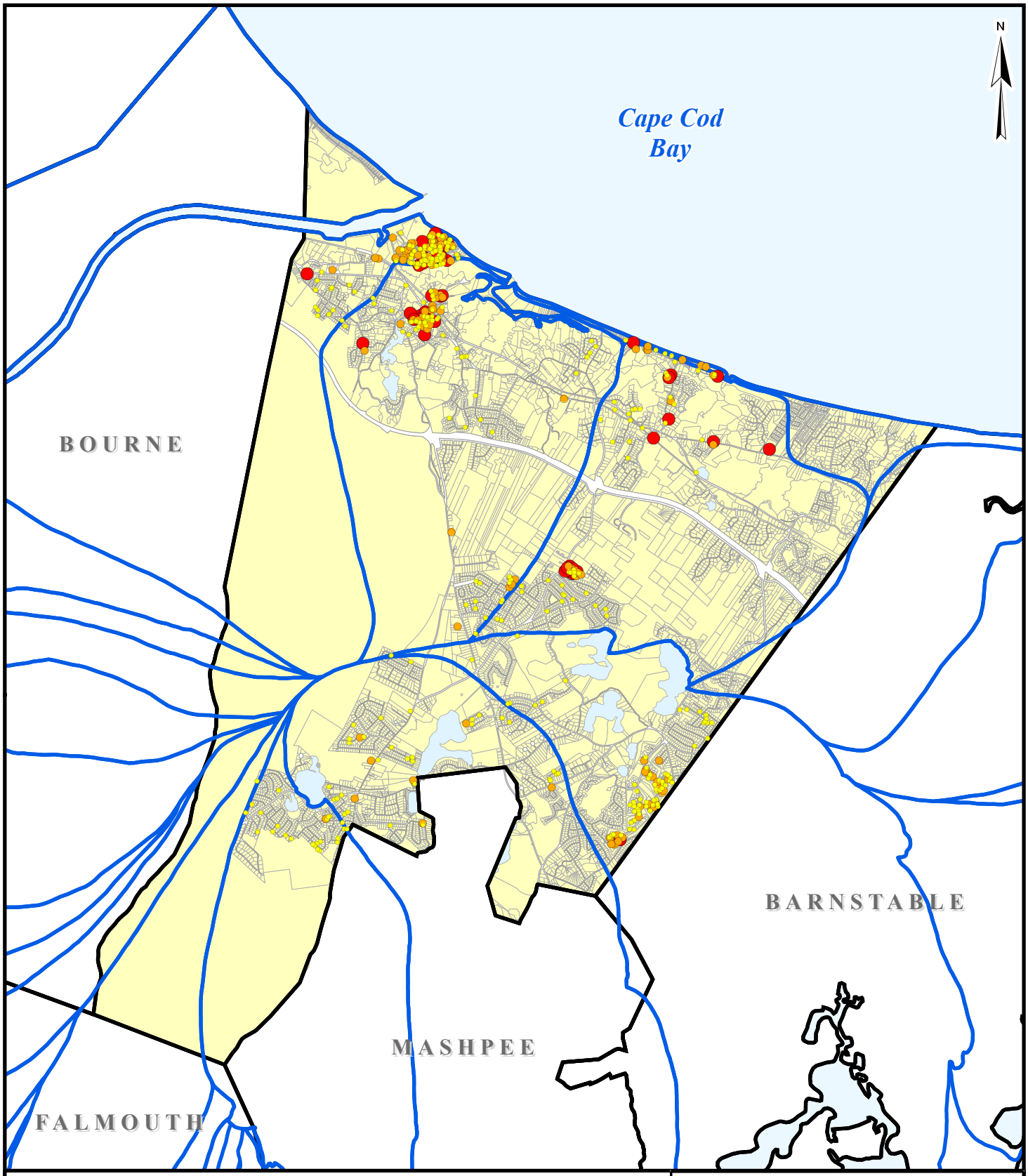
Conclusions

Since there are approximately 9,000 conventional on-site disposal systems in Sandwich, the total number of permits granted represent about 25% of the total number of septic systems. Assuming that these findings are representative of town-wide conditions, extrapolation of these results would result in 72 properties, generating 13,500 gpd of wastewater which might require alternative wastewater management. These extrapolated flows represent less than 1% of the current town-wide wastewater generation rate. This very low percentage indicates that existing wastewater disposal under Title 5 (and supplemental local regulations) is generally effective from a sanitary perspective. The thorough approach of the Health Department and Board of Health has resulted in very good compliance with applicable requirements.

3.2.2 Intensive Water Use

The intensity of water use (i.e. the amount of water per square foot of parcel area) is an indirect measure indicator of parcels which could have potential wastewater disposal problems. The greater the water use per square foot, the greater the potential difficulty. Title 5 uses a similar approach to determine if a project warrants nitrogen control in the recharge areas of public water supply wells. The nitrogen control threshold is 110 gpd per 10,000 sq.ft. as calculated using Title 5 flow rates (i.e., short term peak flow), which is equivalent to 55 gpd per 10,000 sq.ft. as an *annual average* flow rate. The Sandwich GIS database, which includes water use and assessor's records, was used to identify lots with potential sanitary needs based on the intensity of water use. Parcel size was calculated based on overall property boundaries (without deduction for wetlands) and compared with annual average water use, as described in Section 2.9. For example, a parcel with an average daily water use of 200 gpd and a total lot area of 50,000 sq. ft. has a water use intensity of 40 gpd per 10,000 sq. ft. Figure 3-2 shows the water use intensity for all developed parcels in Sandwich. Table 3-3 summarizes the results of this analysis.



Water Use Intensity
(annual average gpd/10,000 sq ft)

- < 200
- 200-299
- 300-499
- 500 +

Watershed Boundary

Freshwater Pond

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009), the Sandwich Water District (2007 - 2009), and MassGIS (2009)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan
Water Use Intensity

PROJ NO:	DATE:	FIGURE:
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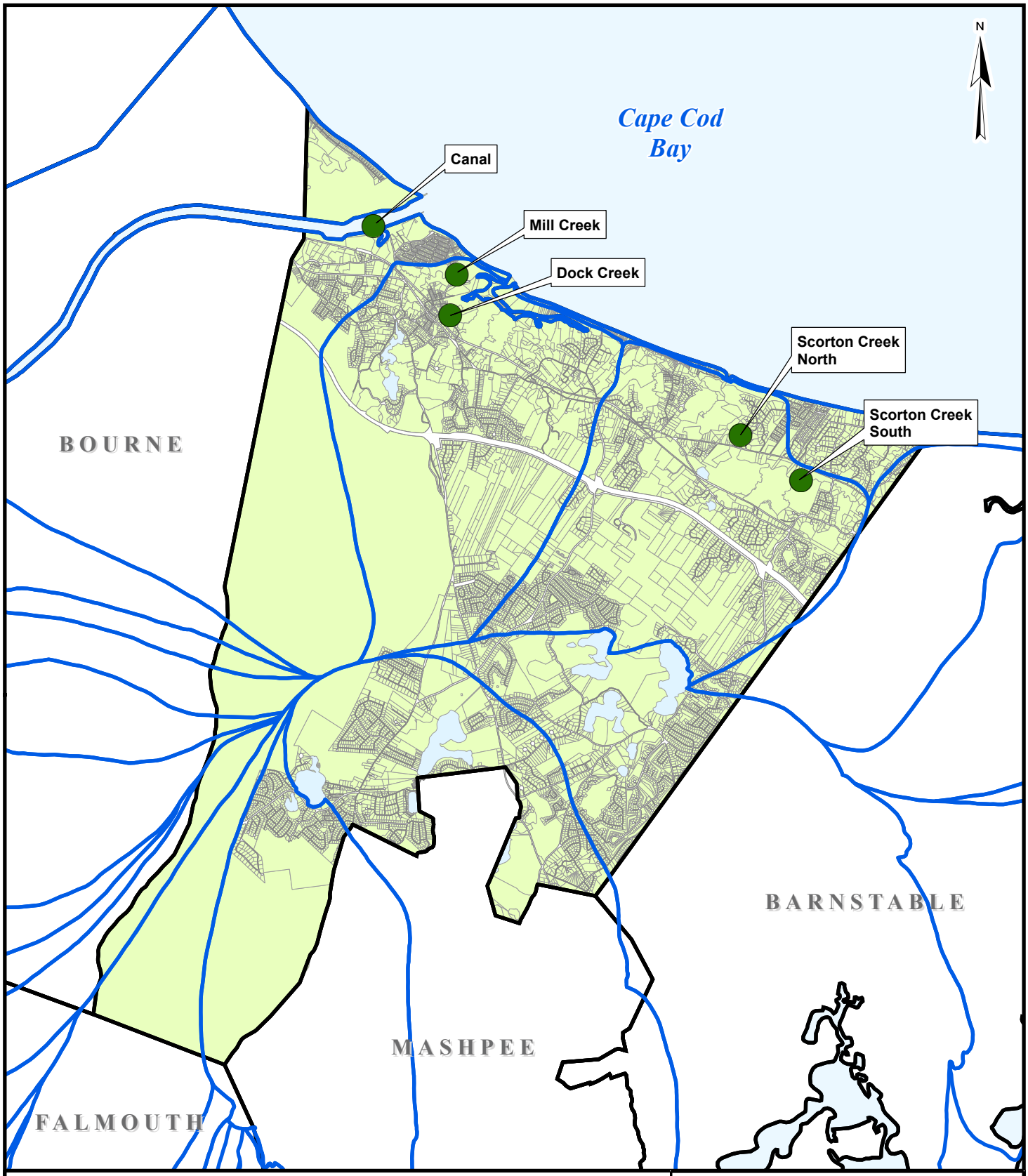
TABLE 3-3
SUMMARY OF INTENSIVE WATER USE NEEDS

Intensity	Number of Properties	Aggregate Wastewater Flow, gpd
200 to 299 gpd per 10,000 sq. ft	273	115,000
300 to 499 gpd per 10,000 sq. ft	165	68,000
500 or greater gpd per 10,000 sq. ft	42	52,000

The most intensive water uses are fairly well distributed across town. Some of these parcels have received one or more Title 5 variance; others may not have come before the Board of Health during the period of analysis. We have selected 500 gpd per 10,000 sq.ft. as the threshold for this category of need. There are 42 parcels, generating an estimated 52,000 gpd of wastewater flow, which fall in this category.

3.2.3 Receiving Water Impacts

A significant presence of bacteria in surface waters can have a negative impact on humans or aquatic animals in contact with these waters. Bacterial sources can include road runoff, animal feces (pets, livestock, waterfowl, etc.), or in rare cases, septic tank effluent. In almost all cases, Title 5 systems can be sited such that bacteria in the septic tank effluent are not a threat when the effluent-impacted groundwater reaches nearby surface waters. Based on historic sampling results, the Town reported that there are five sampling locations in Sandwich that have recorded positive bacteria testing. Figure 3-3 identifies these locations, all of which are along the north shore of town. According to the Health Department, the presence of bacteria at three of these locations (the Canal, and both Scorton Creek sampling stations) are attributable to stormwater runoff; however, at Mill Creek and Dock Creek, there are septic systems with leaching fields very close to the water table, and/or a short distance to these surface waters. As a rule of thumb, we consider a groundwater travel time of 30 days as generally sufficient to ensure that bacteria are no longer viable in the diluted leachfield effluent and 90 days as generally sufficient for inactivation of virus. Some of the septic systems in these areas may not meet this guideline. There are 25 parcels with a combined wastewater flow of 2,900 gpd that could fall within this category. These systems are being considered as having a potential sanitary need.



Legend

- Locations With Historic Positive Bacteria Test Results
- Watershed Boundary
- Freshwater Pond

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009), and MassGIS (2009)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

Positive Bacteria Tests In Surface Waters

PROJ NO:	DATE:	FIGURE:
12217A	Dec 2011	3-3

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3.2.4 Combined Indicators of Sanitary Needs

Table 3-4 shows how the three indicators of sanitary needs were combined. The record of Title 5 variances is the most definitive indicator and the one that deserves the most weighting. As a means to anticipate properties that may come before the Board of Health in the upcoming years, the sanitary need category also includes those properties with water use intensity greater than 500 gpd per 10,000 sq.ft. Finally, properties located directly adjacent to surface waters with positive bacteria test results have been included as well. We believe this represents a conservative estimate of properties with sanitary needs. Figure 3-4 shows the properties that have a sanitary need using these criteria.

3.3 WATER SUPPLY PROTECTION

3.3.1 Public Wells

Approximately 68% of the developed properties in Sandwich have access to public water. Figure 3-5 highlights the area of town with public water service. The Sandwich Water District draws water from several groundwater wells located across town. There are three DEP-prescribed areas around public water supply wells:

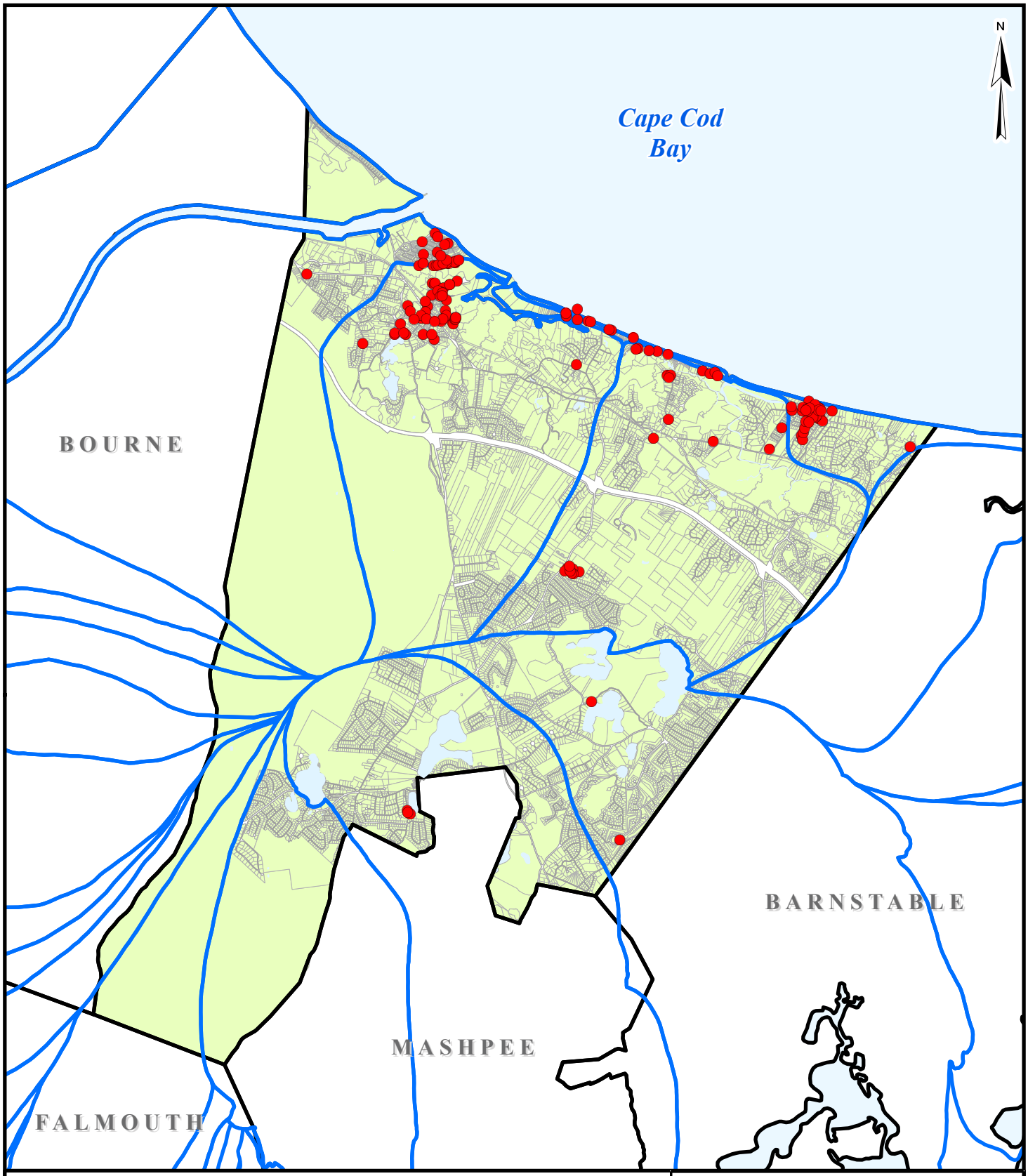
- Zone I - The area within a 400 foot radius of public water supply well greater than 100,000 gpd.
- Zone II - The area of an aquifer which contributes water to a public water supply well under severe pumping and recharge conditions (i.e., 180 days of pumping at approved yield with no recharge from precipitation).
- Zone III - The area beyond the extent of the Zone II from which surface water and groundwater flow into the Zone II.

Figure 3-5 also shows the DEP approved Zone II areas for groundwater sources within Sandwich and surrounding towns. It is important to note that some of the Zone II area in Sandwich is for water supply well(s) located in Barnstable, and some of Sandwich's Zone II area is on MMR land.

TABLE 3-4
SUMMARY OF SANITARY NEEDS

	Watershed										
	Barnstable Harbor	**Canal North**	**Canal South**	**Popp. Bay**	**Sandwich Harbor**	**Sandy Neck**	**Scorton Creek**	**Three Bay**	**Waquoit Bay East**	**Cape Cod Bay**	**Town-wide**
Title 5 Variances											
Number of Parcels	0	0	0	0	12	52	8	0	0	0	72
Current Flow, gpd	0	0	0	0	2,200	9,800	1,500	0	0	0	13,500
Intensive Water Use											
Number of Parcels	0	0	11	0	13	0	17	1	0	0	42
Current Flow, gpd	0	0	7,700	0	23,400	0	20,400	500	0	0	52,000
Receiving Water Quality											
Number of Parcels	0	0	0	0	25	0	0	0	0	0	25
Current Flow, gpd	0	0	0	0	2,900	0	0	0	0	0	2,900
Aggregated - Sanitary Needs											
Number of Parcels	0	0	11	0	50	52	25	1	0	0	139
Current Flow, gpd	0	0	7,700	0	28,500	9,800	21,900	500	0	0	68,400

Note: Town-wide totals are additive across the row. Totals by major watershed are not additive by column. The category total by watershed accounts for parcels that have more than one need.
Source: See text for data sources and analysis.
Note: Parcel specific Title 5 Variances are for 18 parcels with 2,500 gpd of flow. The remainder of the parcels and flow are extrapolated and are not parcel specific.



Lots with Sanitary Needs

Watershed Boundary

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009), and MassGIS (2009)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

Lots with Sanitary Needs

PROJ NO: 12217A	DATE: Dec 2011	FIGURE:
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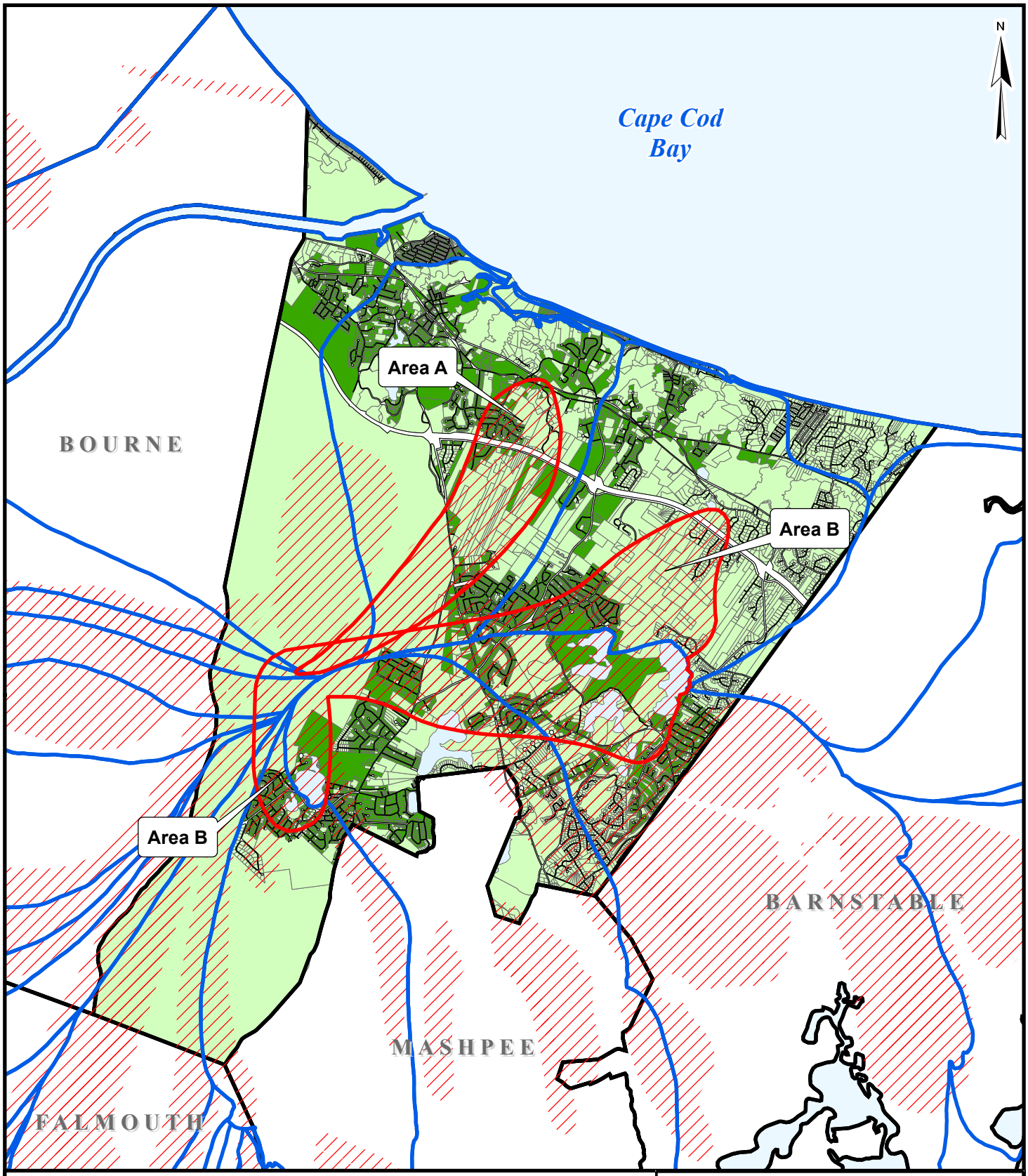

Public Water Supply User

Private Water Supply User

Zone II

Watershed Boundary

Freshwater Pond

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009), and MassGIS (2009, 2011)

Note: Area A and B are the Zone II areas contributing to Sandwich water supply wells.

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

Zone II and Public Water Service Area

PROJ NO:	DATE:	FIGURE:
12217A	Dec 2011	3-5

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In order to determine whether public water supply protection from nitrates was warranted, we prepared a DEP-endorsed nitrate loading model for Sandwich. This desktop analytical model aggregates all of the nitrogen loads and compares them with the sum of all of the recharge sources within the Zone II. The result is an approximation of the wellhead nitrogen concentration which will eventually occur. This model was applied to the portions of the Zone II in Sandwich that correspondence to the Sandwich Water District wells. These areas are identified as follows:

- "Area A" for Wells 2, 3 and 9: a Zone II that crosses North Sandwich Residential District, Ridge District, Industrial District and MMR; and
- "Area B" for Wells 4, 5, 6, 7, 8, 10 and 11: a Zone II that encompasses Forestdale Residential District, MMR, Ridge District, East Sandwich Residential District, Growth Technology District and South Sandwich Village Center.

The drinking water standard for nitrate (which is the most common form of nitrogen in groundwater) is 10 mg/l. Since wellhead concentrations should never exceed that level, the Cape Cod Commission has established a planning guideline for nitrate of 5 mg/l at the wellhead to be protective of water supplies. The results of our analytical model for Sandwich indicate that the wellhead nitrate concentrations in both "Area A" and "Area B" will not exceed 2 mg/l under current conditions. At Planning Horizon (an estimated 30% increase in wastewater flow, described in Section 4), the wellhead nitrate concentrations remain less than 3 mg/l.

Considering all factors, there is no over-riding need for improved wastewater management to protect public water supplies from nitrate impacts; however, research over the past few years has shown that nitrate also functions as a good surrogate for other contaminants that could reach the groundwater from septic systems. That is, low levels of nitrate typically reflect low levels of other parameters. Wastewater management in the future may also require consideration of so-called "contaminants of emerging concern" (CECs, such as pharmaceuticals and personal care products). Recent studies by the Silent Spring Institute have analyzed water from Cape Cod ponds and from public and private drinking water supplies, and have found many CEC at low concentrations.

In the Silent Spring analysis, public wells were categorized based on the density of development in their recharge areas. "Moderate" density areas were characterized as those with nitrate concentrations in the range of 0.5 to 2.5 mg/l, and "high" density areas were characterized with nitrate concentrations greater than 2.5 mg/l. Pharmaceuticals were identified in 80% of the public well samples from recharge areas with moderate or high density. While the public health significance of the measured CEC concentrations has not been determined (either for individual compounds or for the cumulative impact of multiple compounds), the projected nitrate concentrations at public wells in Sandwich are comparable to the thresholds identified in the Silent Spring studies. At the present time, the research community is striving to determine the threshold values where CEC compounds have either human or ecological impacts and how these compounds can be removed from wastewater. Research findings should be closely monitored and, if necessary, Sandwich's water and wastewater management needs should be re-addressed in the future.

The Cape Cod Commission has identified land which has the potential for future water supply development, known as PLAAP (Priority Land Acquisition Assessment Program). If this land remains undeveloped, the potential for new nitrogen contributions to the Zone II will be somewhat decreased. However, the build-out analysis described in Section 4 does include some development occurring within the PLAAP lands.

The Town's Board of Health Groundwater Protection District regulations identify industrial-type activities within the Zone II as activities which warrant additional scrutiny. Given that the Industrial Zone and Industrial Park is located in the Zone II, it would be appropriate to consider these parcels in this category of need.

3.3.2 Private Wells

According to Town records, approximately 32% of the developed lots in Sandwich rely on private wells for their water supply. Most of these lots are located in the eastern portion of town. The Health Department is aware of two areas of development where nitrogen concentrations in

private potable wells have exceeded the 5 mg/l nitrate planning threshold. These locations are identified on Figure 3-6. Elevated nitrate concentrations are not surprising in these locations because the neighborhoods consist of small lots, and are almost completely built-out. The high density of Title 5 systems is the most likely source impacting private potable wells. Nitrate concentrations this high may also be of concern in light of the recent Silent Spring studies.

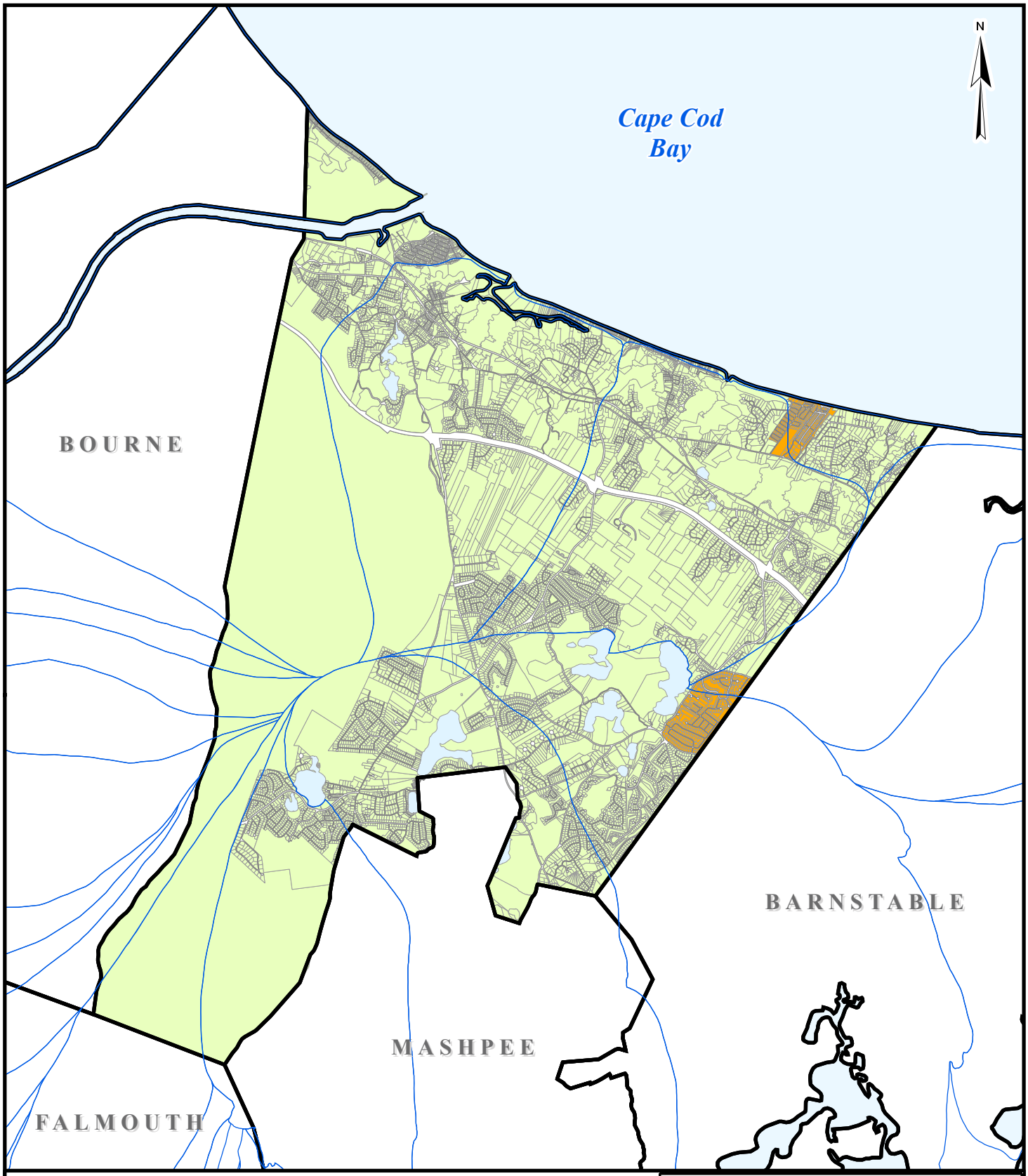
The reduction in nitrogen from these parcels (either through connection to public sewers, installation of on-site nitrogen removing systems, or composting toilets) might not be the best solution for these areas of high nitrate concentrations in groundwater. Prior groundwater contamination would not be affected by the improvement or elimination of the septic systems, and the private well owner would still be at risk for some period of time into the future (e.g. 10 or more years). The best solution in these areas may be to extend the public water supply to the affected properties. Depending on whether the parcel has other wastewater management needs (e.g. sanitary, nitrogen reduction), alternative wastewater management may also be necessary.

3.3.3 Overview of Water Supply Protection Needs

Protection of public and private water supplies is a major consideration for the Town. Fortunately, in Sandwich's case, the area where water supply protection is warranted is relatively modest. For the purposes of this report, we have identified the following parcels as a water supply protection need:

- Industrial zoned parcels that are within the Zone II to public water supply wells; and
- Neighborhoods with lots that are smaller than 20,000 square feet (each) and that are located within DEP approved Zone II area.

There are 152 parcels that in total generate 27,200 gpd of wastewater flow and meet the previously stated criteria. In addition, the Town and the Water District should monitor research on CECs. It is possible that, in the future, these compounds may be identified as posing a threat to public and private wells even at wellhead nitrate concentrations that are now thought to be protective.



Legend

- Areas with Elevated Nitrogen in Private Wells (>5 mg/L, est.)
- Watershed Boundary
- Freshwater Pond

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009), and MassGIS (2009, 2010)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

Elevated Nitrogen in Private Wells

PROJ NO:	DATE:	FIGURE:
12217A	Dec 2011	3-6

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3.4 SURFACE WATER PROTECTION

3.4.1 Freshwater Ponds

The freshwater ponds targeted for reviewed in the CWRMP were identified in Section 2. A pond assessment report was prepared for these ponds by Water Resource Services, Inc. (included in Appendix A). One of the principal causes of water quality degradation in freshwater ponds is the increased loading of phosphorus. Phosphorus sources include subsurface wastewater disposal, lawn fertilization, stormwater runoff, and release from bottom sediments.

There is a lack of current, quantitative water quality data for most of the ponds in Sandwich; accordingly, the analysis and interpretation used professional judgment. The "trophic status" is a relative measure of the biological productivity in the ponds -- ranging from "oligotrophic" (least amount of biological growth) through "mesotrophic" to "eutrophic" (most amount of biological growth). Based on the limited data available, most or all of the ponds appear to be meeting their designated uses; however, most of the Sandwich ponds have been identified as having moderate to high risk of water quality degredation from one or more sources. A summary of the pond health and management priorities is presented in Table 3-5.

TABLE 3-5
POND HEALTH AND MANAGEMENT PRIORITIES

Water Body	Waste-water	Storm-water	Internal Nutrient Cycling	Rooted Plants	Algal Blooms	Preliminary Trophic State Assessment
Peters Pond	M	M	H	L	M	Meso-Eut
Snake Pond	M	M	M	L	L	Oligo-Meso
Pimlico Pond	M	M	L	M	L	Meso-Eut
Weeks Pond	L	M	L	M	L	Meso
Lower Shawme Lake	M	H	L	H	H	Eut
Upper Shawme Lake	M	H	L	H	H	Eut
Hog Ponds	L	L	L	L	L	Oligo
Triangle Pond	M	L	M	L	H	Meso-Eut
Lawrence Pond	M	L	M	L	L	Oligo-Meso
Spectacle Pond	H	M	H	L	M	Meso
Hoxie Pond	M	L	H	L	M	Meso-Eut

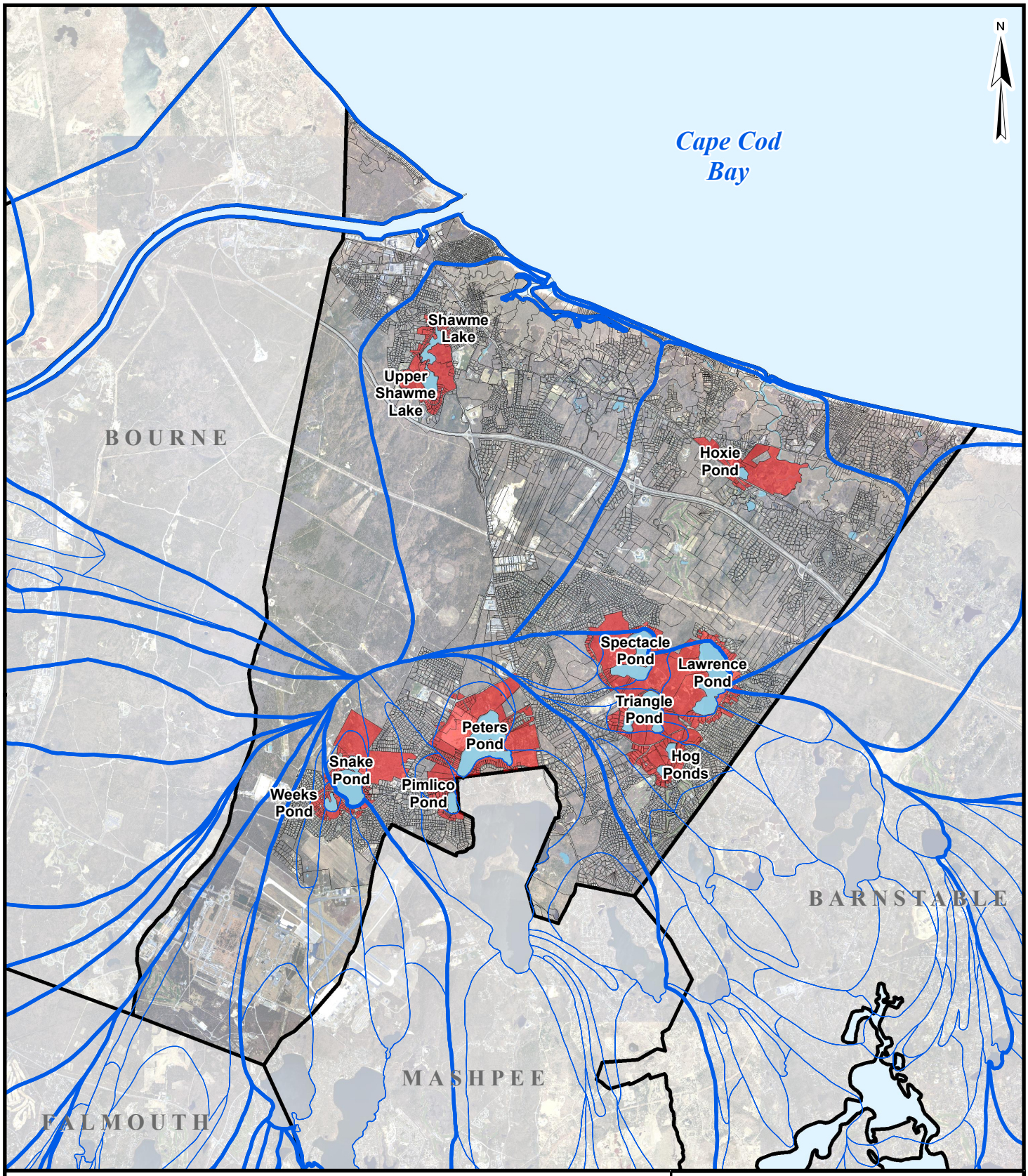
Notes: H=high, M=medium, L=low; Oligo=Oligotrophic, Meso=Mesotrophic, Eut=Eutrophic

Travel time in the groundwater is significantly different for phosphorus than for nitrogen. Under typical Cape Cod conditions, nitrogen will move at about 300 feet per year. In contrast, phosphorus tends to chemically bind to the soil and moves down-gradient only after soil uptake sites are exhausted. As a rule of thumb, phosphorus will take about 100 years to travel 300 feet, or about 100 times as long as nitrogen. Given the slow groundwater travel of phosphorus, stormwater runoff (both in general and especially from near-shore fertilized lawns) is often the first priority for pond protection, while septic systems represent a longer-term threat.

For the southern embayments with completed MEP technical reports, the subwatersheds for ponds are delineated. For the northern embayments without completed MEP technical reports, we have estimated the parcels that are tributary to the ponds; these parcels will need to be confirmed when the MEP technical report is completed. Parcels tributary to ponds are tabulated in Table 3-6 and are shown on Figure 3-7. Some parcels are greater than 300 feet away from the ponds, but are included because flow from these parcels will eventually get to the ponds. This analysis identified 710 parcels. Currently, 559 of those parcels are developed, and generate an estimated 107,970 gpd of wastewater on an annual average basis. Approximately 52% of this wastewater flow is tributary to ponds that have had recurrent issues with algal blooms.

TABLE 3-6
WASTEWATER FLOWS UPGRADIENT OF EVALUATED PONDS

Pond Name	**Parcels Tributary to Ponds**		**Wastewater Flow**	**History of Algal Blooms?**	**Major Watershed**
	Total	Developed	gpd		
Peters Pond	108	89	21,450	N	Popponesset
Snake Pond	50	35	5,090	N	Popponesset
Pimlico Pond	114	96	13,560	Y	Popponesset
Weeks Pond	77	62	11,050	N	Waquoit Bay East
Lower Shawme Lake	86	57	11,140	Y	Sandwich Harbor
Upper Shawme Lake	63	52	6,520	Y	Sandwich Harbor
Hog Ponds	50	36	12,180	N	Three Bay
Triangle Pond	41	31	4,520	Y	Three Bay
Lawrence Pond	63	52	10,790	Y	Three Bay/Scorton Creek
Spectacle Pond	44	38	9,090	Y	Three Bay/Scorton Creek
Hoxie Pond	14	11	2,580	N	Scorton Creek
Total	710	559	107,970		



MEP and Subwatershed Boundary

Parcel With in 300' of Pond

Principal Freshwater Ponds

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009), and MassGIS (2009)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

Pond Protection

PROJ NO: 12217A	DATE: Mar 2012	FIGURE:
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3.4.2 Coastal Embayments

Coastal embayments and their biological resources have been the focus of much recent and on-going attention in Sandwich and neighboring towns due to their status as nitrogen-sensitive waters and their functional role in the environment. The Massachusetts Estuaries Project (MEP) includes study of all the coastal embayments within, or impacted by, Sandwich. As noted in Section 2, only 10 of the Sandwich watersheds will be considered in the CWRMP analyses (i.e. Barnstable Harbor, Canal North, Canal South, Popponesset Bay, Sandwich Harbor, Sandy Neck, Scorton Creek, Three Bay, Waquoit Bay East, and Cape Cod Bay) because several watersheds originate on MMR land over which the Town has no control. MEP technical reports have been completed for 7 of these 10 watersheds which find that 4 watersheds <u>are not</u> sensitive to nitrogen (Canal North, Canal South, Sandy Neck, and Cape Cod Bay) and that 3 watersheds <u>are</u> sensitive to nitrogen (Waquoit Bay East, Popponesset Bay, and Three Bays). The executive summary from the 3 nitrogen sensitive watersheds are included in Appendix B and a summary of key technical information from the MEP technical reports is provided in Table 3-7.

Several MEP technical reports, <u>which are critical to Sandwich</u>, are under way but are not yet complete, including Sandwich Harbor, Scorton Creek and Barnstable Harbor. These remaining reports are scheduled to be completed by June 2012 (as draft reports). At this time, only preliminary estimates can be made of the potential wastewater volumes that may need collection and treatment for these watersheds. The Town has requested an "early estimate" of the likely septic nitrogen control requirements from the MEP technical team for these watersheds. While the MEP technical team was not willing to provide written estimates, they provided some guidance with regard to similar watersheds with completed MEP technical reports. Specifically, salt marsh dominated systems have typically had low removal requirements or excess capacity as compared to more classical embayments with little or less salt marsh. Based on this informal guidance, we have established the following "placeholder values" for nitrogen removal requirements: Sandwich Harbor (40%); Barnstable Harbor (40%) and Scorton Creek (20%). We anticipate that these are conservative values.

TABLE 3-7

ELEMENTS OF COMPLETED MEP TECHNICAL REPORTS

	Three-Bay	Popponesset	Waquoit Bay--East
Location of Embayment	Barnstable	Barnstable Mashpee	Falmouth Falmouth
Towns in Watershed	Barnstable Sandwich Mashpee (minor)	Barnstable Sandwich Mashpee	Falmouth Sandwich Falmouth
Lead Town	Barnstable	Mashpee	Falmouth
Consultant	GHD	GHD	GHD
CWMP status	Underway	Underway	Underway
Status of MEP Work			
Date of Final Technical Report	April 2006	Sept. 2004	January 2005
Date of TMDL	Sept. 2007	April 2006	January 2006
Watershed Area			
In Sandwich, acres	2,688	3,415	2,072
Total watershed, acres	12,484	13,101	9,809
% in Sandwich	22%	26%	21%
Wastewater Flow			
Total watershed, gpd	Unknown	Unknown	Unknown
In Sandwich, gpd (by W-P)	264,300	298,800	89,800
% of all flow in Sandwich	15.9%	17.9%	5.4%
Sub-watersheds			
Total number	59	29	37
No. entirely in Sandwich	12	8	6
No. partially in Sandwich	4	3	4
Nitrogen Control Needs, %			
Aggregate for watershed	60%	61%	100%
Sub-watersheds in Sandwich	<25%	35%--41%	100%
Natural Attenuation in Sandwich Ponds	Spectacle Pond (48%) Lawrence Pond (91%) Triangle Pond (85%)	Snake Pond (51%) Pimlico Pond (89%) Peters Pond (80%) Wakeby Pond (86%)	None Weeks Pond
Unattenuated Nitrogen Loads in Watershed, kg/yr			
Total	74,567	48,513	23,938
Septic only	53,584	32,300	13,517
Attenuated Nitrogen Loads in Watershed, kg/yr			
Total	54,657	31,885	18,823
Septic only	36,570	18,659	10,622
Target septic load	14,486	7,285	0
Sandwich Share of Septic load			
Unattenuated	14%	22%	24%
Attenuated	7%	9%	unknown
TMDL Allocation Status	DEP Pilot Study	DEP Pilot Study	No action to date

Table 3-8 summarizes the distribution of wastewater flow by watershed. The matrix lists the current conditions and future conditions (refer to Section 4) for "high", "low" and "baseline" estimates of potential nitrogen removal requirements. The implications of these placeholders should be refined when the MEP technical reports are issued.

TABLE 3-8 REQUIRED NITROGEN LOAD REDUCTIONS BY WATERSHED

Planning Horizon = 66% of Theoretical Build-out	MEP Watershed										Total Flow	% of Total
	Barnstable Harbor	Canal North	Canal South	Popp. Bay	Sandwich Harbor	Sandy Neck	Scorton Creek	Three Bay	Waquoit Bay East	Cape Cod Bay		
Estimated Wastewater Flows, gpd, annual average												
Current Flows	21,590	17,363	139,495	296,817	362,205	92,140	373,259	264,311	89,846	8,084	1,667,110	77%
Planning Horizon Flows	26,854	21,311	216,482	444,350	686,341	92,892	467,635	335,203	123,216	8,084	2,422,369	
New Flows - Vacant Land	2,606	1,613	47,896	85,419	188,391	124	44,545	40,275	20,473	0	431,341	20%
New Flows - Redevelopment	869	993	2,916	10,633	25,539	372	17,743	6,514	1,551	0	67,130	3%
Future Flows at Planning Horizon	25,064	19,969	190,307	394,869	576,135	92,636	435,547	311,100	111,870	8,084	2,165,581	100%
"Baseline"												
Septic Nitrogen Removal												
- For Current Flows	**40%**	0%	0%	41.3%	**40%**	0%	**20%**	25%	100%	0%		
- For New Flows	**100%**	0%	0%	100%	**100%**	0%	**100%**	100%	100%	0%		
Flow Requiring Nitrogen Control (gpd)												
- For Current Flows	8,640	0	0	123,410	144,880	0	74,650	66,080	89,850	0	507,510	30%
- For New Flows	3,470	0	0	96,050	213,930	0	62,290	46,790	22,020	0	444,550	89%
- For Future Flows	12,110	0	0	219,460	358,810	0	136,940	112,870	111,870	0	952,060	44%
"Low End"												
Septic Nitrogen Removal												
- For Current Flows	**0%**	0%	0%	41.3%	**0%**	0%	**0%**	25%	100%	0%		
- For New Flows	**0%**	0%	0%	100%	**0%**	0%	**0%**	100%	100%	0%		
Flow Requiring Nitrogen Control (gpd)												
- For Current Flows	0	0	0	123,410	0	0	0	66,080	89,850	0	279,340	17%
- For New Flows	0	0	0	96,050	0	0	0	46,790	22,020	0	164,860	33%
- For Future Flows	0	0	0	219,460	0	0	0	112,870	111,870	0	444,200	21%
"High End"												
Septic Nitrogen Removal												
- For Current Flows	**60%**	0%	0%	49.2%	**60%**	0%	**60%**	60%	100%	0%		
- For New Flows	**100%**	0%	0%	100%	**100%**	0%	**100%**	100%	100%	0%		
Flow Requiring Nitrogen Control (gpd)												
- For Current Flows	12,950	0	0	147,020	217,320	0	223,960	158,590	89,850	0	849,690	51%
- For New Flows	3,470	0	0	96,050	213,930	0	62,290	46,790	22,020	0	444,550	89%
- For Future Flows	16,420	0	0	243,070	431,250	0	286,250	205,380	111,870	0	1,294,240	60%

NOTES:
1) Current, new and future flows based on Wright-Pierce 30 August 2011 letter (Estimates of Town-wide Current and Build-Out Wastewater Flow)
2) Nitrogen Removal requirements are indicated as follows: PLACEHOLDER in **bold**; PUBLISHED MEP REPORT in plain text; Popponessett Fair Share in *italics*.

There are a variety of nitrogen sources and many ways to reduce the overall nitrogen loads from the watersheds in question. A broad range of nitrogen control strategies have been identified including improved on-site treatment, wastewater collection/treatment/disposal, management of fertilizer load, stormwater management, and enhancement of natural attenuation. If these other nitrogen control strategies are identified and found to be feasible, the volumes of wastewater to be treated can then be commensurately reduced. At the end of this planning process, the Town will have identified the best combination of nitrogen control steps that, once implemented, will attempt to reduce nitrogen loads to levels at or below the TMDLs. As nitrogen control measures are implemented, monitoring of water quality and estuarine habitats will be needed to confirm TMDL compliance.

TABLE 3-9
SUMMARY OF NITROGEN CONTROL NEEDS

	Town-Wide Wastewater Flow, gpd	**Flow Requiring Nitrogen Removal, gpd**		
		Low	**High**	**Baseline**
Current	1,667,000	280,000	850,000	508,000
Planning Horizon	2,164,000	444,000	1,295,000	952,000

In some of the other areas of wastewater needs, it is possible to identify specific parcels for alternative wastewater management (e.g., those with significant Title 5 variances, high water use, or frequent septage pumping). In the category of coastal embayment surface water protection, the specific lot identity is less important. This is because nitrogen loading is a cumulative problem, and effecting the necessary overall nitrogen reduction is more important than the specific lot location. Lots will be prioritized (if possible) based on their proximity to the surface water (restoration will occur faster if near-shore septic systems are eliminated), the water use (which is proportional to the wastewater volume), the density of development, and their occupancy status (on average, year-round homes produce more nitrogen than seasonal homes).

3.5 CONVENIENCE AND AESTHETICS

On-site wastewater disposal can be inconvenient and/or aesthetically displeasing to property owners or neighbors under certain circumstances. These instances can be independent of public health issues or the protection or drinking water or surface waters. Based on discussions with the Health Agent, five types of convenience or aesthetic factors were identified:

- The presence of an enhanced (I/A) treatment system;
- A record of frequent septage pumping;
- A tight tank;
- A mounded septic system;
- Septic systems with a high replacement cost; or
- Septic system with probable sanitary need.

Some people do not like the appearance of above-grade private wastewater treatment systems (often called Innovative/Alternative or I/A systems). Further, these systems require regular sampling and monitoring that homeowners view as inconvenient and/or expensive. On-site systems that require frequent pumping of septage, or tight tanks that require frequent pumping of wastewater, can create impacts due to truck traffic, noise and odor. Mounded systems, particularly those associated with severe retaining walls and lack of landscaping, are often viewed as aesthetically displeasing by neighbors or passers-by. If lots with any of these characteristics were provided with off-site wastewater options, the property owners and/or neighbors would probably support the abandonment of the current system and participation in the off-lot option. (Conversely, property owners who have made a significant investment in an I/A system or mounded leaching field may not wish to abandon those facilities.)

The Health Agent has identified parcels that have convenience and aesthetic factors. The majority of the identified neighborhoods are located in the northern extent of town. The operation of these systems related to maintaining safe public health conditions is considered good. A handful of systems in the Village Center neighborhood are associated with tight tanks and frequent pumping. There also exist a few I/A cluster systems, mostly in the southern and eastern residential parts of town. The Town Neck area has very high septic system replacement costs (due to the presence of clay in that area) and has been included in this category of need.

Based on a detailed review of Board of Health records, it was determined that 1,066 parcels generating 122,200 gpd of wastewater flow meet one or more of the convenience and aesthetic factors. The locations of these properties are shown town-wide in Figure 3-8. Based on this evaluation, there are two areas with significant convenience and aesthetic needs: 1) the Village Center and Historic Village Center areas (tight tanks, frequent pumping, mounded systems); and 2) the Town Neck area (high septic system replacement costs). Aside from these areas, this is not a widespread issue in Sandwich.

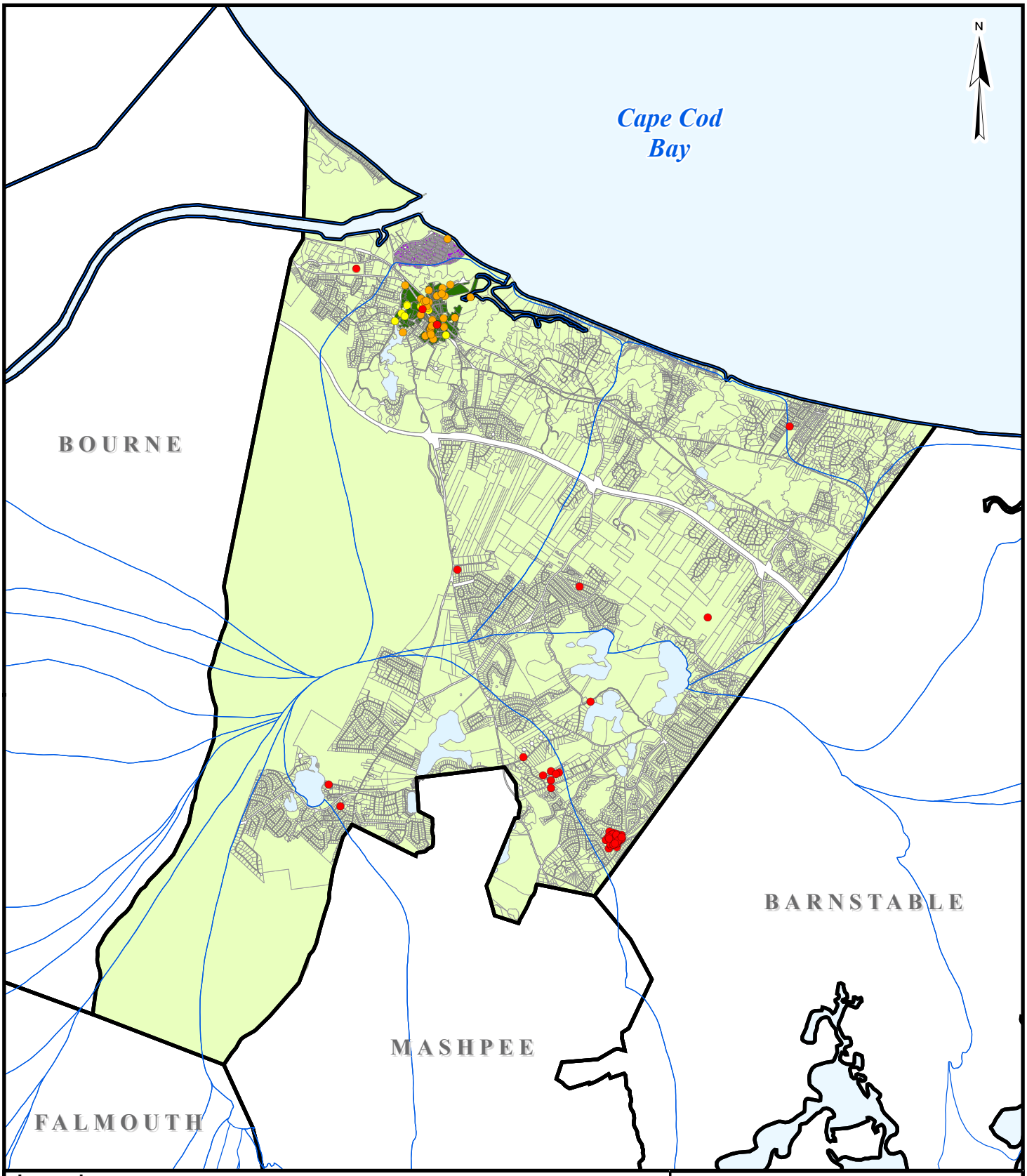
3.6 ECONOMIC GROWTH

Economic growth is, by definition, a "future condition"; however, it is included in this section of the report in order to introduce all categories of sanitary needs in one location. Wastewater needs for economic growth under current conditions are not applicable.

Of these strategic planning areas identified in the Local Comprehensive Plan, four were specifically identified as areas where public sewerage should be considered to allow for sustainable development in accordance with the LCP. These 4 areas are identified below (including the respective categories of need).

- South Sandwich Village Center (water supply protection, nutrient management)
- Sandwich Industrial Park/District (water supply protection, nutrient management-presumed)
- Town Marina/Tupper Road/Route 6A (sanitary/convenience/aesthetics)
- Historic Village District (sanitary, nutrient management-presumed)

Some of the new wastewater flow in these areas will be the results of planned growth, while some would be expected to occur without public sewerage. In addition, there are valid reasons for listing new wastewater flows in these areas in one of the other four environmental categories of need. Accordingly, the new wastewater flows in these areas will be attributed to a combination of environmental need and economic growth in Section 4 (Table 4-4).



Legend

- High Replacement Cost
- IA-Systems
- Mounded-Systems
- Tight-Tanks
- Presumed Sanitary Need
- Watershed Boundary
- Freshwater Pond

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009), and MassGIS (2009)

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

Convenience and Aesthetic Factors

PROJ NO:	DATE:	FIGURE:
12217A	Mar 2012	3-8

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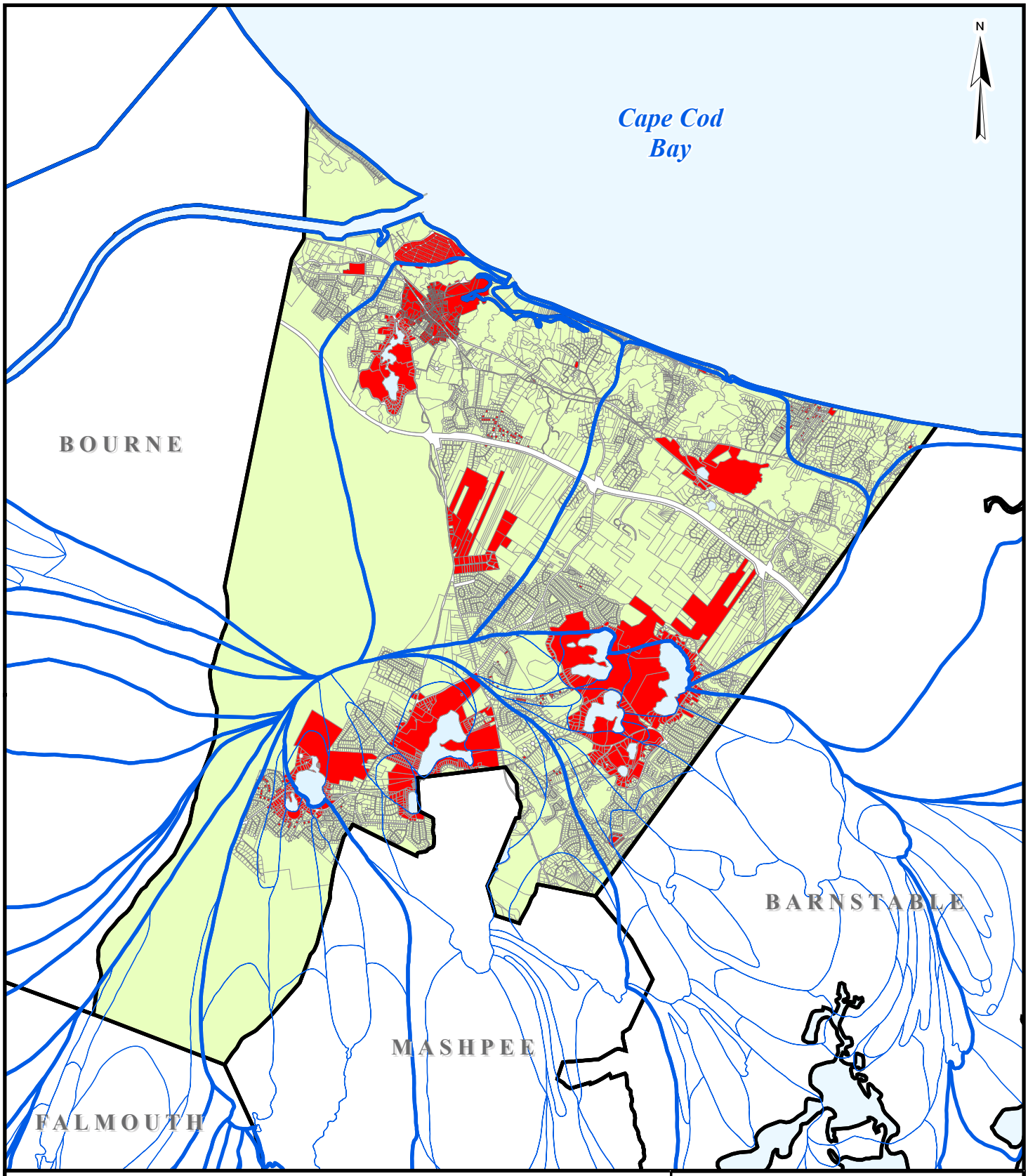
3.7 SUMMARY OF CURRENT NEEDS

Table 3-10 summarizes the results of this needs assessment in terms of both numbers of properties and annual average wastewater flow. Protection of surface waters from nutrient enrichment is by far the most important need in Sandwich, affecting perhaps 25% of the existing developed lots. Needs associated with sanitary issues and convenience/aesthetics factors apply to approximately 12% of the existing developed lots in town. Needs associated water supply protection apply to approximately 2% of the existing developed lots in town.

Each of the five needs categories has been addressed separately in the paragraphs above. While it is important to characterize wastewater needs in these separate categories, it is also important to recognize that some properties in Sandwich fall into more than one category of need. For example, a Village Center lot may have experienced high septage pumping (convenience/aesthetics need), multiple Title 5 variances (sanitary need), and be located in an area where nitrogen control is needed and can be cost-effectively achieved (surface water protection). This parcel would be counted in each of the respective rows in Table 3-10, but the "summary of aggregated needs" row of the data would count this parcel only once. Figure 3-9 shows the locations of individual lots in the sanitary, pond protection, water supply protection and convenience/aesthetics categories. Nitrogen control needs are not shown on Figure 3-9.

A review of Table 3-10 and Figure 3-9 reveals that the sanitary and convenience/aesthetics needs are concentrated in the north shore embayments. This finding agrees with the findings from the Town's earlier wastewater reports which were essentially only looking at these issues (they were written prior to nutrients being identified as a driving concern on Cape Cod). The completed MEP reports indicate that Three Bays and Popponesset Bay have the greatest need for nitrogen control.



Legend

- Summary of Needs in All Categories
- MEP and Subwatershed Boundary
- Freshwater Pond

Source: Base data obtained from the Town of Sandwich (2011), the Cape Cod Commision (2009), and MassGIS (2009)

Note: Does not show parcel specific Nitrogen contol needs.

0 8,000 16,000 Feet

Sandwich Comprehensive Water Resources Management Plan

Aggregated Needs for Current Conditions

PROJ NO:	DATE:	FIGURE:
12217A	Mar 2012	3-9

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TABLE 3-10
SUMMARY OF AGGREGATED NEEDS (CURRENT CONDITIONS)

	Watershed										
Needs Category	**Barnstable Harbor**	**Canal North**	**Canal South**	**Popp. Bay**	**Sandwich Harbor**	**Sandy Neck**	**Scorton Creek**	**Three Bay**	**Waquoit Bay East**	**Cape Cod Bay**	**Town-wide**
Sanitary											
Number of Parcels	0	0	11	0	50	52	25	1	0	0	139
Current Flow, gpd	0	0	7,700	0	28,500	9,800	21,900	500	0	0	68,400
Water Supply Protection											
Number of Parcels	0	0	0	0	62	0	0	32	58	0	152
Current Flow, gpd	0	0	0	0	16,300	0	0	4,200	6,700	0	27,200
Surface Water Protection (ponds)											
Number of Parcels	0	0	0	220	109	0	56	112	62	0	559
Current Flow, gpd	0	0	0	40,100	17,660	0	12,520	26,640	11,050	0	107,970
Surface Water Protection (estuaries)											
Number of Parcels	45	0	0	615	725	0	375	330	450	0	2,540
Current Flow, gpd	9,000	0	0	123,000	145,000	0	75,000	66,000	90,000	0	508,000
Convenience and Aesthetics											
Number of Parcels	0	0	701	9	327	1	2	26	0	0	1,066
Current Flow, gpd	0	0	73,500	1,800	40,100	200	400	6,200	0	0	122,200
Economic Development											
Number of Parcels	0	0	0	0	0	0	0	0	0	0	0
Current Flow, gpd	0	0	0	0	0	0	0	0	0	0	0
Summary of Aggregated Needs											
Number of Parcels	45	0	710	615	728	53	375	330	450	0	3,306
Current Flow, gpd	9,000	0	73,700	123,000	145,800	10,000	75,000	66,000	90,000	0	592,500

Note: Town-wide totals are additive across the row. Totals by major watershed are not additive by column. The category total by watershed accounts for parcels that have more than one need.
Source: See text for data sources and analysis.

3.8 OVERVIEW OF OTHER WATER RESOURCE PROTECTION NEEDS

In addition to the wastewater management items described herein, there are several other water resource protection management categories that should be considered by the Town on an on-going basis. Some of these items are enumerated in the Local Comprehensive Plan and are included here for emphasis.

- *Management of Contaminants from the Massachusetts Military Reservation (MMR)* - There are a number of historic groundwater contamination plumes on MMR. These plumes have been extensively investigated and are actively being remediated. One of these plumes impacted the Weeks Pond Well, which has been shutdown. The Town and Water District should remain mindful of the potential for previously undiscovered plumes.

- *Management of Other Legacy Plumes* - The Town has plumes associated with the closed/capped landfill and the closed septage lagoons. These plumes have been extensively investigated and are monitored. Depending on the level of nitrogen in these legacy plumes, there is the potential that these plumes may require remedial efforts depending on the results of the Sandwich Harbor MEP Report.

- *Management of Stormwater from the Town's Drainage Systems* - Stormwater discharges to surface water and wetlands can have a dramatic impact on water quality and ecosystem health. These discharges need to be carefully monitored and managed in order to minimize or mitigate impacts associated with siltation, road salt, trash/debris, fertilizers and other nutrients that are commonly found in stormwater. The Town should continue to fund and implement the action items contained in the Stormwater Management Plan and the Local Comprehensive Plan through the Town Public Works Department.

- *Management of Household Hazardous Product Storage and Disposal* - The Town organizes Household Hazardous Product Collection days throughout the year. This program provides residents with a method to properly dispose of hazardous products.

- Public Water Supply Source Protection and Monitoring - The Town, through its Board of Health and its Planning Board, and the Sandwich Water District are actively engaged in managing, protecting and monitoring the source water for the public water supply. The Town and District should continue to facilitate source protection and monitoring to the maximum extent practicable.

- Regional Coordination - The results of this Needs Assessment report will be used as the basis for outreach and coordination with municipal, state and federal (as necessary) officials to address the water resource protection needs identified herein. Regional coordination efforts are intended to accomplish two major goals: 1) to address shared responsibilities in shared watersheds; and 2) to identify if there are opportunities to save management and/or infrastructure costs by working together with other municipalities to create economies of scale.

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Section 4

SECTION 4

FUTURE CONDITIONS

Water resource protection planning must consider both the current and future needs which will occur within the planning period. As Sandwich grows in population, wastewater management needs will increase. Wastewater flows will increase as vacant lots are developed, as seasonal homes are converted to year-round use (or are occupied a greater percentage of the year), and as commercial development expands to serve the larger population.

4.1 FUTURE WASTEWATER QUANTITIES

For the purposes of water resource management planning, wastewater volumes have been used as the "measure" of future growth. The estimates of town-wide wastewater flow are presented as annual average values.

4.1.1 Definition of Terms

As described in Section 2, "current" conditions are defined as the general population, level of commercial activity and wastewater generation rates that exist today. "Future" conditions are defined as the conditions that will exist once additional development occurs in Sandwich. For the future conditions, the following terms apply to this discussion:

- *New Flow*. In wastewater terms, it is appropriate to characterize growth as the difference between "current" conditions and "future" conditions and call it "new" flow.

- *Theoretical Build-Out.* The population and commercial activity associated with the ultimate development of Sandwich to the fullest extent possible under current zoning and other regulation, regardless of economic issues.

- *Practical Build-Out.* The population and commercial activity associated with more realistic assumptions on the extent of build-out, factoring in such concerns as economic realities, other limitations on growth (such as infrastructure capacity), land protection efforts, and retention of estate properties.

- *Planning Horizon.* A future population, level of commercial activity, and associated wastewater flow that will be the basis for analyzing wastewater management options and for the design of whatever infrastructure may be recommended. This value could be less, or equal to, the level of development anticipated at Practical Build-Out (depending on year the town believes Practical Build-Out will be attained). The planning period for wastewater facilities are generally considered to have a 20-year design life; therefore, including time for planning and construction of recommended measures, a planning horizon should be 25 to 30 years into the future. The planning horizon for this study is 2040.

4.1.2 Development of Theoretical Build-Out Flows

A subcommittee of the WQAC and the Planning Director met on a number of occasions to: 1) review the growth projections included in the 2009 Local Comprehensive Plan; 2) "allocate" this growth to the Massachusetts Estuaries Project (MEP) watersheds; and 3) project new flows resulting from redevelopment of existing parcels. This working group also estimated the redevelopment of existing properties in the following manner: 1) for residential redevelopment, the total number of currently developed parcels in each strategic planning area (as shown on LCP page 1-35) was multiplied by an estimated percentage of parcels which would be subject to redevelopment; and 2) for commercial/civic/industrial, the total amount of existing building area (as shown on LCP page 1-50) was multiplied by an estimated percentage of building square footage which would be subject to redevelopment. This work resulted in some modest revisions to the 2009 Local Comprehensive Plan, as shown below. The working group did not "assign" growth to specific parcels; accordingly, the new and future flows identified herein are not parcel specific.

The WQAC subcommittee developed these projections anticipating several changes to local zoning, which are expected to be presented at Annual Town Meeting or Special Town Meeting in 2012. These changes include: modifications to the Zoning Permitted Uses table and a new Development Agreement article.

TABLE 4-1
THEORETICAL GROWTH POTENTIAL

Growth Area	2009 Local Comprehensive Plan	2011 WQAC Review
New Residential units	2,696 units	2,833 units
New Commercial space	971,270 sq. ft.	1,738,347 sq. ft.
New Civic space	146,000 sq. ft.	171,000 sq. ft.
New Industrial space	1,307,045 sq. ft.	963,299 sq. ft.
Redeveloped Residential Units	-	1,000 units
Redeveloped Commercial space	-	139,600 sq. ft.
Redeveloped Civic space	-	0 sq. ft.
Redeveloped Industrial space	-	24,400 sq. ft.

It has been assumed that new development will generate wastewater flow at the same rate as current development for each type of land use (e.g., 188 gpd for residential). Redevelopment can occur as either a building expansion (e.g., additional bedroom, accessory apartment, commercial expansion, etc.) or a conversion to a more intense use (e.g., seasonal to year-round home, small shop to a restaurant, etc.). For the residential category, it has been assumed that an additional 94 gpd would be generated per unit redeveloped (i.e., 282 gpd). For the non-residential category, it has been assumed that an additional 30 or 50 gpd would be generated per thousand square foot redeveloped.

Under these assumptions, we estimate that approximately 755,000 gpd of new wastewater flow will be generated town-wide. This results in a Theoretical Build-out future wastewater flow of 2,422,000 gpd. This represents a 45% increase over the estimated current wastewater flows of 1,667,000 gpd. Of this increase in flow, 86% is associated with development of vacant land and 14% is associated with the redevelopment of existing properties.

4.1.3 Development of Planning Horizon Flows

The WQAC in conjunction with the Planning Department determined an estimate of the amount of growth that will occur by the Planning Horizon. The portion of the future growth that will occur within the Planning Horizon is two-thirds (or 66%) of the Theoretical Build-out.

The quantities of wastewater produced at Planning Horizon are summarized in Tables 4-2 and 4-3, by watershed and planning district, respectively. Accordingly, at the Planning Horizon, we estimate that approximately 497,000 gpd of new wastewater flow will be generated. This results in a Planning Horizon future wastewater flow of 2,164,000 gpd. This represents a 30% increase over the estimated current wastewater flows.

4.1.4 Future Population Projection

Working with Town staff to review demographic data combined with a review of water use data, resulted in an estimated current equivalent annual population of 25,600 individuals. The population estimates associated with Planning Horizon and Theoretical Build-out are 30,100 and 33,700 individuals, respectively.

4.2 FUTURE WASTEWATER NEEDS

A summary of future wastewater needs at the Planning Horizon are presented in Table 4-4. With the exception of nitrogen control needs, the increase in wastewater flow associated with each needs category reflects a 30% increase over current conditions. For nitrogen control needs, the value indicated in Table 4-4 is the "baseline" scenario for each watershed.

Once the all the MEP technical reports are completed, the future wastewater needs will need to be adjusted to reconcile the differences between the planning data set used for the CWRMP (2007 to 2009) and the data set used for each MEP watershed (the years will vary between 2001 and 2011 depending on when the MEP work was completed). This will modify the total wastewater flows which require alternative wastewater management.

It is important to note that this value does not address the ramifications of continued "in-watershed" disposal of wastewater from a parcel, or a collection of parcels, that implement some form of nitrogen removal. That is, if disposal remains within the watershed, some amount of residual nitrogen remains in the watershed (variable depending on treatment and disposal method). Accordingly, an incremental increase in nitrogen control needs will be dependent on the wastewater management alternatives under consideration. This variable will be addressed in the Alternatives Analysis phase of the project.

It is also important to note that the identified wastewater needs do not include the municipal wastewater treatment facilities which are located at the schools (i.e., Forestdale School, Oak Ridge School, High School, and Wing School). These existing facilities will be evaluated in Phases 2 and 3 to determine whether they are expanded (to accommodate other wastewater needs) or abandoned (and incorporated into alternative wastewater management approaches).

TABLE 4-2
ANNUAL WASTEWATER QUANTITIES BY WATERSHED
(PLANNING HORIZON)

Watershed	Wastewater Flow, gpd	Percentage of Total
Barnstable Harbor	25,000	1
Canal North	20,000	1
Canal South	190,000	8
Popponesset Bay	394,000	18
Sandwich Harbor	576,000	27
Sandy Neck	93,000	4
Scorton Creek	435,000	20
Three Bay	311,000	15
Waquoit Bay East	112,000	5
Cape Cod Bay	8,000	1
Total	**2,164,000**	**100**

TABLE 4-3
ANNUAL WASTEWATER QUANTITIES BY PLANNING DISTRICT
(PLANNING HORIZON)

Planning District	Current Wastewater Flow, gpd	Future Wastewater Flow, gpd	Percentage of Total
East Old Kings Highway Corridor	24,900	28,000	1
East Sandwich Residential	263,300	315,000	15
Forestdale Residential	291,100	331,000	15
Growth Technology Center/Golf Course	200	200	<1
Historic Village Center Route 6A	27,600	38,000	2
Mass. Military Reservation	n/a	n/a	n/a
North Sandwich Neighborhoods	264,600	325,000	15
Ridge	78,600	133,000	6
Route 130 Medical Park	1,100	6,000	< 1
Sandwich Industrial Park	15,700	66,000	3
Scussett Beach Area	17,400	20,000	1
South Sandwich Residential	560,300	621,800	29
South Sandwich Village Center	26,600	130,000	6
Town Marina-Tupper Rd-Route 6A	58,900	107,000	5
Village Center Neighborhoods	36,900	45,000	2
Total	**1,667,000**	**2,164,000**	**100**

TABLE 4-4
SUMMARY OF AGGREGATED NEEDS (PLANNING HORIZON)

Category	Barnstable Harbor	Canal North	Canal South	Popp. Bay	Sandwich Harbor	Sandy Neck	Scorton Creek	Three Bay	Waquoit Bay East	Cape Cod Bay	Town-wide
Sanitary Conditions											
Wastewater Flow, gpd	0	0	12,800	0	39,100	10,000	34,300	800	0	0	95,600
Water Supply Protection											
Wastewater Flow, gpd	0	0	0	0	27,000	0	0	7,000	11,200	0	45,200
Surface Water Protection (ponds)											
Wastewater Flow, gpd	0	0	0	48,000	22,000	0	15,000	32,000	13,000	0	130,000
Surface Water Protection (estuaries)											
Wastewater Flow, gpd	12,400	0	0	219,500	358,800	0	136,900	112,800	111,900	0	952,300
Convenience & Aesthetics											
Wastewater Flow, gpd	0	0	75,900	3,000	80,000	900	700	10,300	0	0	170,800
Economic Growth											
Wastewater Flow, gpd	0	0	48,100	34,000	104,100	0	3,100	34,000	0	0	223,300
Summary of Aggregate Needs											
Wastewater Flow, gpd	12,400	0	124,200	218,200	359,600	10,900	136,700	112,700	112,200	0	1,077,900

Note: Town-wide totals are additive across the row. Totals by major watershed are not additive by column. The category total by watershed accounts for parcels that have more than one need.
Source: See text for data sources and analysis.
Note: Once MEP reports are completed, future wastewater flows will need to be reconciled between the CWRMP data set (2007-2009) and the respective MEP data sets (variable, 2001 to 2011).

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Section 5

SECTION 5

NEXT STEPS

This section presents the "next steps" for the Town in the CWRMP process, generally listed in order of action.

1. Circulate the Needs Assessment report for review by the Town, DEP, CCC and the public. Present the Needs Assessment report findings at a Board of Selectmen meeting.

2. Meet with DEP and CCC to discuss the report.

3. Initiate discussions with neighboring communities regarding Sandwich's share of regional Total Maximum Daily Loads for nitrogen.

4. Initiate CWRMP Phase 2 (*Development and Screening of Alternatives*) with the WQAC.

5. Restart a regular pond sampling program in Spring 2012. Parameters should include temperature, dissolved oxygen, pH, alkalinity, phosphorus, nitrogen, chlorophyll, Secchi disk clarity and algal analysis (if blooms are present). Frequency should be at least two (May and July) or three (September) times annually. Conduct more detailed assessment of ponds with data in hand, including physical assessment of rooted plants and pond bottom sediments. Secure additional funding, if necessary.

6. Explore the feasibility and cost of implementation measures that will allow Sandwich to maintain or enhance natural attenuation of nitrogen in the ponds. Secure additional funding, if necessary.

7. Present the anticipated zoning amendments at Annual Town Meeting or Special Town Meeting. Consider additional zoning and/or by-law modifications to protect Sandwich's ponds from additional negative impacts due to development and agriculture (refer to Appendix A, 50-51).

8. Consider adopting the Environmental Significance Rating System and spreadsheet documentation system (as documented in Section 3 herein) as a part of the Board of Health review of Title 5 variance requests.

9. Consider implementing a private well testing program to document nitrate levels.

10. Coordinate with the Sandwich Water District to review the technical, legal and procedural actions necessary to extend public water to areas with high nitrate levels in private wells.

11. Continue to coordinate with MEP/SMAST to obtain the pending Massachusetts Estuaries Project (MEP) reports for the Sandwich Harbor, Scorton Creek and Barnstable Harbor watersheds. Review the MEP reports when they become available. Update the Needs Assessment report findings to reconcile: a) differences between the "placeholder values" used herein and the "actual values" issued by the MEP; b) differences between baseline data sets used for "existing conditions" between the CWRMP and MEP; and c) properties that fall into or out of ponds subwatersheds once delineated by MEP.

12. Update the mapping for the existing Zoning By-law Groundwater Protection District to reflect any changes in DEP-approved Zone II delineations as/when Sandwich Water District updates its model(s).

13. Update the Stormwater Management Plan as planned by the Engineering Department.

14. In preparation for the next phases of the CWRMP, review the Barnstable County report entitled "*Enhancing Wastewater Management on Cape Cod: Planning, Administrative and Legal Tools*" (July 2004) and the regional wastewater management plan when published.

Appendix A

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Engineering a Better Environment

AN EVALUATION OF SELECTED SANDWICH PONDS

BY WATER RESOURCE SERVICES, INC.

JANUARY 2012

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Introduction

The ponds of Sandwich represent valuable resources by themselves, but they are also an integral part of the overall ecosystem and community fabric of the Town of Sandwich. While much of the cumulative shoreline is under private control, many ponds have public access and some support major public facilities. All have been part of the community for many years. Consideration of their attributes and health is an integral part of any comprehensive water resource management plan. The ponds have not been the subject of any long-term detailed study, but some have been monitored as part of the Pond and Lake Stewards (PALS) program and the Shawme Ponds were the subject of one investigation by a consultant. This assessment is intended to provide a status report as of this time with recommendations for further action.

Study Approach and Methods

This assessment is based on existing information and a brief field review of conditions. Available information was provided by town sources, and includes monitoring data from past efforts and assimilation projects such as the Local Comprehensive Plan update of 2009. Limited relevant information is available in the Jacobs Engineering report (1999) on the Ashumet ground water pollution plume. A consultant report (ENSR 2001) on the Shawme Ponds provides some useful background on those waterbodies, but there are few other original reports on any ponds in Sandwich. The MA Division of Fisheries and Wildlife provides old (pre-1990) water depth maps for 8 of 12 ponds included in this assessment. Each pond was visited for visual inspection, but no sampling or detailed field work was conducted. An overview of town pond resources is provided, with pond by pond assessments for those waterbodies selected for further evaluation, as allowed by the available data. Considerations for future assessment and management are then offered.

Overview of Sandwich Ponds

Much background information is contained in the Local Comprehensive Plan for the Town of Sandwich, actually a major update of previous plans that incorporates most efforts conducted through 2008. There are relatively few pond-related reports for Sandwich ponds, Upper and Lower Shawme Lakes have been the subject of several investigations and are listed on the 2010 Integrated Waters List from MA DEP as needing development of a Total Maximum Daily Load (TMDL) for nutrients and eutrophication. Peters and Snake Ponds are also on the 2010 Integrated Waters List as having complete TMDLs for metals. Work on MMR sites has included limited assessments of possible impacts on Sandwich ponds, most notably Peters and Triangle Ponds. Lawrence, Spectacle and Triangle Ponds have been monitored by the Pond And Lake Stewards (PALS) program for several years. Additional information comes from personal experience with other Cape Cod ponds, including assessments and management efforts in Falmouth, Barnstable, Harwich, Brewster, Orleans, Chatham, and Eastham.

Location of Ponds

The Sandwich Ponds (Figure 1) are surface water features within the Sagamore lens of the sole source aquifer of Cape Cod which tends to be at least 60 feet deep in Sandwich. Pathways of ground water flow affect which lands contribute to which ponds (Figure 2), but there is expected variation in those pathways from season to season and year to year, depending mainly on precipitation.There are 63 ponds in total, but only 5 that are larger than 10 acres. One pair of ponds (the Hog Ponds) in close proximity has a total acreage >10 acres as well. Twelve ponds were selected for further evaluation as part of the overall planning process, based on significant size, public access, natural resource significance, and/or elevated housing density along their shorelines. Key features as relates to this assessment are included in Table 1.

Origin of Ponds

Ponds in Sandwich are largely of kettlehole origin, formed by stranded blocks of ice in a large, sandy moraine associated with glaciers at the end of the last ice age, about 11,000 years ago. Dams were sometimes constructed to raise the water level, but with the very sandy soil, creation of completely artificial waterbodies is limited in this area. Of the ponds chosen for further examination, only the Shawme Lakes do not appear to be kettleholes. Weeks Pond is very shallow, more so than most true kettleholes, but it appears to be a natural landscape feature. Each of Upper and Lower Shawme has a dam that impounds ground water that used to form a stream (ENSR 2001). There may have been wetlands in the area now occupied by the ponds, but the maximum depth of each is <10 ft, compared to maximum depths of >25 ft in most kettlehole lakes. They may have been named “lakes” for this reason; kettlehole ponds traditionally are called “ponds” on Cape Cod.

Kettlehole ponds rarely have any permanent stream inflows; they depend on precipitation and ground water flow for inputs. Losses include evaporation and ground water outseepage, but many do have overflows. Overflows tend to feed streams that reach the coast and allow anadromous fish such as alewife to enter ponds and spawn, with the fry spending the summer in the pond before heading downstream to the sea. Of the 10 apparent kettlehole ponds being examined here, Hoxie Pond overflows through wetlands into Scorton Creek, but none of the other nine kettlehole ponds appears to have a surface water outlet. Upper Shawme Lake outlets into Lower Shawme Lake, which outlets into Mill Creek, a tidal creek that connects with the bay.

Uses of Ponds

Historically ponds on Cape Cod were used as local water supplies, sources of ice, fishing resources (including migrating alewife harvest), irrigation supply, and some recreation. Today, uses include mainly recreation, including swimming, boating and fishing, with water supply for cranberry bogs important when bogs are near the ponds. Of the 12 ponds under consideration here, only Hoxie Pond and Upper Shawme Lake appear to ever have had associated cranberry bogs, and only the Hoxie bog is active now. Shoreline residences make use of the ponds for recreation and sometimes landscape irrigation, but where public access exists, town residents or state residents can use the ponds for swimming, boating and/or fishing. There is a 10 hp limit for motorized boats on all but Peters Pond.

Figure 1. Sandwich Ponds, including all ponds covered in this assessment.

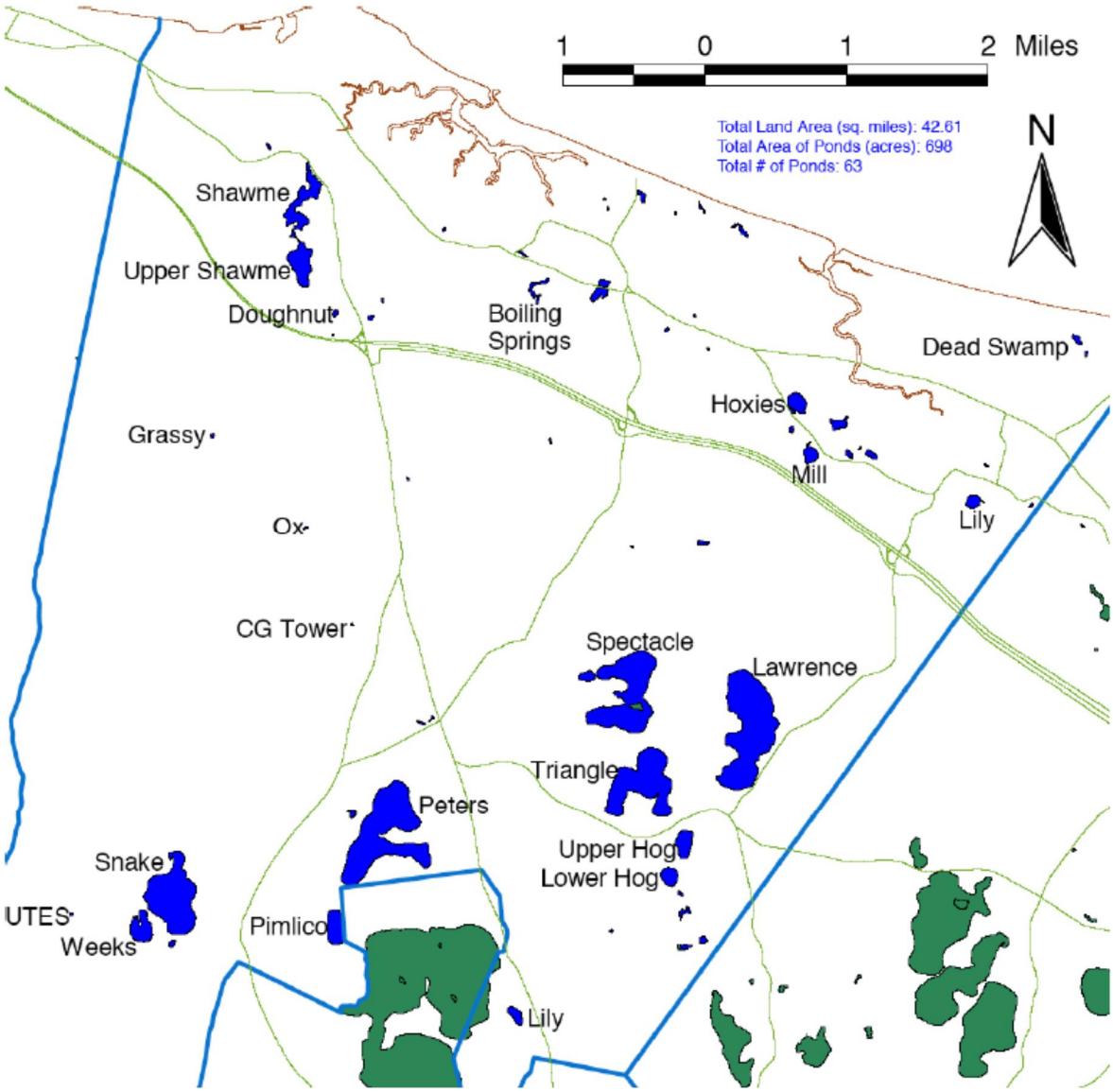


Figure 2. Location of ponds selected for evaluation, with major watershed boundaries.

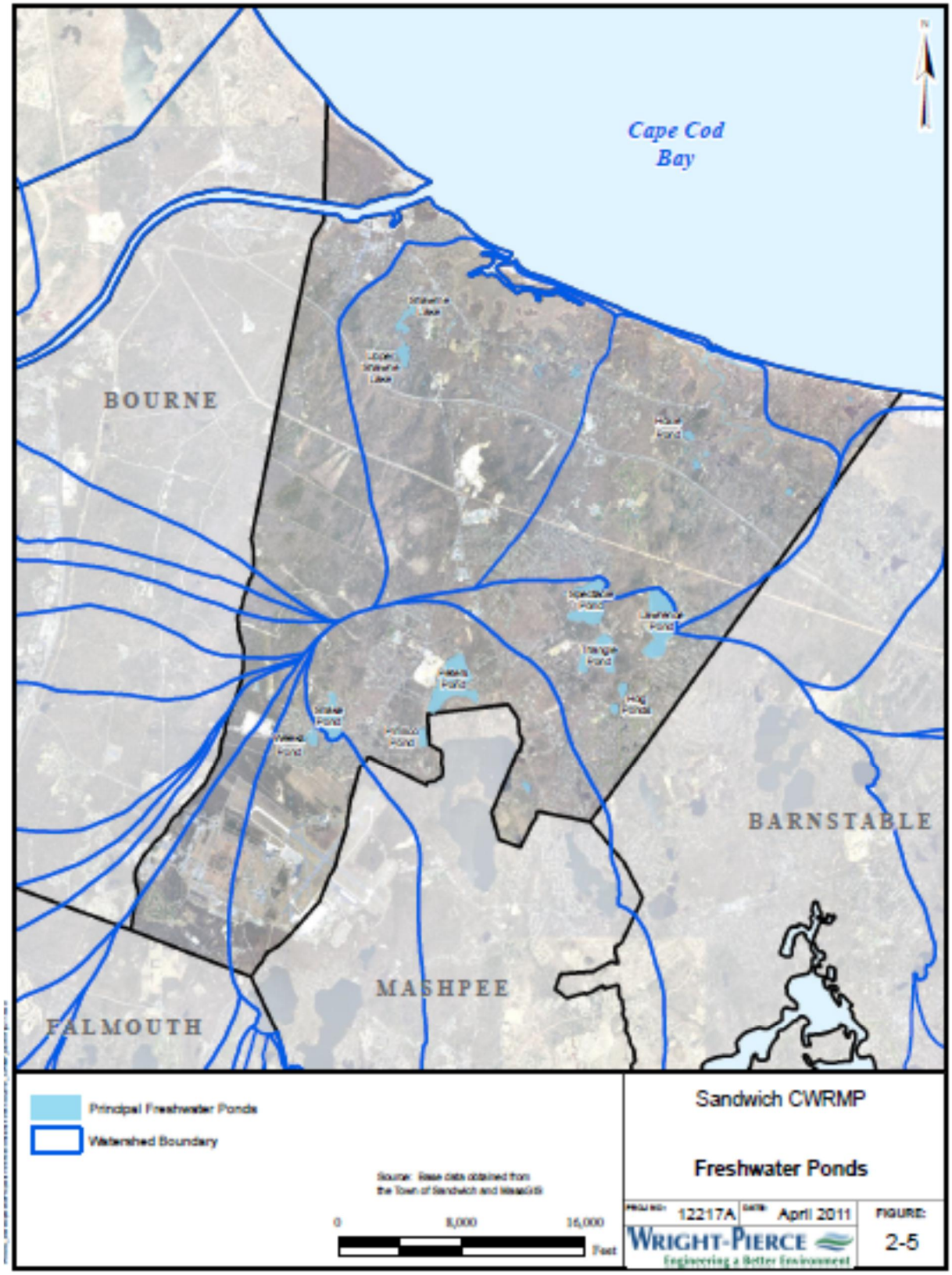


Table 1. Features of ponds evaluated in this assessment.

Pond	Area	Shoreline Length	Max. Depth	Median Depth	Parcels Within 300 Feet	Upgradient Parcels with 300 Feet		Estimated Waste Water Flow	Reported Algal Blooms
	(acres)	(miles)	(feet)	(feet)		Total	Developed	(gdp)	
Lawrence	138.0	2.30	27	15.0	62	7	2	2570	N
Spectacle	91.0	2.60	43	25.0	25	14	11	2740	Y
Triangle	84.0	2.00	30	15.0	39	21	17	3050	Y
Upper Hog	11.3	0.57	20	14.0	15	6	2	575	N
Lower Hog	7.8	0.50	26	12.0	27	5	3	345	N
Peters	127.0	2.90	54	22.0	58	16	10	1960	Y
Pimlico	16.4	0.57	23	12.0	50	32	26	2680	N
Snake	83.0	1.60	33	18.0	87	17	15	1790	N
Weeks	15.0	0.76	15	4.0	32	15	12	2310	N
Hoxie	8.5	0.42	35	12.0	14	6	5	910	N
Lower Shawme	24.0	1.50	5.3	4.0	65	24	15	2460	Y
Upper Shawme	21.0	0.80	11.6	7.5	32	15	11	1310	Y

Access to Ponds

Of the 12 ponds under consideration here, all except the two Hog Ponds have some form of open public access, but only Peters Pond has well known developed access (town beach and state boat launch). Triangle, Spectacle and Snake Ponds also have boat launch ramps, but with limited facilities and parking, and with a 10 hp limit on the ponds. Six other ponds (Lawrence, Pimlico, Weeks, Hoxie, and Upper and Lower Shawme) provide public access in the form of undeveloped roadside parcels or public lands that support only foot traffic or carry on boats. Several ponds have lake association beaches that afford access to people living on parcels near the ponds, and several more ponds have public campgrounds were access can be gained for a fee. Lawrence, Triangle and Spectacle Ponds each have a YMCA camp on them. So except for the two Hog Ponds, recreational use of the ponds is open to people beyond shoreline property owners.

Historic Influences

Initial settlement began in the 1600s, when Cape Cod was largely a dense forest of oak and pine on the high ground and a variety of trees in the lower lands, including sassafras, birch, beech, and maple. Evergreen holly and juniper were also common on the Cape at that time. The native Americans had conducted burns to open areas for agriculture, but not on the scale of clearing conducted by white settlers in the 1700s and beyond. By the late 1800s there were few trees in arable areas on the Cape, and most of the topsoil base accumulated over 10,000 years was lost to wind erosion. The sandy nature of the surficial soils as we know them today was the result.

Agriculture was the most influential land use on Cape Cod for several hundred years, at first more subsistence farming but later with a variety of larger vegetable farms and livestock operations, including major duck, goose and turkey farms that were often located near ponds on the Cape. Yet the sandy soils prevented most of the runoff that plagued surface water resources in many other areas of the northeastern USA subject to these agricultural pursuits. Over the last century cranberry farms became abundant, and while the density has declined, cranberry farming is the most active form of agriculture on the Cape today. As bogs are almost always adjacent to a pond and utilize water from the pond for irrigation and flooding for harvest and frost prevention, the potential for impact from this agricultural source through return water is more obvious. Aerial spraying of pesticides and nutrients is another mode of potential impact from cranberry bogs on nearby ponds. Where historic agriculture was adjacent to or actually on ponds (like cranberry bogs at Long Pond in Brewster or duck farming at Hamblin Pond in Marston's Mills) impacts were sometimes notably severe, but few problems with water quality or pond condition have been reported in anecdotal accounts prior to the last 30 to 40 years.

As agriculture waned and residential development increased, more impervious surface was created and more waste water disposal systems were created, increasing both runoff and ground water impacts by human activity on the Cape. Sandy soils and limited piping systems still limit direct inputs of runoff to most ponds, but inputs to ground water from runoff and waste water have increased dramatically.

Camp Edwards and the Otis Air Force Base, collectively known as the Massachusetts Military Reservation (MMR), represented a source of ground water contamination for many years, and remain

an ongoing concern. Nitrogen and to a lesser extent phosphorus that was discharged to soil moved along ground water flow gradients and was known to contaminate some water resources, the most well documented of which was probably Ashumet Pond (Jacobs Engineering 1999), a site of past and recent remediation. Other contaminants of concern from Camp Edwards include various solvents that have floated on top of the ground water and contaminated wells that penetrate only into the upper level of the aquifer. The position of the "crown" of the aquifer is on the MMR, with ground water apparently radiating out in all directions and potentially affecting all the ponds. However, ground water movement may not be consistent or readily predictable in both vertical and horizontal directions, and can vary over time, especially in response to variation in precipitation, so assumptions need to be documented before drawing conclusions about contamination.

Current Land Use

The primary current developed land uses are residential and commercial, with cranberry farming as the main agricultural activity. Transportation corridors (roads) associated with development constitute a major land use as well. Undeveloped lands include pine and oak forests in uplands and a variety of wetland types in the lowlands.

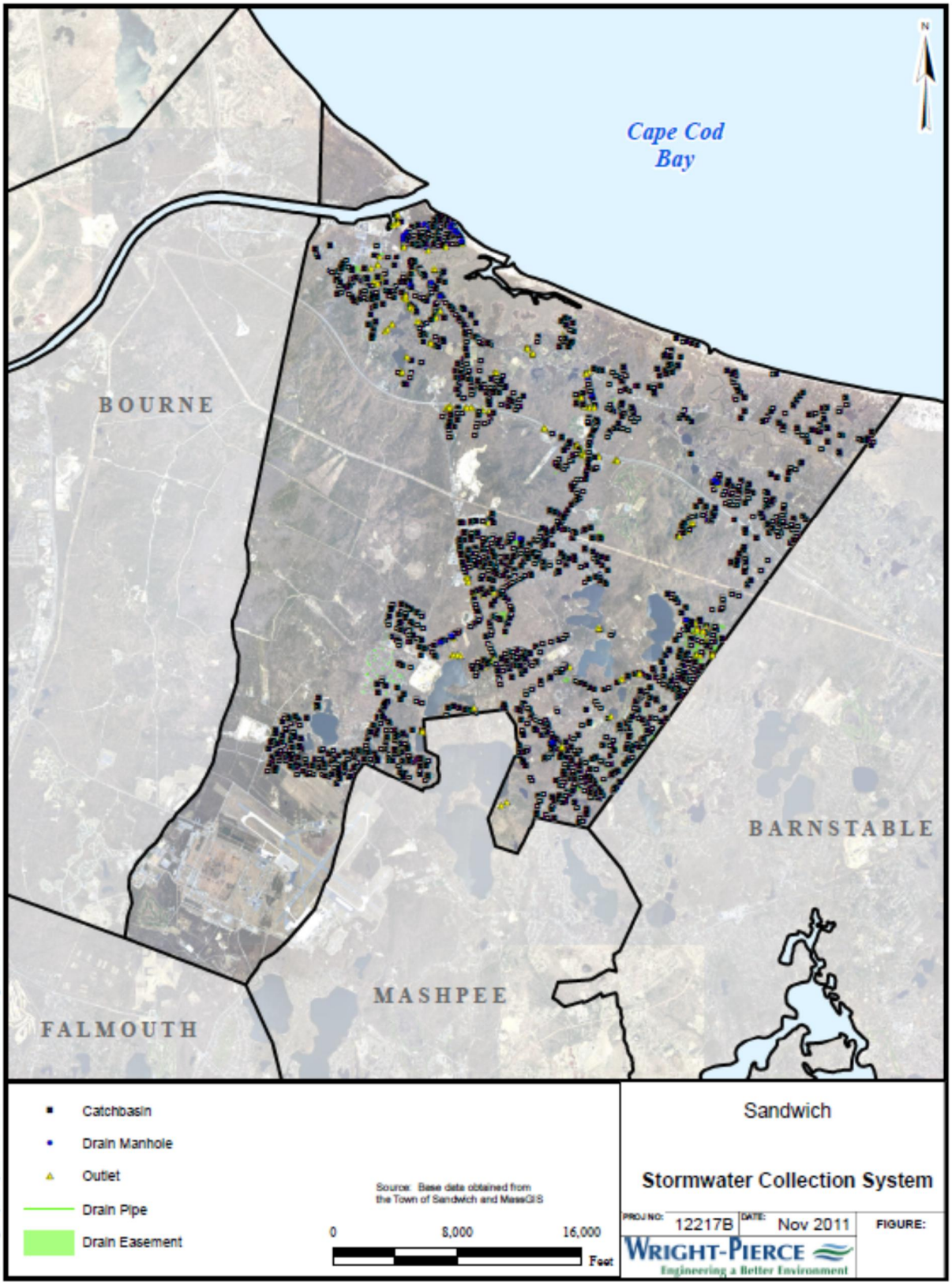
The major pollution threat to ponds is mainly nutrients from developed land and cranberry bogs. Storm water runoff is one form of pollution that may be significant with the level of development now experienced by Sandwich, with nutrients, sediment, bacteria, salt or other deicing chemicals, hydrocarbons and larger trash items all potentially significant. Sandwich has developed a Storm water Management Plan (SMP) that outlines current laws and regulations and specifies best management practices (BMPs) to address storm water impacts. The SMP is intended to meet NPDES Phase II regulations and to provide a framework for protecting water resources. All storm drains in the town have been mapped (Figure 3), but the vast majority are leaching catch basin and do not discharge to any waterbody or stream.

Yet waste water disposal is generally recognized as the biggest pollution threat, and includes nutrients and various household products that can negatively impact ponds receiving significant ground water flow. This pollution source is addressed separately in the next section.

Waste Water Disposal in Sandwich

While there are a few small waste water treatment facilities in Sandwich, Wright-Pierce (unpublished data) reports that approximately 97% of waste water is disposed by on-site subsurface treatment systems with release into soil, particularly near the ponds assessed here. Some larger communal systems exist, but most properties are served by individual systems. Nitrogen is minimally removed by conventional on-site (septic) systems and concentrations can be predicted from housing density, related disposal features and precipitation/recharge features. Concentrations high enough to impact coastal resources have been documented as part of the Massachusetts Estuaries Program, and it is conceivable that ponds are being impacted as well, although impacts have been less studied. Phosphorus is adsorbed to soil particles and travels less freely, but adsorption capacity is lower for sand than many other soils and breakthrough to water resources can occur over time as adsorption capacity is

Figure 3. Storm water drains in Sandwich, Massachusetts.



exhausted. Hydrocarbons tend to “float” on the ground water and create elongate plumes. Various solvents and personal care products mix with ground water and should be diluted to a large extent, but some compounds (e.g., endocrine disruptors, hormone mimics) may cause impacts at very low concentrations. Viruses are known to move through soils and could contaminate ponds.

The MMR has impacted ground water in multiple towns from waste disposal operations over many years. Impacts on pond water quality and biological components, including fish, are still under study, but some cases of documented impact (Ashumet Pond, Mashpee Lake 27) exist. Remediation programs are underway, but the extent of contamination from past spread is an ongoing concern for water resources, including some Sandwich Ponds.

In recognition of the role that ground water plays in surface water quality, Sandwich has also adopted a ground water protection statute under its zoning process that regulates development within 300 feet of any pond or wetland. It is not certain that a 300 foot buffer is sufficient to protect associated surface water resources, but this is a generally recognized setback for limitation of phosphorus impacts and is thought to provide enough adsorption and dilution capacity to address many other contaminants.

In 2000 the Cape Cod Commission designated the Three Ponds Area of south Sandwich as a District of Critical Planning Concern to help protect these water resources. Such a district allows establishment of special regulations to protect resources in the designated area, which in this case includes 692 acres of land associated with Lawrence, Spectacle and Triangle Ponds. One focus of the district is protection of endangered species, and there are multiple listed plant species associated with some of the ponds in Sandwich. However, the District includes only the three ponds mentioned above, leaving other ponds with less protection.

Internal Recycling Influences

The accumulation of nutrients in ponds on Cape Cod has become a significant issue for eutrophication (overfertilization) over the last couple of decades. There is a lot that is not thoroughly understood about this accumulation, such as whether there is a clear threshold for impact or how much organically bound phosphorus may contribute, but it is clear that phosphorus bound to iron can be released when oxygen is lacking and that iron-bound phosphorus is a major component of accumulated surficial sediment phosphorus in many Cape Cod ponds. It appears to take a fairly long time (many years) for enough phosphorus to build up to allow significant internal recycling, so the sources may not be consistent or obvious over time. Yet once internal recycling becomes a significant influence, it tends to accelerate and become a dominant influence in a few years. At that point, watershed inputs from surface or ground water become less important to pond condition, which is typically poor as a consequence of algal blooms.

Internal recycling of phosphorus in deeper (>25 ft) ponds is facilitated by low oxygen at the bottom of those ponds and typically results in high bottom water phosphorus levels, but there is not enough light in deep water to support algal blooms. How much of that phosphorus gets into better lit upper waters where it can support algal blooms is a function of wind-induced mixing, upward diffusion, and iron sulfide formation, which limits the amount of iron available to re-bind the phosphorus when it reaches

the upper waters. When sediment release of phosphorus results in concentrations >20 ug/L in upper waters, algal blooms tend to develop. As there is not nearly as much nitrogen being recycled with the phosphorus, the N:P ratio is relatively low and cyanobacteria (blue-green algae) are favored. Cyanobacterial blooms are also favored by warm summer temperatures, can float to form surface scums, and some forms can cause taste and odor and even toxicity. Such blooms are therefore a serious concern in Cape Cod ponds and have been increasing in frequency and severity over the last two decades.

Other Threats to Use Support

Climate change is an issue for Cape Cod ponds, leading to greater extremes in weather. Higher precipitation in storms leads to more runoff, and warmer summer temperatures promote algal blooms and favor cyanobacteria. Rooted plant growths may also be favored. Variability will increase, and that may be more of a problem than any shift in average conditions. Lack of predictability requires greater management effort to maintain desirable conditions.

Invasive species represent another threat to use support, including both plant and animal species that can invade a pond and alter its utility for various uses. Cape Cod ponds are not particularly susceptible to zebra mussels or Asian clams, but a number of invasive aquatic plants can thrive in the low alkalinity, acidic aquatic habitats of the Cape. Variable leaf water milfoil (*Myriophyllum heterophyllum*) and fanwort (*Cabomba caroliniana*) are two species of concern that have invaded Cape ponds already.

Pond by Pond Assessment

Lawrence Pond

Pond Features

Lawrence Pond is one element of the "Three Pond District" that also includes Spectacle and Triangle Ponds. Lawrence Pond has an area of 138 acres, about 2.3 miles of shoreline, a median depth of 15 ft and a maximum depth of 27 ft (Table 1). Bathymetry (Figure 4) is slightly irregular but not unusual for kettlehole ponds. Lawrence Pond has a largely sandy to rocky shoreline and sand and gravel in the shallow areas. There are no surface inlets or outlets at this pond. Access for the public is informal, off Great Hill Road on the southeast side of the pond, with no developed boat ramp or facilities. Lawrence Pond has a typical warm water fishery for Cape Cod, with largemouth and smallmouth bass, chain pickerel, yellow perch, pumpkinseed sunfish, brown bullheads and killifish.

Watershed Features

The exact area of the watershed has not been delineated, and would depend largely on ground water flow paths. Surface water runoff to Lawrence Pond appears minor; runoff from Great Hill Road and many adjacent lots along the eastern shore (Figure 5) has been captured and routed to leaching catch basins as part of the towns storm water mitigation plan. There are many leaching catch basins on the east side of the pond (Figure 3), but it is generally believed that ground water influence from this side of the pond is low. There is a YMCA camp adjacent to Lawrence Pond on the west side and a campground

Figure 4. Bathymetry of Lawrence Pond from pre-1990 MA DFW records.

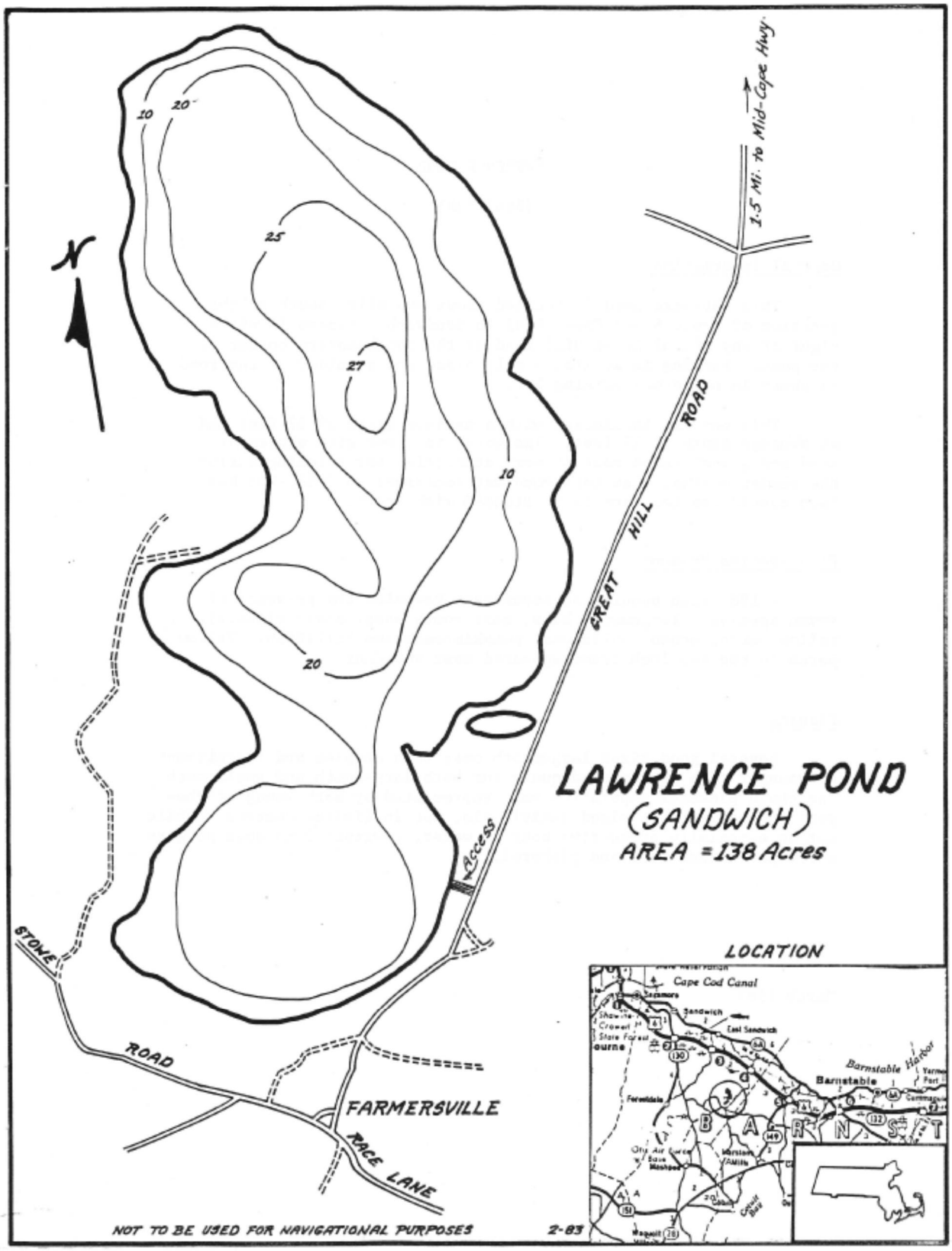


Figure 5. Pond and parcel layout for Lawrence, Spectacle, Triangle and the Hog Ponds.

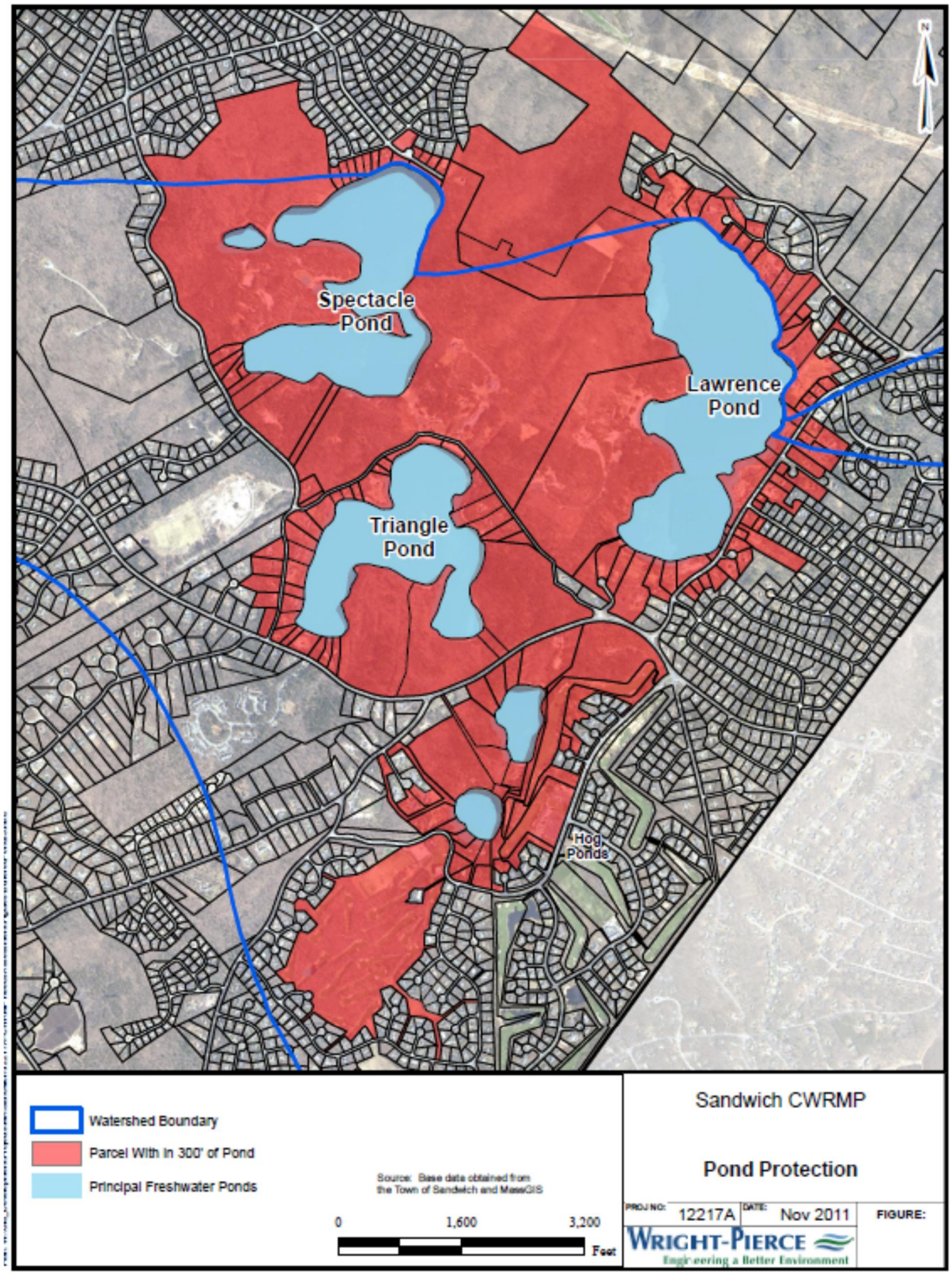
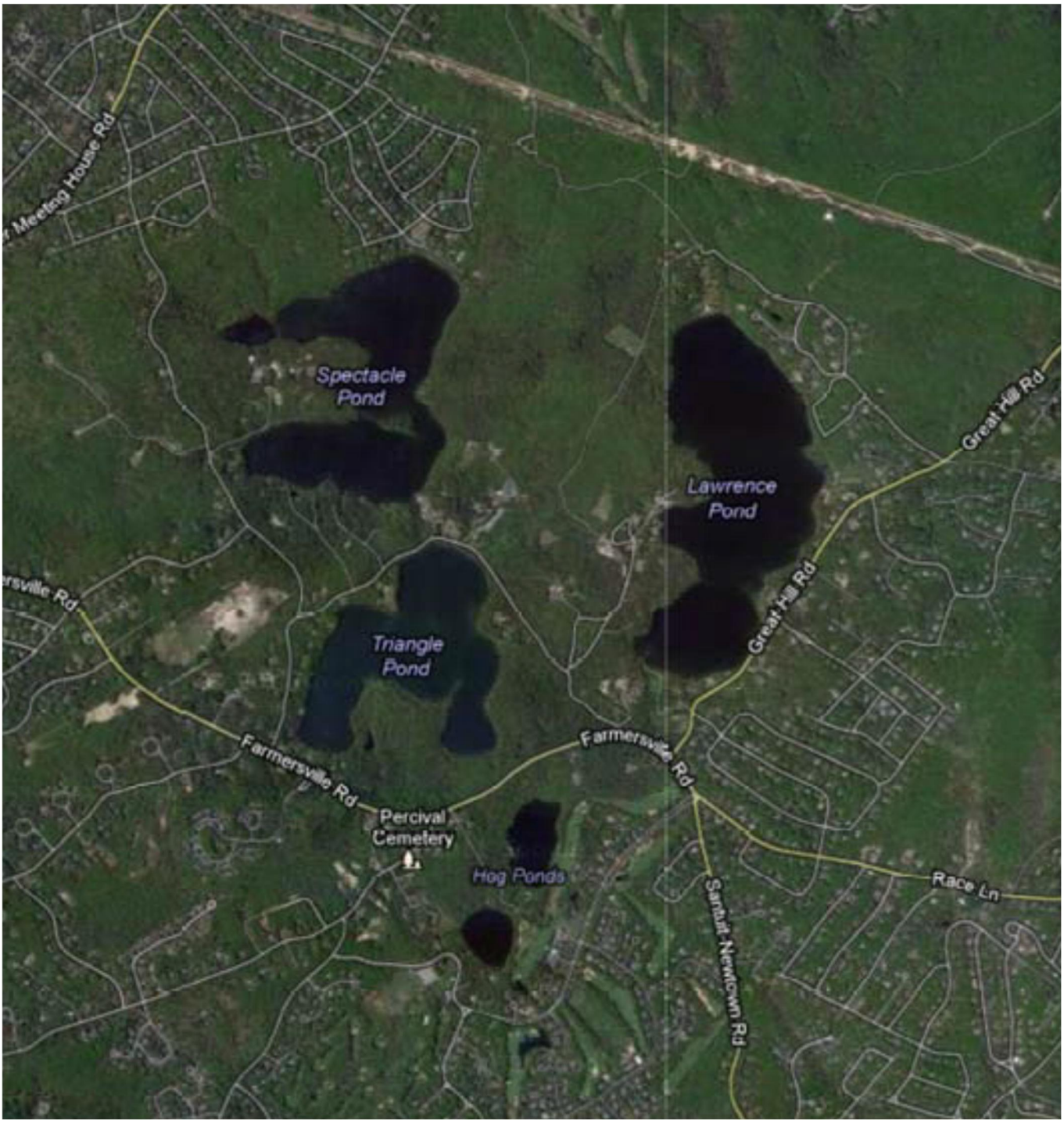


Figure 6. Aerial view of immediate area of Lawrence, Spectacle, Triangle and the Hog Ponds.



on the southeast side. There are two community associations, each with lake access points. There is a lot of undeveloped land in large parcels along the western shore (Figures 5 and 6), much of under conservation easement and extending all the way to Spectacle Pond. While there are many itemized parcels within 300 ft of the shore (Figure 4), there are only 6 parcels in the immediate upgradient direction of ground water flow and only 2 of these are developed. Impact from other parcels is certainly possible, including from developed land farther from the lake to the west, and there is concern by town officials regarding intense development to the northwest.

Pond Condition

Water quality data and some biological observations are available through the PALS program, supported by the School for Marine Science and Technology at UMASS Dartmouth (Table 2). Water clarity ranged from 4 to 7.7 m in three samplings in 2008-2010, with depleted oxygen only right at the sediment water interface. The pond is too shallow to stratify strongly, so oxygen problems should not be severe. The pH is acidic, alkalinity is very low, as are phytopigments and nutrients. Phosphorus is <10 ug/L in all samples, while nitrogen is close to or less than 300 ug/L. Water color varies but appears to be a function of natural color more than algae, rooted plants are reported as sparse, but no detailed survey has been conducted. In 2010, peripheral algal mats were noted, but no surface blooms have been reported. Lawrence Pond supports a warmwater fishery, with at least largemouth bass, chain pickerel and yellow perch stocked historically by the former MA Division of Fisheries and Game. However, no recent survey data for fish are available.

Designated Use Support

Lawrence Pond is used mainly for swimming, boating and fishing, and supports those uses.

Risk from Future Development

Most land around the pond is privately held, and additional development would represent a substantial threat to pond condition. The undeveloped lands to the west represent a very valuable buffer, and should be protected. There is concern over inputs via ground water from the intensely developed area beyond Spectacle Pond to the northwest. The Three Ponds (or South Sandwich Ponds) District of Critical Planning Concern was established to further that protection, with a focus on rare plant species, but some emphasis on water quality as well.

Assessment Needs

Knowledge of specific ground water flow paths and the quality of that water would be valuable to have. Detailed monitoring of inputs to Lawrence Pond has not been conducted. A full plant survey would be useful, as would analysis of the available fraction of sediment phosphorus in the surficial pond sediments. If Lawrence Pond experiences algae problems, it will almost undoubtedly be related to internal recycling of long-term inputs.

Management Needs

There are no obvious remediation needs at this time. Lawrence Pond is in relatively good condition, and most actions would be preventive. Land protection and assessment of inputs are the primary needs.

Table 2. Lawrence Pond water quality and related observations from the PALS program, 2008-2010.

Date	Depth (M)	Number of Samples	Total Depth (M)	Secchi Depth (M)	% Secchi	Temp (C)	DO (mg/L)	pH (SU)	Alk (mg $CaCO_3$/L)	Chla (ug/L)	Phaeo (ug/L)	TP (ug/L)	TN (ug/L)	Water Color	Plants	Notes
8/20/2008	0.5	2	8.2	4.5	54.4%	24.6	5.91	6.02	1.80	2.05	0.46	8.8	239.1	brown/green	<1%	
8/20/2008	1					24.7	6.18							brown/green		
8/20/2008	2					24.8	6.22							brown/green		
8/20/2008	3					24.8	6.07							brown/green		
8/20/2008	4					24.9	6.11							brown/green		
8/20/2008	5					24.9	6.13							brown/green		
8/20/2008	6					24.8	6.08							brown/green		
8/20/2008	7					24.8	5.95	6.17	1.90	2.68	0.48	8.1	242.4	brown/green		
8/20/2008	8					24.8	6.08							brown/green		
9/8/2009	0.5		8.1	7.7	95.1%	22.8	8.7	5.32	2.10	1.07	1.11	4.5	233.1	blue	Emergent grasses/sedges: 1%, other: 1%, no waterlilies or floating algal mats	
9/8/2009	1					22.9	8.5							blue		
9/8/2009	2					22.9	8.5							blue		
9/8/2009	3					22.9	8.4							blue		
9/8/2009	4					22.9	8.4							blue		
9/8/2009	5					22.9	8.3							blue		
9/8/2009	6					22.9	8.3							blue		
9/8/2009	7					22.8	8.3	5.36	2.10	1.04	0.95	6.2	252.3	blue		
9/8/2009	8					22.8	8.2							blue		
8/26/2010	0.5	2	8.7	4	46.0%	22.9	6.50	6.93	27.5	2.91	1.38	7.6	314.3	brown	<1%	Higher than normal accumulation of green algae around the shore. Also highest water level in at least 15 years
8/26/2010	1					24.4	6.20							brown		
8/26/2010	2					24.5	5.90							brown		
8/26/2010	3					24.5	5.90							brown		
8/26/2010	4					24.5	5.80							brown		
8/26/2010	5					24.5	5.70							brown		
8/26/2010	6					24.4	5.50							brown		
8/26/2010	7					24.4	5.50							brown		
8/26/2010	8					19.9	1.90	6.40	4.6	1.91	0.84	8.4	306.9	brown		
8/26/2010	9					18.0	0.20							brown		

Spectacle Pond

Pond Features

Spectacle Pond covers 91 acres in south Sandwich, part of the Three Pond District with Lawrence and Triangle Ponds. It has 2.6 miles of shoreline with an average depth of 26 ft and a maximum depth of 43 ft (Table 1). It is a "double kettlehole", with two basins separated by a shallower sandy zone and an island (Figure 7). There are no surface inlets or outlets at this pond. Access is available at the southwest corner of the lake, including a boat ramp, but public recreational facilities are very limited. Nearshore areas are mostly sand and gravel. Plant cover is very limited in sandy, shallow areas.

Watershed Features

The watershed has not been delineated, but surface runoff is possible only from the immediate shoreline, most of which is undeveloped. The area to the north, which is densely residential (Figures 5 and 6), presents a runoff threat; this Lakewood Hills area has numerous leaching catch basins, installed around 2000 to minimize direct storm water outlet to the lake. There is also a direct entry storm drain at the southeast corner of the pond, draining part of the YMCA camp, and further evaluation of this drainage system is warranted. Ground water flow paths will be more important to pond inputs, and the dominant pathway for ground water flow is from the densely developed land to the northwest. Spectacle Pond has a YMCA Camp (Camp Haywood) adjacent to it, and considerable undeveloped forest to the east and west.

Pond Condition

Water quality data and some biological observations are available through the PALS program, supported by the School for Marine Science and Technology at UMASS Dartmouth (Table 3). Water clarity ranged from 3 to 5 m in three samplings in 2008-2010. There is thermal stratification at about 30 ft (9 m), with oxygen depression observed below that depth. Oxygen depletion occurs only in the last few feet above the bottom in the deepest area, however. The pH is acidic and alkalinity is very low, as are phytopigments, although algal blooms have been reported for this lake in recent years. Phosphorus levels ranged from 5.4 to 16.1 ug/L, while nitrogen ranged from 211 to 561 ug/L, both in the low to moderate range. Water color varies but may be affected by algae at times. Rooted plants are reported as sparse, but no detailed survey has been conducted. The pond has been stocked with trout and smallmouth bass in the past, but fishery management effort appears very limited and no recent surveys have been conducted.

Designated Use Support

Spectacle Pond is used mainly for swimming, boating and fishing, and appears to support those uses, although there is a perception of increasing algal abundance that is consistent with the nutrient data.

Risk from Future Development

There is considerable land near the pond that, if developed, would constitute a substantial threat to its quality. The Three Ponds (or South Sandwich Ponds) District of Critical Planning Concern was established to further that protection, with a focus on rare plant species, but some emphasis on water quality as well.

Figure 7. Bathymetry of Spectacle Pond from pre-1990 MA DFW records.

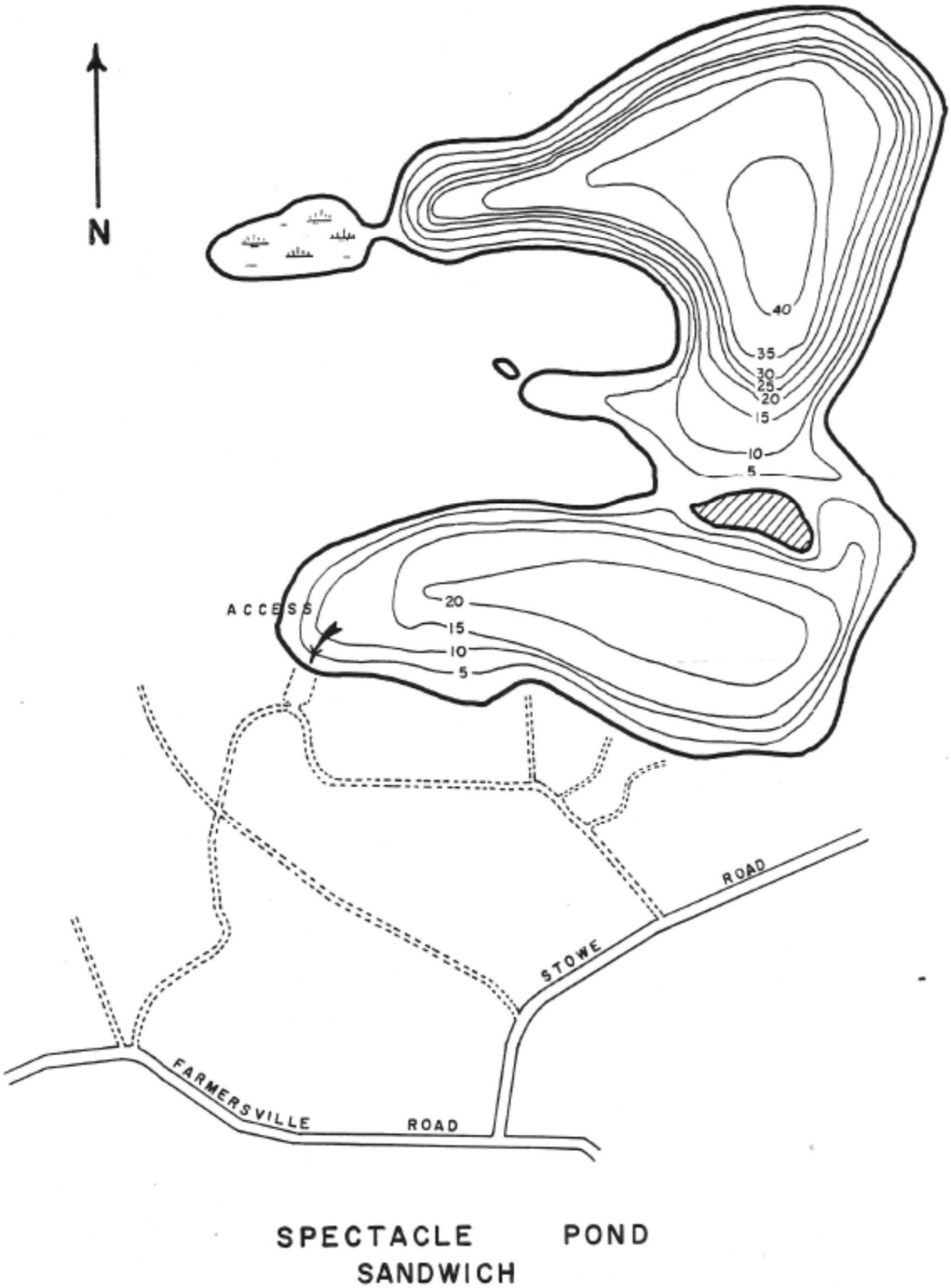


Table 3. Spectacle Pond water quality and related observations from the PALS program, 2008-2010.

Pond	Date	Depth (M)	Number of Samples	Total Depth (M)	Secchi Depth (M)	% Secchi	Temp (C)	DO (mg/L)	pH (SU)	Alk (mg $CaCO_3$/L)	Chla (ug/L)	Phaeo (ug/L)	TP (ug/L)	TN (ug/L)	Water Color	Plants	Notes
Spectacle	8/26/2008	0.5	4	12.2	4.1	33.7%		6.78	6.32	3.40	2.07	0.55	5.7	247.4	blue	10% submerged algae	
Spectacle	8/26/2008	1					24.9	6.80							blue		
Spectacle	8/26/2008	2					24.9	6.75							blue		
Spectacle	8/26/2008	3					24.8	6.73	6.62	3.50	1.71	0.27	6.0	218.4	blue		
Spectacle	8/26/2008	4					24.8	6.71							blue		
Spectacle	8/26/2008	5					24.8	6.71							blue		
Spectacle	8/26/2008	6					24.8	6.67							blue		
Spectacle	8/26/2008	7					24.6	6.56							blue		
Spectacle	8/26/2008	8					22.7	7.13							blue		
Spectacle	8/26/2008	9					18.5	9.08			2.03	0.91	5.4	217.2	blue		
Spectacle	8/26/2008	10					16.5	8.26							blue		
Spectacle	8/26/2008	11					14.7	3.65	6.37	3.40	2.34	1.28	6.9	211.0	blue		
Spectacle	8/26/2008	12					13.8	0.17							blue		
Spectacle	9/8/2009	0.5		11.3	5	44.2%	23.3	6.7	5.69	3.40	1.81	0.95	16.1	272.0	ND	Waterlilies: <1%, floating algae: <1%, emergent grasses/sedges: up to 10%	
Spectacle	9/8/2009	1					23.2	6.1							ND		
Spectacle	9/8/2009	2					ND	ND							ND		
Spectacle	9/8/2009	3					23.1	6.7	5.54	3.20	2.16	0.72	7.9	281.8	ND		
Spectacle	9/8/2009	4					23.1	6.5							ND		
Spectacle	9/8/2009	5					23.0	6.3							ND		
Spectacle	9/8/2009	6					23.1	6.2							ND		
Spectacle	9/8/2009	7					22.9	6.0							ND		
Spectacle	9/8/2009	8					22.9	5.8							ND		
Spectacle	9/8/2009	9					21.5	4.1	5.32	4.30	4.29	2.89	9.1	372.9	ND		
Spectacle	9/8/2009	10					18.6	3.2							ND		
Spectacle	9/8/2009	11					17.2	1.0	5.77	4.50	3.17	2.73	8.9	375.0	ND		
Spectacle	9/8/2009	12					16.8	<0.1							ND		
Spectacle	8/31/2010	0.5	3	7.2	3	41.7%	24.0	7.43	6.45	4.1	0.89	<0.05	14.1	561.0	blue/green	<1%	Samplers could not find deepest area
Spectacle	8/31/2010	1					23.9	7.33							blue/green		
Spectacle	8/31/2010	2					23.6	7.18							blue/green		
Spectacle	8/31/2010	3					23.3	7.26	6.48	4.2	2.39	1.44	9.7	320.0	blue/green		
Spectacle	8/31/2010	4					23.0	6.92							blue/green		
Spectacle	8/31/2010	5					22.8	6.88							blue/green		
Spectacle	8/31/2010	6					22.3	6.29							blue/green		
Spectacle	8/31/2010	7					21.4	2.96	6.72	4.0	0.85	0.84	10.5	380.4	blue/green		

Assessment Needs

Knowledge of specific ground water flow paths and the quality of that water would be valuable to have. There is some monitoring of Town wells to the west, but detailed monitoring of inputs to Lawrence Pond has not been conducted. Monitoring of ground water inputs near the north end of the lake would be advisable now. The direct entry storm water drainage system at the southeast end of the pond should be further evaluated and possibly mitigated. A full plant survey would be useful, as would analysis of the available fraction of sediment phosphorus in the surficial pond sediments.

Management Needs

It is difficult to define management needs with a lack of basic background information, but the densely developed area to the north and northwest of the pond represents a big enough threat to pond quality to suggest as the key target of management at this time. The first step in sound management would be an evaluation of inputs from this area, focusing mainly on ground water contamination. Education of residents about their role in maintaining water quality would be desirable.

Triangle Pond

Pond Features

Triangle Pond covers 84 acres in south Sandwich and is part of the Three Pond District with Lawrence and Spectacle Ponds. It has 2 miles of shoreline with an average depth of 15 ft and a maximum depth of 30 ft (Table 1). No bathymetric map is available for this pond, and there is controversy over the maximum depth; some parties claim a depth in excess of 60 ft, but data from past sampling effort suggests that the depth is no more than 32 ft. There are no surface inlets or outlets at this pond. Access is available from a little known state boat launching area on the west side of the pond. Nearshore areas are mostly sand and gravel. Plant cover is very limited in sandy, shallow areas.

Watershed Features

The watershed of Triangle Pond has not been carefully delineated, but only land in close proximity presents any threat of overland flow, and development is light around this pond (Figures 5 and 6). Most of the nearby land is wooded. A YMCA camp is adjacent to Triangle Pond at the north end. Ground water flow from the MMR and the residential area to the north and west represent threats, but these have not been studied in any appreciable detail for this pond.

Pond Condition

Water quality data and some biological observations are available through the PALS program, supported by the School for Marine Science and Technology at UMASS Dartmouth (Table 4). Water clarity ranged from 3.4 to 3.9 m in three samplings in 2008-2010. The pond appears to be just deep enough to undergo thermal stratification, with just a small deep water layer below 27 ft (8 m); oxygen depression is observed below that depth, with oxygen depletion only right at the sediment-water interface in the deepest area. The pH is acidic and alkalinity is very low, as are phytopigments, although algal blooms have been reported for this lake with increasing frequency over the last 6 years. Phosphorus levels ranged from 5 to 142 ug/L in surface water, a striking range, and reached 467 ug/L at the sediment-

Table 4. Triangle Pond water quality and related observations from the PALS program, 2008-2010.

Pond	Date	Depth (M)	Number of Samples	Total Depth (M)	Secchi Depth (M)	% Secchi	Temp (C)	DO (mg/L)	pH (SU)	Alk (mg $CaCO_3$/L)	Chla (ug/L)	Phaeo (ug/L)	TP (ug/L)	TN (ug/L)	Water Color	Plants	Notes
Triangle	8/26/2008	0.5	3	9.2	3.9	42.1%	25.2	6.73	6.45	3.20	1.32	0.43	141.7	199.4	blue green	10% bottom algae	pond receding
Triangle	8/26/2008	1					25.0	6.67							blue green		
Triangle	8/26/2008	2					24.8	6.66							blue green		
Triangle	8/26/2008	3					24.8	6.67	6.45	3.10	1.29	0.32	31.4	179.9	blue green		
Triangle	8/26/2008	4					24.7	6.60							blue green		
Triangle	8/26/2008	5					24.6	6.50							blue green		
Triangle	8/26/2008	6					24.5	6.47							blue green		
Triangle	8/26/2008	7					24.4	6.42							blue green		
Triangle	8/26/2008	8					21.7	2.39							blue green		
Triangle	8/26/2008	9					19.1	0.07	6.11	9.40	1.17	15.06	42.4	302.5	blue green		
Triangle	8/26/2008	10					18.3	0.04							blue green		
Triangle	9/8/2009	0.5		8.8	3.6	40.9%	22.8	8.3	5.88	3.30	2.25	0.92	4.5	262.1	ND	Waterlilies:<1% to none, floating algae: <1% to none, emergent grasses/sedges: <2%	
Triangle	9/8/2009	1					22.9	8.7							ND		
Triangle	9/8/2009	2					22.8	8.6							ND		
Triangle	9/8/2009	3					22.8	8.5	5.60	3.20	1.56	1.01	11.9	256.6	ND		
Triangle	9/8/2009	4					22.8	8.5							ND		
Triangle	9/8/2009	5					22.8	8.4							ND		
Triangle	9/8/2009	6					22.8	8.3							ND		
Triangle	9/8/2009	7					22.8	8.2							ND		
Triangle	9/8/2009	8					22.5	7.2	5.77	4.50	15.99	107.32	467.9	3962.0	ND		
Triangle	9/1/2010	0.5	3	9.7	3.4	35.1%	24.5	7.66	6.69	4.1	0.17	0.56	10.5	365.2	blue/green	<1%	Water level highest in many years- least amount of algae in years! Very nice swimming
Triangle	9/1/2010	1					24.3	7.51							blue/green		
Triangle	9/1/2010	2					24.0	7.46							blue/green		
Triangle	9/1/2010	3					23.6	7.44	6.60	3.6	0.56	0.11	9.9	284.3	blue/green		
Triangle	9/1/2010	4					23.2	7.42							blue/green		
Triangle	9/1/2010	5					22.8	7.47							blue/green		
Triangle	9/1/2010	6					22.4	7.32							blue/green		
Triangle	9/1/2010	7					21.8	6.86							blue/green		
Triangle	9/1/2010	8					20.2	5.35							blue/green		
Triangle	9/1/2010	9					16.0	0.42	6.28	7.0	3.35	2.47	18.9	307.3	blue/green		

water interface in one sampling (2009). Nitrogen ranged from <200 to almost 4000 ug/L. The wide variation in nutrients, coupled with what we know of the immediate watershed and pond depth, suggests internal recycling as a dominant process. Water color varies but may be affected by algae at times. Rooted plants are reported as sparse, but no detailed survey has been conducted. A warmwater fishery is present, with smallmouth bass added historically, but no indication of any trout fishery.

Designated Use Support

Triangle Pond is used mainly for swimming, boating and fishing. It appears to support those uses, and has not been placed on the state list of waters not attaining use designations, but concern over the last few years for increasing algae suggests that there is a threat to uses. Nutrient levels are high enough to be a concern in that regard.

Risk from Future Development

Much of the immediate watershed is not densely developed, and further development would constitute a threat to pond condition. The Three Ponds (or South Sandwich Ponds) District of Critical Planning Concern was established to further that protection, with a focus on rare plant species, but some emphasis on water quality as well.

Assessment Needs

Triangle Pond represents one of the more troubling combinations of limited data and perceived problems of any assessed pond in Sandwich. We have no bathymetric map or fishery data, no plant survey has been conducted, no algae samples have been analyzed, the watershed has not been delineated, and sediments have not been surveyed, yet there are clear signals that this pond is suffering from seasonal and erratic elevated nutrient levels and possible algal blooms. Given its inclusion in the Three Ponds District of Critical Planning Concern, further studies on every aspect of this pond are warranted. Assessment of ground water inputs and in-lake physical, chemical and biological features are needed to characterize current conditions and evaluate threats.

Management Needs

Assuming that anecdotal evidence of algal blooms and declining quality is valid, and considering the available nutrient data, there is a need for nutrient management in Triangle Pond. It is too early to provide a definitive program, but either a mixing system that would prevent anoxia and phosphorus release or a phosphorus inactivation program to permanently bind phosphorus in deep sediments might be considered. There does not appear to be any localized watershed management need, but an evaluation of incoming ground water quality may reveal a need for remediation of associated inputs. It is most likely that current problems stem from internal loading from sediment phosphorus reserves accumulated over many years; inactivation of that phosphorus is a practical approach.

Upper Hog Pond

Pond Features

Upper Hog Pond covers about 11.3 acres in south Sandwich, with about 0.6 miles of shoreline, an average depth of about 14 ft and a maximum depth of about 20 ft (Table 1). Relatively little is known about this pond; the shoreline is privately held, so there is no public access. However, the area of the

pond qualifies it as a Great Pond under Commonwealth of Massachusetts statute, making the pond itself a public resource, and access could be made across private property within reason. No bathymetric map appears available, and there is no annual or other sampling to assess pond condition. There are no reports of algal blooms or other problems.

Watershed Features

Upper Hog Pond sits in a sandy bowl, a small but classic kettlehole formation. There are just a few residences around the pond, most seasonal, many derived from old hunting camps. An old, historic home was apparently relocated to the south end of this pond, and represents the largest and most well-kept property in the area. The immediate watershed is largely forested, but there are more densely residential areas to the west that may influence the pond via ground water flow (Figures 5 and 6). There are two golf courses to the east and south (Holly Ridge and Ridge Club), but it is generally believed that ground water in that area flows away from the Hog Ponds.

Pond Condition

Little is known of the condition of Upper Hog Pond. There are no reports of problems, the water appears clear, and it is known as a local bird sanctuary. The area adjacent to the pond is believed to support multiple protected plant species.

Designated Use Support

Upper Hog Pond is not used extensively, but would appear to support swimming, fishing, small boating, aesthetics, and other passive uses such as bird watching.

Risk from Future Development

The area around the pond could be developed, as it is not part of the District of Critical Planning Concern associated with the ponds just to the north. Transformation of the small seasonal homes into much larger dwellings with potentially greater lawn area and larger waste disposal needs does represent a threat to this small pond.

Assessment Needs

As almost nothing is known of the physical, chemical and biological features of Upper Hog Pond, a baseline survey would be in order. This is not likely to have a high priority, given the lack of known problems and private nature of the shoreline, but no management program can be contemplated without such baseline information.

Management Needs

No management needs are recognized at this time.

Lower Hog Pond

Pond Features

Lower Hog Pond covers about 7.8 acres in south Sandwich, with about 0.5 miles of shoreline, an average depth of about 12 ft and a maximum depth of about 26 ft (Table 1). As with nearby Upper Hog Pond, relatively little is known about this pond. The shoreline is privately held, so there is no public access, and Lower Hog Pond is not large enough to be a Great Pond under Massachusetts law. No bathymetric map

appears available, and there is no annual or other sampling to assess pond condition. There are no reports of algal blooms or other problems.

Watershed Features

Lower Hog Pond sits in a sandy bowl, a small but classic kettlehole formation. There are just a few residences around the pond, seemingly all seasonal, many derived from old hunting camps. The immediate watershed is largely forested, but there are more densely residential areas to the west that may influence the pond via ground water flow (Figures 5 and 6). There are two golf courses to the east and south (Holly Ridge and Ridge Club), but it is generally believed that ground water in that area flows away from the Hog Ponds, and a small buffer strip was maintained when the courses were built to minimize the chance of surface water impact.

Pond Condition

Little is known of the condition of Lower Hog Pond. There are no reports of problems, the water appears clear, and it is known as a local bird sanctuary. The area adjacent to the pond is believed to support multiple protected plant species.

Designated Use Support

Lower Hog Pond is not used extensively, but would appear to support swimming, fishing, small boating, aesthetics, and other passive uses such as bird watching for the seasonal dwelling around the pond.

Risk from Future Development

The area around the pond could be developed, as it is not part of the District of Critical Planning Concern associated with the ponds just to the north. Transformation of the small seasonal homes into much larger dwellings with potentially greater lawn area and larger waste disposal needs does represent a threat to this small pond.

Assessment Needs

As almost nothing is known of the physical, chemical and biological features of Lower Hog Pond, a baseline survey would be in order. This is not likely to have a high priority, given the lack of known problems and private nature of the shoreline, but no management program can be contemplated without such baseline information.

Management Needs

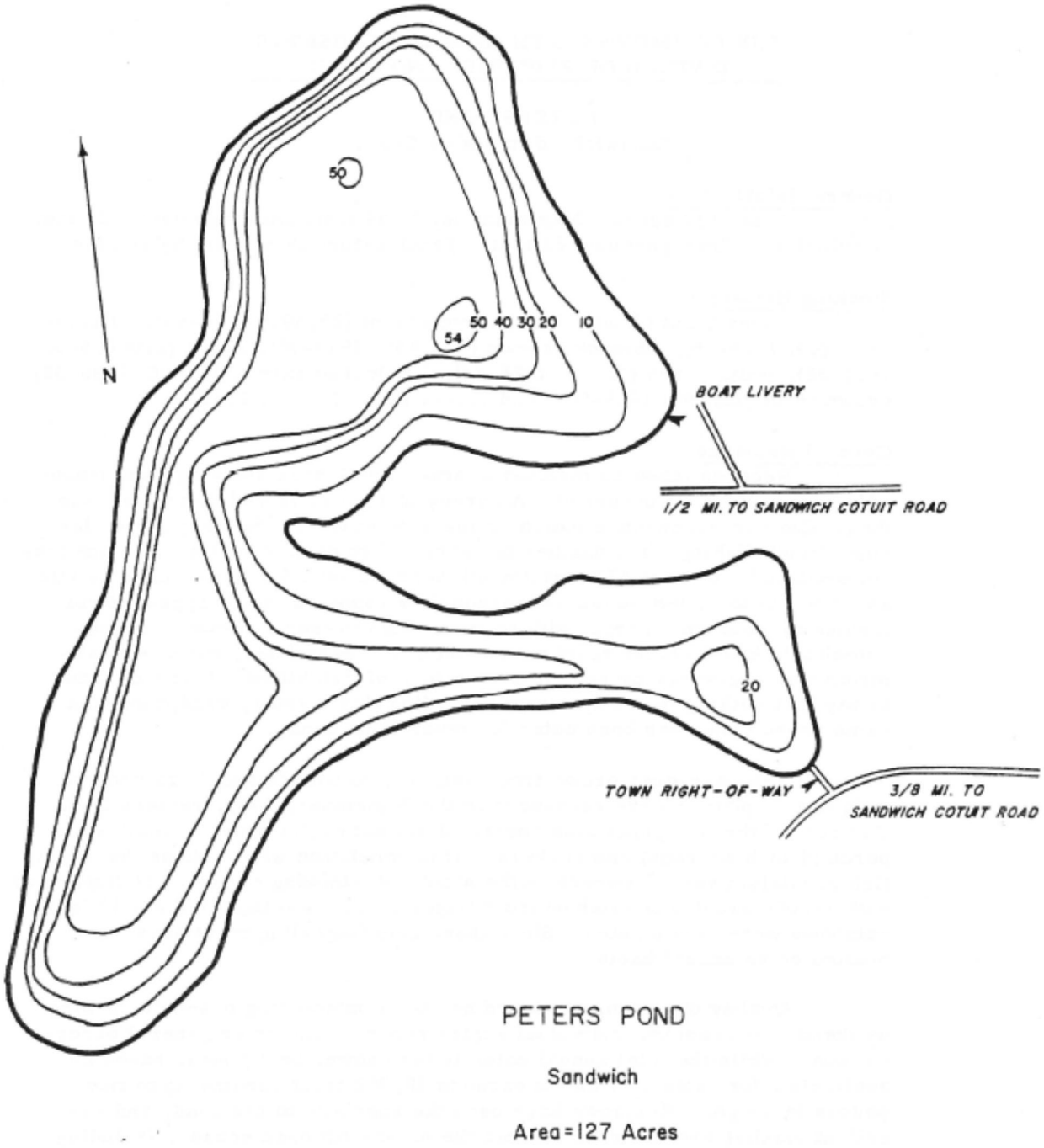
No management needs are recognized at this time.

Peters Pond

Pond Features

Peters Pond covers about 127 acres, although there is variability in areal estimates, with a range of 123 to 130.6 acres (some water level fluctuation occurs, so this is not unusual). Average depth is 22 ft while maximum depth is 54 ft (Table 1). The bathymetry is somewhat irregular, with an elongate cove to the east and the deepest part far to the north (Figure 8). The pond has no surface water inlets or outlet. There is a paved state boat launch and a town right of way for boat launching across a sandy beach, plus two campgrounds that afford access for a fee. There is a large community association beach as well.

Figure 8. Bathymetry of Peters Pond from pre-1990 MA DFW records.



Peters Pond is stocked with brown, brook and rainbow trout annually. Peters Pond is the most publicly used pond in Sandwich, with many large boats launched on it during summer.

Watershed Features

The complete watershed of Peters Pond has not been determined. The immediate watershed of Peters Pond includes several large parcels around the northern half of the pond, including campgrounds, town land, and a gravel pit (Figures 9 and 10). Many smaller parcels, containing mainly seasonal cottages, are present around the southern half of the lake. Residential density is moderate to high moving further from the pond, and there are catch basins in some of those areas (Figure 3), but surface runoff is unlikely to reach the lake from more than the immediate shoreline. Ground water flow is expected mainly from the west and north. The gravel pit reportedly experienced a blow out from a berm that dumped silty water into the lake a few years ago, but overall impact appears low.

Pond Condition

The former Division of Fisheries and Game, now the Division of Fisheries and Wildlife, was actively involved in the management of Peters Pond as early as 1911. A variety of salmonid species have been stocked over the last century, and the pond was reclaimed (all fish killed or salvaged, followed by restocking of salmonids) in 1955. Historically, Peters Pond was habitat for a wide variety of warm water fish species, but was considered to have very poor population structure prior to reclamation. While some warm water species undoubtedly remain, Peters Pond is largely a managed trout fishery. Plant growth appears very limited in the shallow areas of the pond, but no detailed survey is known.

Water quality in 1948 appeared excellent, with stratification at 30 ft but no oxygen depletion in the bottom waters (DO >4 mg/L). Yet in 2001 the oxygen profile exhibited no oxygen below 40 ft, an apparent deterioration of bottom water quality over a 50-year period, a common observation for deeper Cape Cod lakes. Water quality data have not been collected since 2002, however, so there is no documentation of conditions in recent years. Data from the PALS program in 2001 indicate slightly acidic pH, alkalinity of 12 to 15 mg/L, low surface nutrients (phosphorus = 8 ug/L, nitrogen = 290 ug/L) and moderate to slightly elevated bottom nutrients (phosphorus = 28 ug/L, nitrogen = 400 ug/L). Chlorophyll *a* was 5 ug/L at the surface and 20 ug/L in deep water. There have been reports of algal blooms in the eastern cove, with wind-driven blue-green scums in the northern cove as well. The 1960 DFW estimate was that 19% of the pond volume would support trout, but more recent estimates appear unavailable.

Peters Pond is on the Massachusetts 2010 Integrated Waters List as having a completed TMDL for metals. The TMDL relates to mercury and is not lake-specific; Peters Pond and Snake Pond in Sandwich are two of almost 100 Massachusetts ponds included in the Northeast Regional Mercury Total Maximum Daily Load developed by the New England states plus New York and finalized in 2007. This Total Maximum Daily Load (TMDL) document outlines a strategy for reducing mercury concentrations in fish in northeastern freshwater systems. This will require reductions from mercury sources within the Northeast region, U.S. states outside of the region, and global sources. In the Northeast, the majority of mercury pollution is a result of atmospheric deposition, so there is little that Sandwich can do on its own. This TMDL could very well apply to all Sandwich Ponds, but only Peters Pond and Snake Pond were included in the project.

Figure 9. Pond and parcel layout for Peters, Pimlico, Snake and Weeks Ponds.

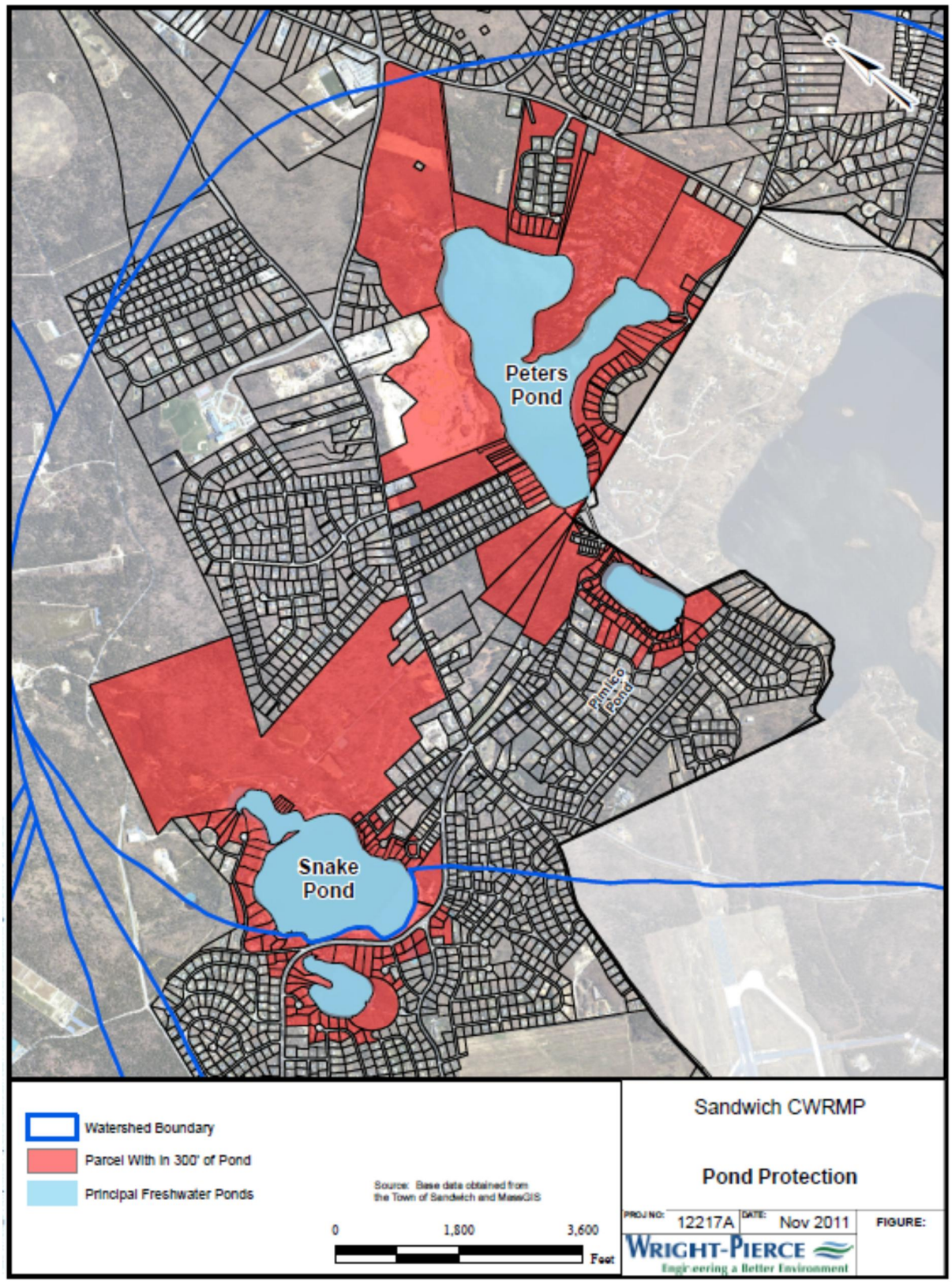
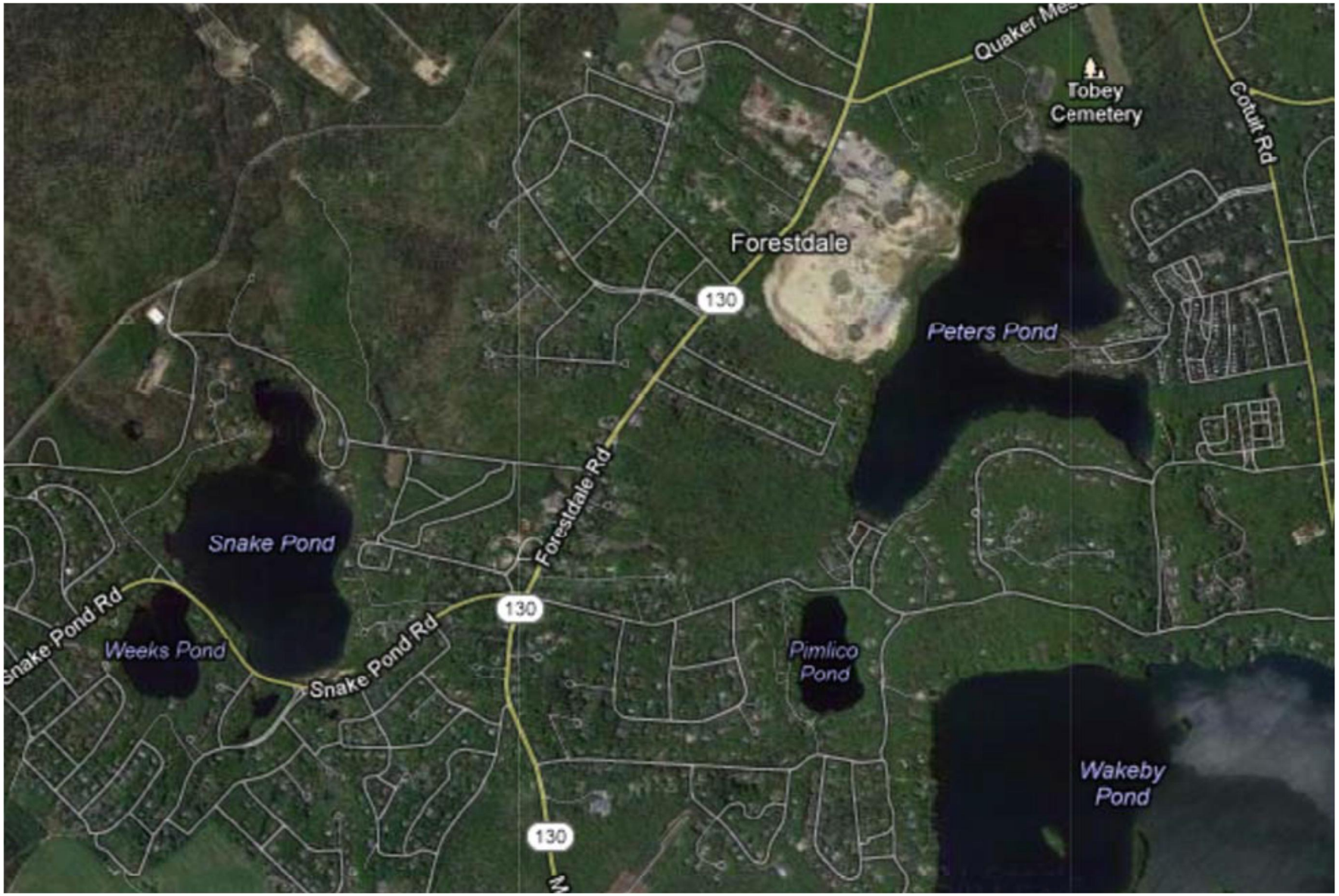


Figure 10. Aerial view of immediate area of Peters, Pimlico, Snake and Weeks Ponds.



Designated Use Support

Peters Pond is very popular for swimming, boating and fishing, and appears to support those uses. Anecdotal evidence suggests that those uses may be threatened, but there are no data to document conditions or evaluate trends. Inclusion in a TMDL for mercury for a pond with an active trout fishery is a concern, but no recent data were found to indicate any contamination of fish.

Risk from Future Development

Although there are some large parcels that are not developed as residential housing in the immediate area of the pond, most are tied up in easements or uses that may not be appreciably more beneficial to the pond. There are fewer developable parcels with the potential to impact Peters Pond than for many of the other ponds in Sandwich. There does appear to be a risk of continued deterioration from current development, but additional development is viewed as less of a risk.

Assessment Needs

The lack of a routine monitoring program for Peters Pond in recent years, such as that conducted for Lawrence, Spectacle and Triangle Ponds, is a major shortcoming for such a publicly used lake and local economic driver. At a minimum, annual assessment of water clarity, temperature and oxygen profiles, and pH, alkalinity, chlorophyll and nutrients at the top and bottom is needed. Surficial sediment in the deep zone should be tested for available phosphorus; if reports of algal blooms are correct, they are likely linked to internal recycling. Assessment of ground water inputs and any storm water discharges is also highly advisable.

Management Needs

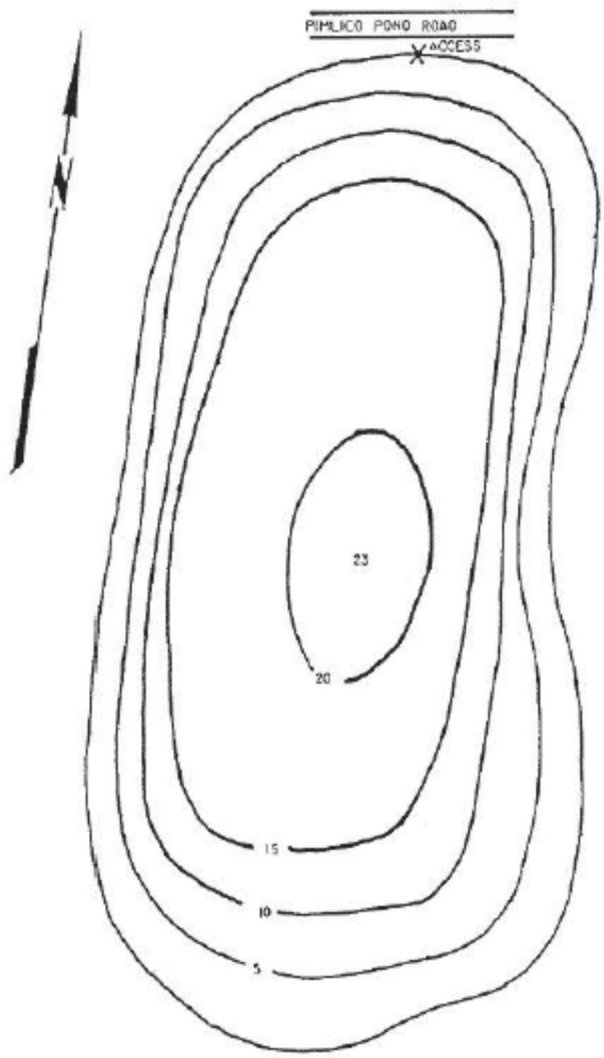
It would appear that there is a need to counter algal blooms, but without further information on what types of algae are involved and the timing and frequency of such blooms, it is difficult to recommend a specific approach. Aeration of bottom waters without breaking stratification would be a positive step, minimizing internal recycling while enhancing habitat for trout. If ground water inputs of nutrients are substantial, sewering in the path of ground water flow may be desirable. Storm water inputs from nearby land may be significant and could be better managed. Action to limit mercury inputs is called for by the regional TMDL, but this relates to widespread atmospheric contamination; there is little that Sandwich can do in this regard.

Pimlico Pond

Pond Features

Pimlico Pond covers 16.4 acres to an average depth of 12 ft, with a maximum depth of 23 ft (Table 1). It has about 0.6 miles of shoreline. Bathymetry (Figure 11) indicates a simple kettlehole “bowl”, although this pond is slightly shallower than most kettlehole ponds. The pond has no surface water inlets or outlet. Access to Pimlico Pond is from an undeveloped boat launch along Pimlico Pond Road. Pimlico Pond is stocked with trout each spring, but does not have enough cold water to support a resident population all year. Pimlico Pond is known to have dense subsurface rooted plant growths, but the pond periphery exhibits little obvious plant growth.

Figure 11. Bathymetry of Pimlico Pond from pre-1990 MA DFW records.



Watershed Features

The immediate drainage area of Pimlico Pond is a fairly steep hillside much of the way around the pond, with a number of small lots on the zoning map (Figure 9). However, many of these lots are not developed, and housing density around the pond is low (Figure 10). Most homes have substantial buffer zones and there has been relatively little clearing of trees. Ground water flow is mostly from the west, but there could be surface or subsurface drainage from the immediately adjacent land into the pond, given the slope. There is direct drainage off Pimlico Pond Road, with evidence of erosion and possible impacts.

Pond Condition

Pimlico Pond was sampled in 2001 and 2002 as part of the PALS program, and this is the only sampling known to have occurred at this pond. The pond is well mixed from top to bottom, and there is no oxygen depression. The pH was slightly acidic, alkalinity was low, and nutrient levels were also low.

While no algal blooms have been reported, growths of rooted plants are dense. While no detailed survey has been conducted, fragments of low watermilfoil (*Myriophyllum humile*), bladderwort (*Utricularia sp*.) and spikerush (*Eleocharis acicularis*) were observed on the shore at the public access point in fall of 2011.

Designated Use Support

Pimlico Pond supports swimming, fishing and boating. Dense plant growths may not be impeding these uses, but concern over potential impairment has been expressed and the need for more study to support management planning has been noted.

Risk from Future Development

It is not clear that the many small listed land parcels around the lake are actually buildable lots, but construction on many of these would constitute a threat to pond quality. The steep slopes would be prone to erosion and waste water may reach the pond on any side. However, there are relatively few additional parcels on which building could occur further from the lake to the west and north, from which most ground water is expected to come.

Assessment Needs

Resumption of annual monitoring through the PALS program is highly recommended. A thorough survey of the plant community is also advisable. Investigation of ground water movement and quality all the way around this pond is warranted.

Management Needs

Protection of the pond through control of any additional building near the pond is the most obvious management need. Some mitigation of storm water inputs from Pimlico Pond Road appears warranted. There may be a need to control rooted aquatic vegetation, but if that vegetation is not impairing uses, it might be better left in place to act as a nutrient sink and water quality enhancer.

Snake Pond

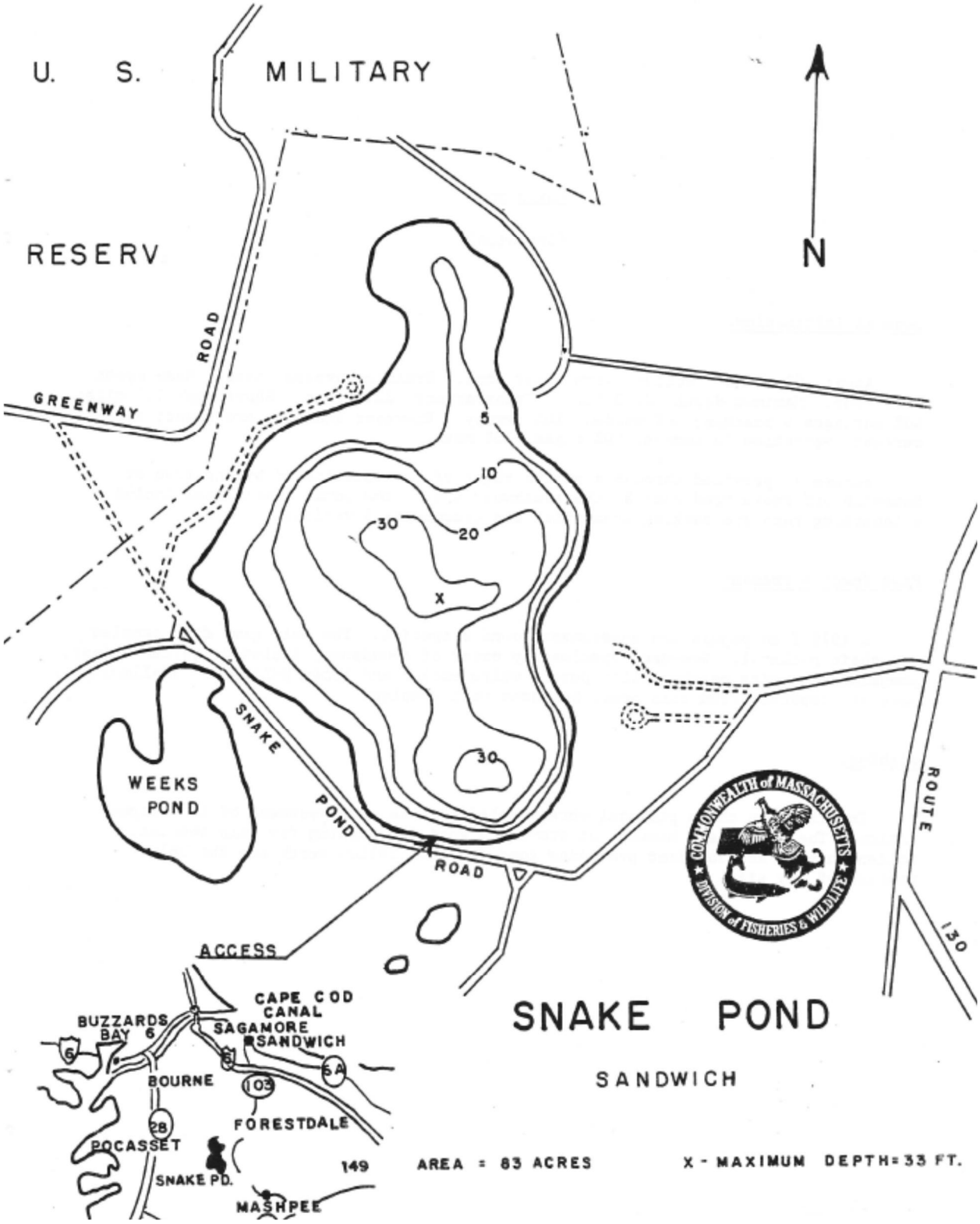
Pond Features

Snake Pond covers 83 acres, offers about 1.6 miles of shoreline, has an average depth of 18 ft and a maximum depth of 33 ft (Table 1), although some accounts suggest a maximum depth of no more than 27 ft. Bathymetry (Figure 12) is bowl-like to 20 ft, with two separate depressions of 30 ft. The pond has no surface water inlets or outlets. Access is off Snake Pond Road, with a small boat ramp and limited parking area. There is also a town beach on the south side. Snake Pond hosts a warm water fishery, with chain pickerel, smallmouth bass, golden shiner, white and yellow perch, pumpkinseed, white sucker and brown bullhead reportedly present.

Watershed Features

Camp Good News occupies a large parcel at the north end of the pond, and the MMR boundary is not far from the pond to the northwest. The remainder of the shoreline is broken into smaller lots (Figure 9). However, there is substantial wetland around this pond, and housing density is not as high as parcel listing might make it seem (Figure 10). There is a town beach and boat launch on the south side, but

Figure 12. Bathymetry of Snake Pond from pre-1990 MA DFW records.



most shoreline land is privately held. Storm water drainage systems are limited near this pond, and the town diverted storm water from Snake Pond Road east of the pond into vegetated areas to limit impact to the pond. Storm water from the west side of the pond remains a concern and addressing it is part of the town storm water mitigation plan. Weeks Pond is directly across the road to the southwest. Ground water flows mainly from the northwest, the direction of least development in this case, but the MMR lies in that direction and there are monitoring wells used to evaluate possible contaminant movement from that military site.

Pond Condition

A water clarity reading from at least two decades ago was 22 ft (6.7 m) and oxygen profiles in 1948, 1997, 2001 and 2002 indicate no anoxia near the bottom. Given its bathymetry, it is unlikely that Snake Pond would experience any widespread oxygen depletion. In 2001, the pH was slightly acidic, alkalinity was very low, chlorophyll was low (1-2 ug/L), phosphorus was low (12 ug/L) and nitrogen was low (40 to 160 ug/L). It has been speculated that Snake Pond is in a relatively unimpacted condition and has been stable for over 50 years, but data from the last decade are lacking.

The pond supports a warm water fishery and is considered to offer good ice fishing opportunity. The former Division of Fisheries and Game stocked the pond with various warmwater species decades ago, but no recent management appears to have occurred and this is not a trout pond. No algae blooms have been reported. Plant growth is minimal in shallow water in the associated sand and gravel, but is reportedly denser in deeper offshore areas; no survey has been conducted. Ground water inputs relating to the MMR are monitored in wells at Snake Pond, but no data appear to be available.

Snake Pond is on the Massachusetts 2010 Integrated Waters List as having a completed TMDL for metals. The TMDL relates to mercury and is not lake-specific; Peters Pond and Snake Pond in Sandwich are two of almost 100 Massachusetts ponds included in the Northeast Regional Mercury Total Maximum Daily Load developed by the New England states plus New York and finalized in 2007. This Total Maximum Daily Load (TMDL) document outlines a strategy for reducing mercury concentrations in fish in northeastern freshwater systems. This will require reductions from mercury sources within the Northeast region, U.S. states outside of the region, and global sources. In the Northeast, the majority of mercury pollution is a result of atmospheric deposition, so there is little that Sandwich can do on its own. This TMDL could very well apply to all Sandwich Ponds, but only Peters Pond and Snake Pond were included in the project.

Designated Use Support

Snake Pond supports swimming, fishing and boating. No impairment of these uses has been reported, but very little monitoring occurs at this pond. The existence of a TMDL for mercury is a concern, but no recent data were found to indicate any contamination of fish.

Risk from Future Development

Additional development near the pond could be detrimental, but it is not clear that such development could occur under current regulations. Current inputs from the MMR via ground water are an apparent concern, and any future development of MMR property represents a concern for this pond.

Assessment Needs

An assessment of pond conditions, including water quality, algae and plants, is needed. Annual water quality monitoring is advised, through the PALS program.

Management Needs

There may be a need to address ground water contamination, based on the presence of monitoring wells associated with the MMR remediation program, but no data are available to support such a supposition. Action to limit mercury inputs is called for by the regional TMDL, but this relates to widespread atmospheric contamination; there is little that Sandwich can do in this regard. Mitigation of storm water from west of the pond is part of the town storm water mitigation plan. No other problems are currently known for this pond that would require remedial action.

Weeks Pond

Pond Features

Weeks Pond covers 15 acres adjacent to Snake Pond, with just the road separating them. It is likely that they were connected at some point in history. There are 0.76 miles of shoreline. The average depth is listed as 4 ft, with a maximum depth of 15 ft (Table 1), but vegetation protrudes from the pond far from the edges; it is likely that this pond is shallower than listed, but there is no bathymetric map available. Access is along Snake Pond Road, but it is undeveloped and impeded by a guardrail. There is no surface water inlet or outlet. Emergent vegetation, some of it woody, sticks out of the nearshore waters and in some areas quite far from shore. The visible bottom is largely sandy. There is no known significant recreational use of Weeks Pond.

Watershed Features

There are numerous small land parcels around the lake, with 15 within 300 feet and upgradient in terms of expected ground water flow. Twelve of those lots are developed, and a few buildings are very close to the pond, but most of the shoreline is wooded. There are many storm water collection basins near the pond, but no known direct discharges to it; catch basins appear to be leaching basins. Storm drainage improvements along Snake Pond Road to protect Snake Pond are done in a way to also prevent impact to Weeks Pond. Beyond the 300 foot limit in all directions but to the northeast (where Snake Pond is situated) there are many small lots, most developed. There is a nearby town well. As with Snake Pond, there is concern that ground water from the MMR may impact the pond and/or town well.

Pond Condition

No monitoring data were found for Weeks Pond. It is shallow enough that oxygen depletion should not occur, but the nutrient status is unknown. No algal blooms have been reported, but depth and vegetation features of this pond may restrict uses. Aside from emergent brush, multiple species of pondweed (*Potamogeton* spp.) and spikerush (*Eleocharis acicularis*) were observed washed up on shore, and remnant stalks of what appeared to be bulrush (*Schoenoplectus validus*) were common in shallow water. Other emergent plants, such as pickerelweed (*Pontederia cordata*) are also likely to be dense during summer. Water level fluctuations are reportedly frequent and substantial at Weeks Pond.

Designated Use Support

Weeks Pond might support some fishing and non-motorized boating, and swimming may be possible from some shoreline locations. However, little recreational use is apparent and specific conditions that would support or impair such use have not been documented.

Risk from Future Development

Most of the land area within half a mile of Weeks Pond is already developed, at least to a moderate density. While any additional development within the ground water contribution zone may present additional threats, it does not appear that further development is as big a risk for Weeks Pond as it is for many of the other ponds assessed. Shallow depth may limit ground water impacts, as much of the flow may pass under the pond with no interaction.

Assessment Needs

There are few data of any kind for Weeks Pond. A simple but complete diagnostic assessment, with water depth, sediment features, water quality and biological components would be advisable. Ground water inputs and interaction with the nearby town well should also be assessed.

Management Needs

It is not clear that there are any management needs for Weeks Pond at this time. No specific problems are known, but there are some threats to potential uses that bear scrutiny in an assessment project.

Hoxie Pond

Pond Features

Hoxie Pond covers 8.5 acres slightly south of Rt 6A and just north of Old County Road, although some estimates suggest an area of as little as 7.7 acres. Average depth is believed to be about 12 feet (Table 1), while maximum depth is shown as 35 ft on the pond bathymetric map (Figure 13). Hoxie Pond has a typical kettlehole bowl shape and has 0.42 miles of shoreline. There are no natural inlets, but the pond is connected to a cranberry bog to the west, so there is inflow at times. Ground water inflow is expected to be mainly from the south. Hoxie Pond outlets through a wetland area into Scorton Creek, which discharges to the bay. There is no formal access, but Hoxie Pond can be accessed off the railroad bed off Old County Road to the south of the pond. The railroad bed appears to have cut off a small part of the pond many years ago. Fishing from carry in boats is popular, and the pond is stocked with trout annually. Warmwater species are also present, but no surveys have recently been conducted.

Watershed Features

The watershed of Hoxie Pond (Figures 14 and 15) includes relatively few parcels near the pond, with one very large one extending downstream to Scorton Creek and including the former state game farm with considerable wetland. Of the six parcels in the upgradient direction of expected ground water flow, five are developed, but not densely. Most prominent is the cranberry bog, which does withdraw water for irrigation and flooding from Hoxie Pond and returns most of that water to the pond. Further north there are more residential areas with small to moderate sized lots, while further west there are larger parcels that are largely undeveloped. A state fish hatchery produces trout downstream of the pond off Scorton Creek, reportedly the oldest hatchery in the USA.

Figure 13. Bathymetry of Hoxie Pond from pre-1990 MA DFW records.

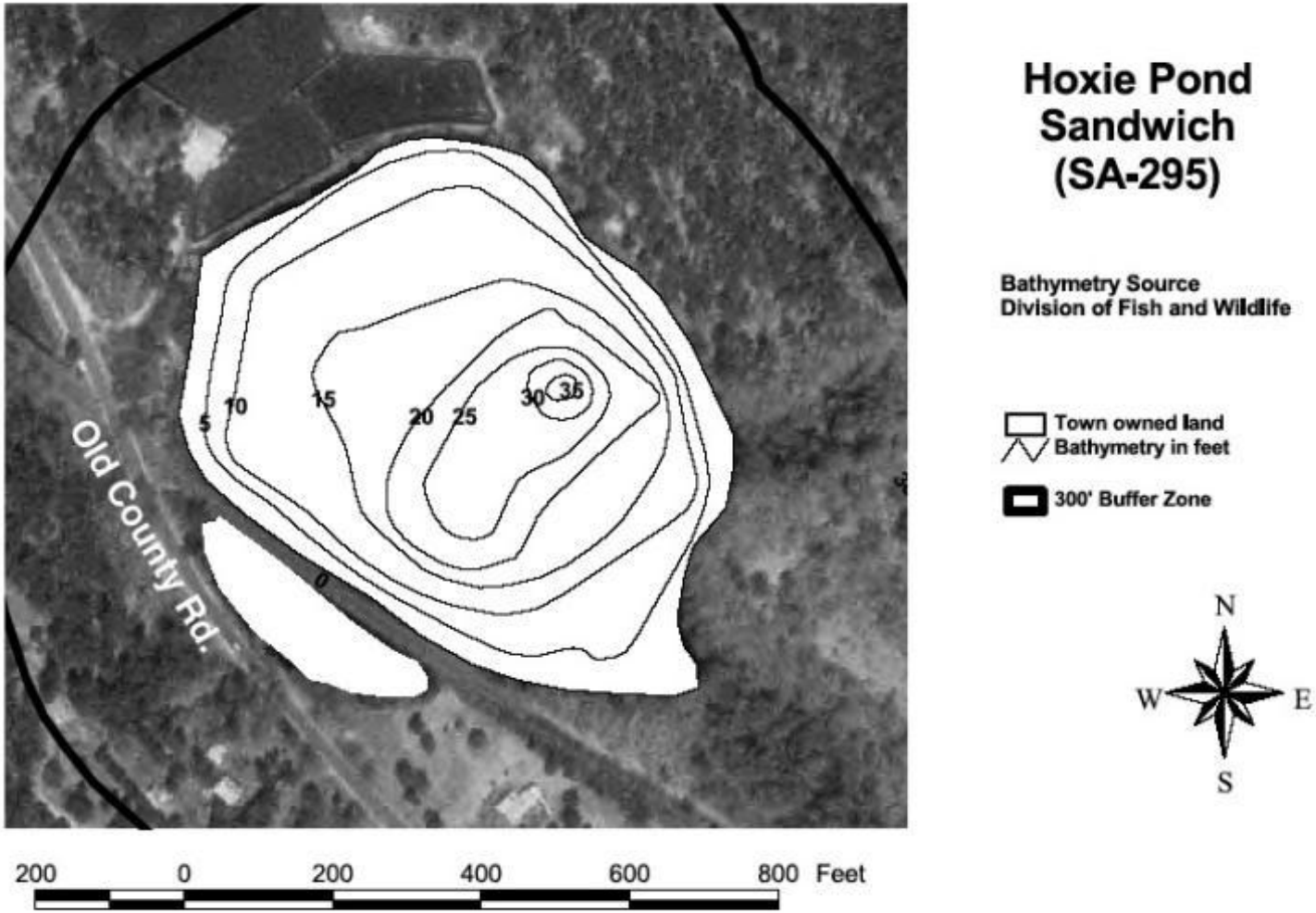


Figure 14. Pond and parcel layout for Hoxie Pond.

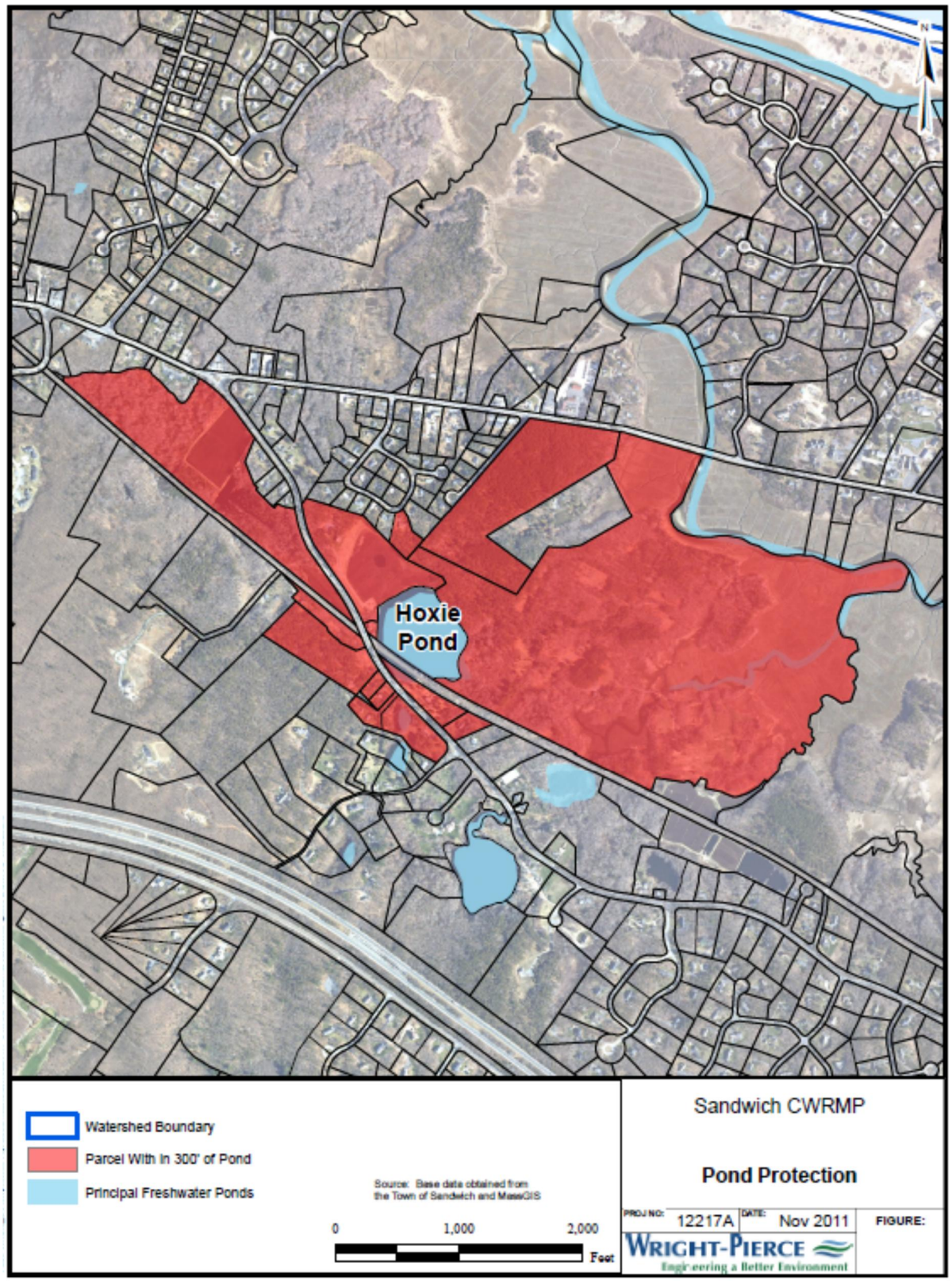
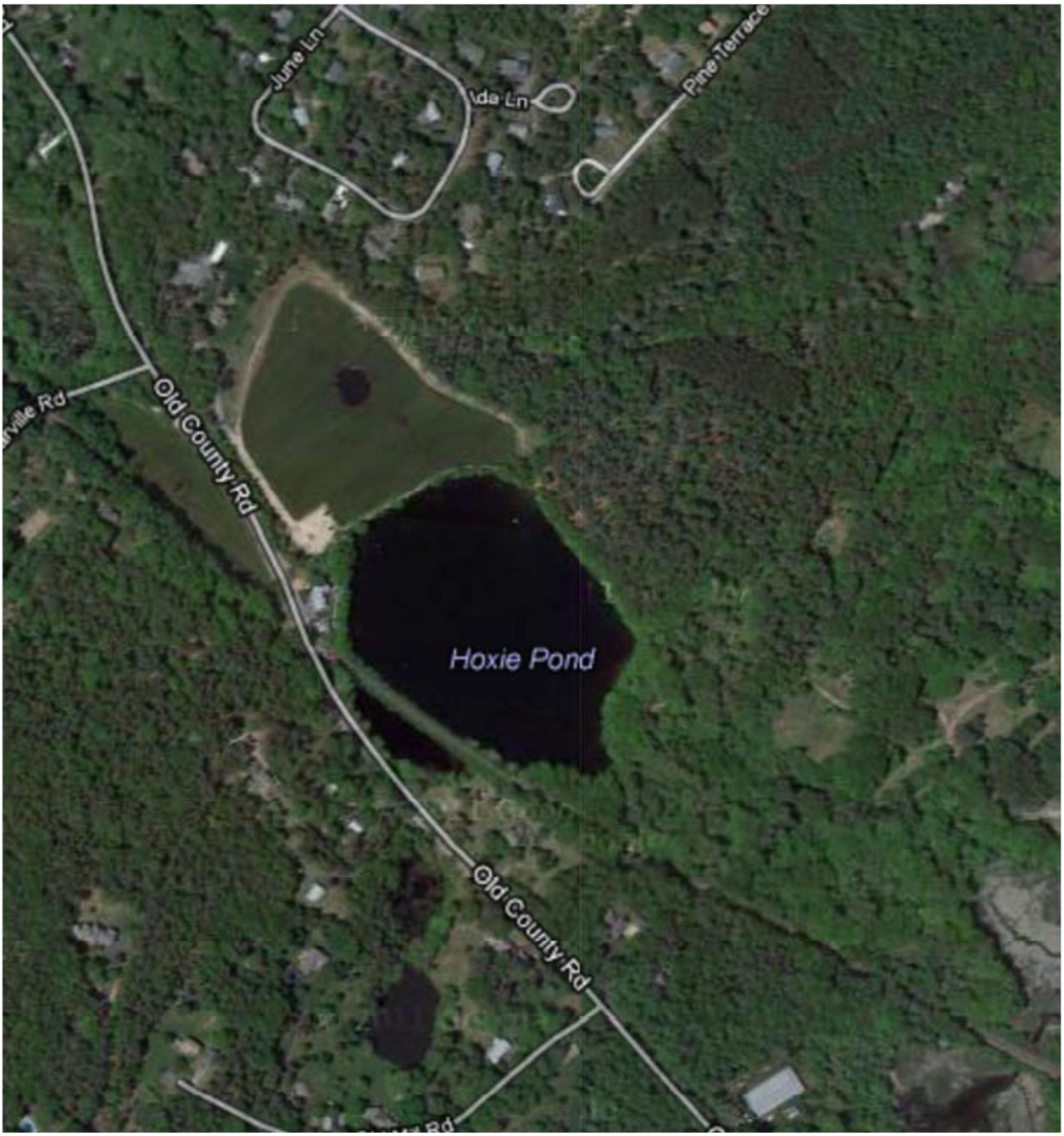


Figure 15. Aerial view of immediate area of Hoxie Pond.



Pond Condition

There are few known water quality data for Hoxie Pond. Water clarity ranged from 1.5 to 3.6 m, and oxygen was low below 18 ft of water depth, based on a MA DFW listing last updated in 2007. Some water lily growth is evident near shore, but vegetation is reportedly limited to shallow peripheral areas. No algal blooms have been reported, and Hoxie Pond is touted as a good swimming pond, but water clarity is marginal at times and the primary use appears to be fishing. This pond was reclaimed for trout management in August 1956, and was reclaimed again seven times prior to 1969. Brook, rainbow and brown trout are stocked each spring on a put and take basis; some tiger trout may also be stocked. During the most recent survey the pond contained yellow perch, largemouth bass, brown trout, sunfish and banded killifish. Chain pickerel have also been caught in the pond. Abundant American eels are expected, based on the connection to the bay, but there is no mention of any alewife use of the pond. The potentially large influence of the cranberry bog is a concern, and may explain the lower water clarity, but no major impacts have been described. Bottom sediments are sandy around the periphery, but are expected to be mainly muck in deeper water.

Designated Use Support

The primary use is fishing, with small boat use and swimming also supported, although the value of the pond as a water source to the cranberry bogs would also seem very important. The cranberry bog represents a threat to some designated uses, but Hoxie Pond is listed on the 2010 Integrated List as a category 3 waterbody, indicating that no uses have been assessed. Low deep water oxygen limits trout habitat, and it is suspected that trout congregate near springs in the southern portion of the pond during summer, but no mortality has been reported.

Risk from Future Development

Increased development on parcels around Hoxie Pond would constitute a threat to water quality, but parcels would have to be subdivided to facilitate additional development in most cases.

Assessment Needs

With relatively little data available and Hoxie Pond representing an apparently valued fishing resource, a survey of physical, chemical and biological characteristics would seem in order. The magnitude of inputs from the cranberry bog and internal recycling within the pond would be important parts of a meaningful assessment of Hoxie Pond.

Management Needs

Water clarity seems marginal at times for swimming, and oxygen in deep water is not suitable for trout, limiting holdover capacity, but there are no data to indicate serious problems and a need for specific management actions. Application of best management practices to the cranberry bog operation would certainly be appropriate. Mixing of the pond to eliminate low oxygen would be desirable, but may increase thermal stress on trout.

Upper Shawme Lake

Pond Features

Upper Shawme Lake is the upstream part of a two pond complex, and covers about 21 acres to an average depth of 7.5 ft with a maximum depth of 11.6 ft (Table 1, Figure 16). However, there are multiple estimates of area and depth from various sources; most area estimates are similar, but some depth estimates are much deeper. However, given the history of the pond as a dammed stream and the presence of considerable accumulated muck sediment (ENSR 2001), greater depth is unlikely. There are about 0.8 acres of shoreline, most of it wooded. There is no surface water inlet, but water outlets through a recently reconstructed dam with a fish ladder, with an average flow of about 7 cfs. Detention time in the lake is about 11 days on average. Access through large public parcels (Cook Trust, Heritage Museum and Gardens) is possible, but there is no formal boat launch or other access facility. Ground water enters mainly from the south, but with steep slopes, some undoubtedly enters from the east and west as well. There are distinct springs in Upper Shawme Lake, with classic "sand boils" where ground water inflow is major. A variety of warmwater fish are present and alewife have been stocked in an apparent effort to establish a sea-run population, as the Shawme Lakes are connected to the bay by Mill Creek. What was known of Upper Shawme Pond and its watershed was summarized by ENSR in a 2001 letter report, and that information is considerable, but there are few data since that time.

Watershed Features

Upper Shawme Lake has a delineated surface watershed of approximately 440 acres. Approximately 55% of the total watershed of Upper and Lower Shawme Lakes is forested, with about 24% in residential uses and another 8% in other developed uses. The rest is wetland or lake, including an inactive cranberry bog on the east side not far upstream of the outlet. Highview Condominiums sit at the top of the drainage area, off to the southwest, with moderate density housing situated on the slope to the lake from the south (Figures 17 and 18). The Cook Trust lands extend along the east side, while the Heritage Museum and Gardens run along the west side.

Identification of spring sources, culverts, drains and property parcels has been completed by both the Shawme Ponds Watershed Association and Lycott in separate efforts in the late 1990s, as summarized by ENSR (2001). Areas surrounding the Shawme Lakes are very permeable sandy loams, generating little runoff and suggesting that ground water inputs will be dominant. Groundwater seepage rates into Upper Pond from 2000 (ESS 2000 as summarized by ENSR 2001) ranged from 18 to 344 $L/m^2/day$. Values in excess of 40 $L/m^2/day$ are considered high, but are not unusual on Cape Cod. Average monthly discharge out of the ponds has ranged from just over 1 cfs to 12 cfs, with an average of about 7 cfs. Assuming direct precipitation of 46 inches per year (about 0.3 cfs) and no appreciable overland runoff, groundwater seepage would have to average 6.7 cfs to achieve the estimated observed average flow. For just the upper lake, the seepage rate would have to be 178 $L/m^2/day$ to provide the observed flow, consistent with observed seepage rates. However, there are two active storm drains from developed areas that do deliver storm water to Upper Shawme Lake (Figure 3), so runoff is not an insignificant factor.

Figure 16. Bathymetry of Upper and Lower Shawme Lakes from pre-1990 MA DFW records.

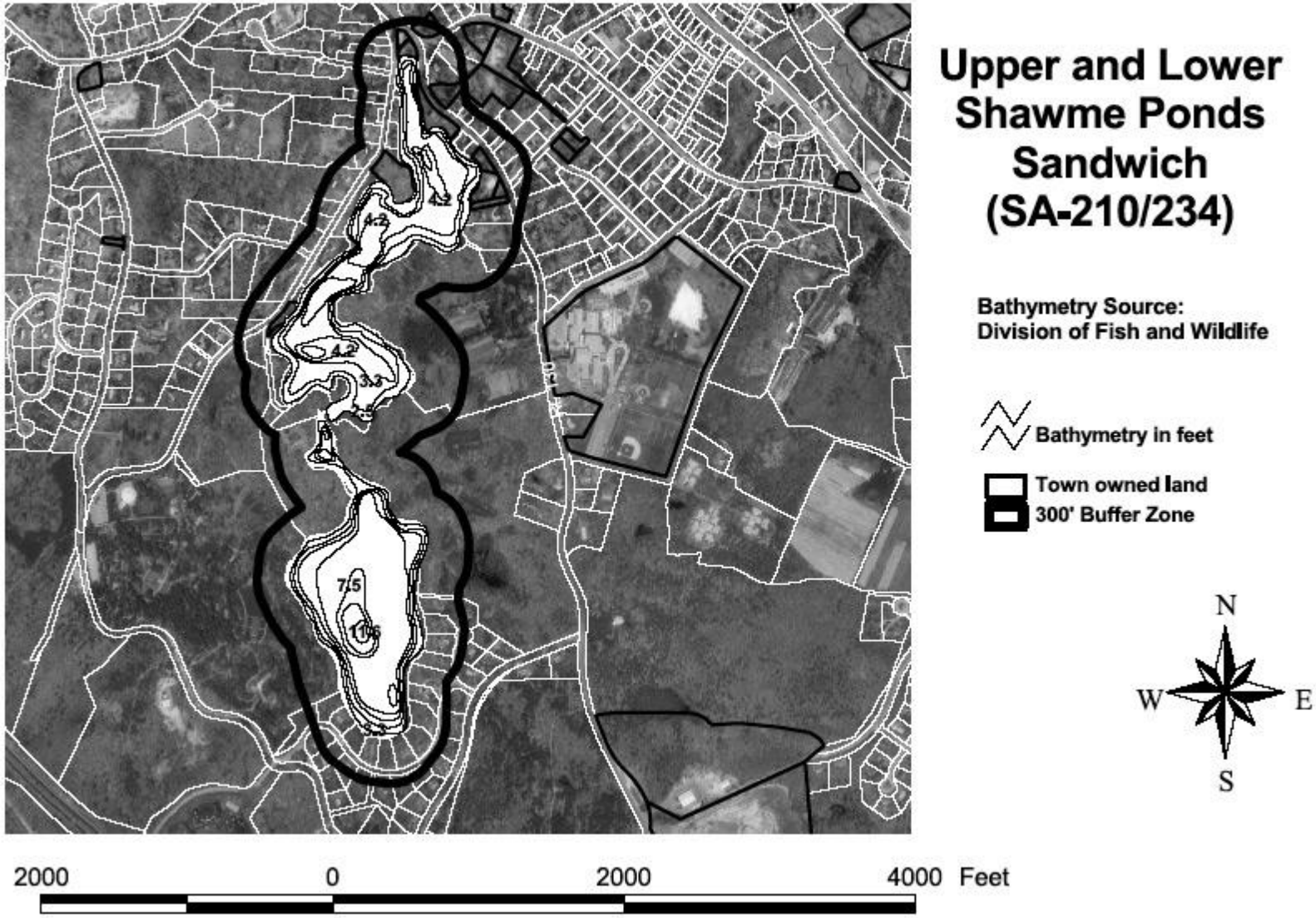


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Figure 17. Pond and parcel layout for Upper and Lower Shawme Lakes.

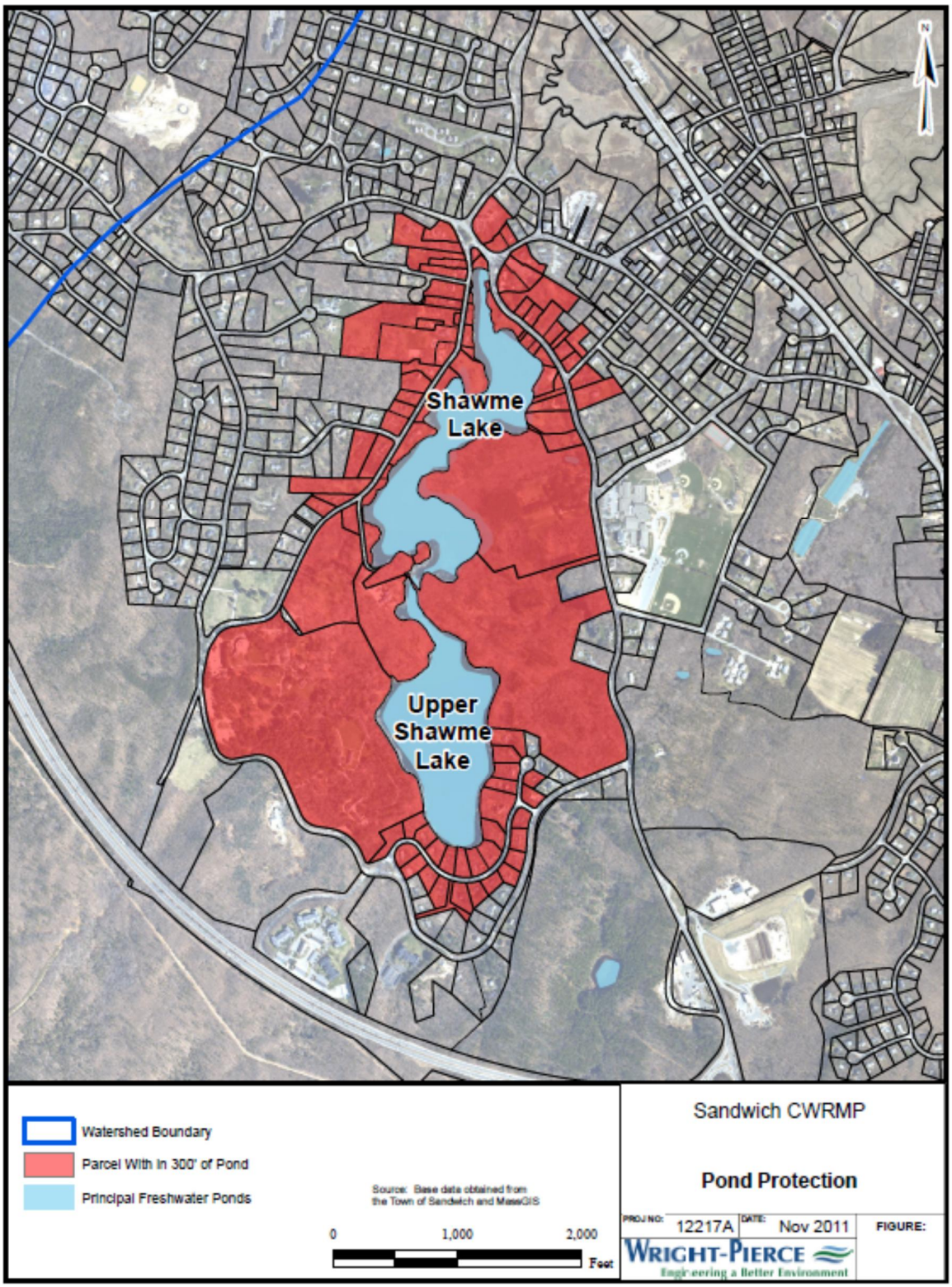
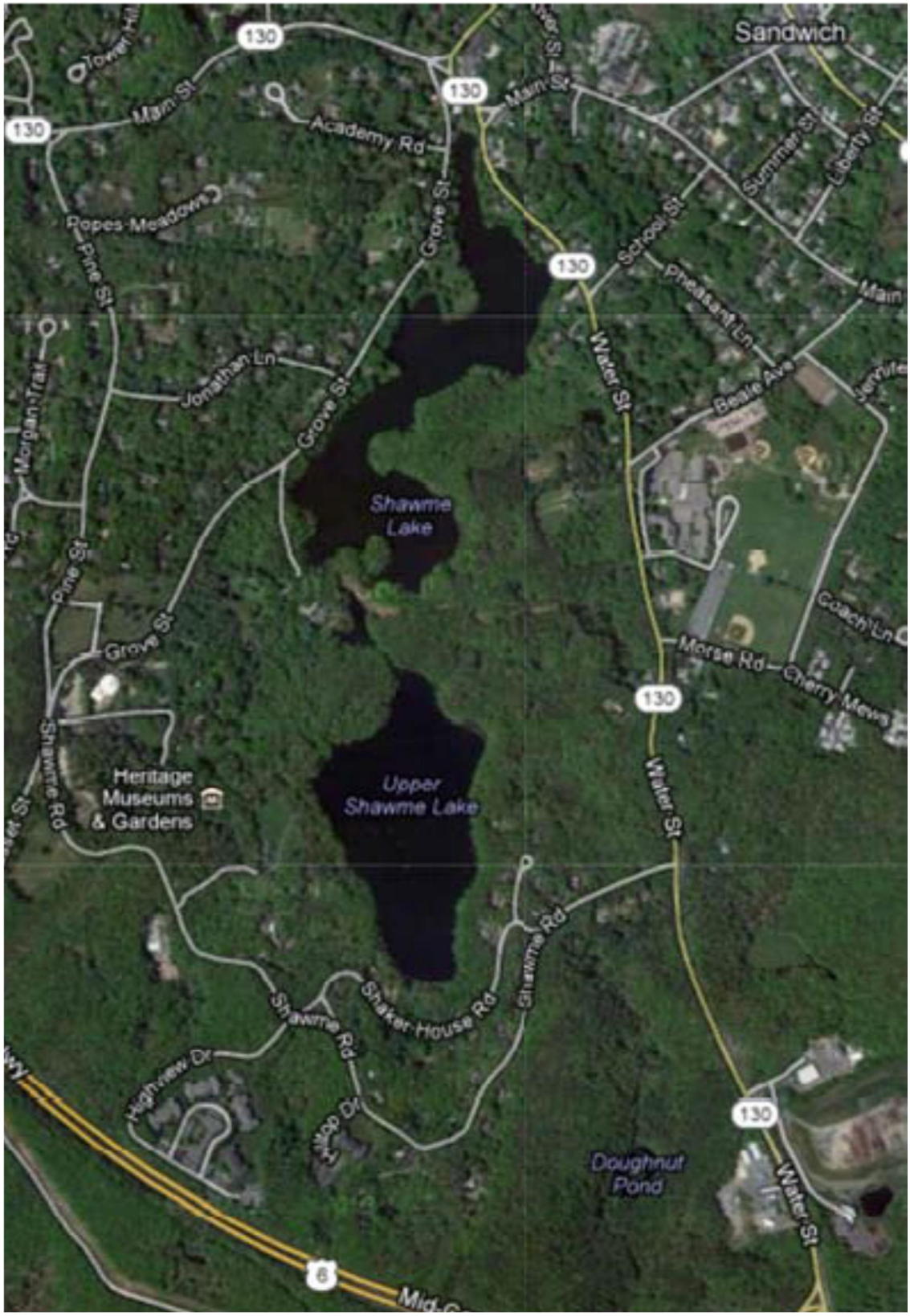


Figure 18. Aerial view of immediate area of Upper and Lower Shawme Lakes.



Pond Condition

Upper Shawme Lake is on the Massachusetts 2010 Integrated List of Waters as a category 5 waterbody, requiring a TMDL for nutrients and eutrophication as evidenced by biological indicators. Total phosphorus values from Upper Shawme Lake and surface inputs are reported as 11-339 ug/L, a rather wide range, with all of the values collected in the fall and winter. The highest value was obtained from a culvert off Water Street during a rain storm. Other high values tended to coincide with heavy precipitation as well. Nitrogen values are generally low for nitrate and higher for ammonium. All nitrogen values were low from a lake management perspective and suggest low N:P ratios that would favor cyanobacterial dominance of the algae.

Levels of total phosphorus in seepage have ranged from 19 to 280 ug/L over a period of about 20 years from 1980 to 2000. While there have been methodological issues that cloud interpretation, it does appear that phosphorus is sometimes elevated. Levels of iron in ground water are relatively low, indicating that the associated phosphorus will not be completely inactivated by the iron. Nitrogen data from seepage samples indicates that nitrate is greater than ammonium, with nitrate values from 0.05 to 0.24 mg/L as N and ammonium levels ranging from <0.01 to 0.04 mg/L, but overall inorganic nitrogen levels are fairly low in those samples. Oxygen appears plentiful in Upper Shawme Lake and the incoming groundwater, given the higher nitrate and lower ammonium values.

Soft sediment has accumulated, and much may have been present in wetlands that were flooded when the lake was created. Average soft sediment depth was about 8 ft in 2000, with a maximum depth of about 12 ft. Sediments are muck material, high in organic content and overlying mostly sand. Nutrient levels are likely high in the sediment, but no testing has been completed to determine if phosphorus release might be affecting measured levels in the pond or seepage.

Blooms of algae were not often reported prior to 2001, but cyanobacterial blooms have been noted over the last decade and are probably the reason that Upper Shawme Lake was placed on the Integrated Waters List. Rooted plants have been abundant for many years, and included mainly Robbin's pondweed (*Potamogeton robbinsii*) and waterweed (*Elodea canadensis*) and aquatic mosses in the 1980s. Waterweed and coontail (*Ceratophyllum demersum*) were observed in fall of 2011, but no recent detailed survey has been conducted. Pickerel is the main gamefish in the lake, but there is an active alewife run, so past stocking was apparently successful in establishing a migratory population.

Designated Use Support

Designated uses for Upper Shawme Lake include swimming, boating and fishing, along with aesthetic and passive uses. As a breeding area of sea-run alewife, the lake is also important for fish and wildlife propagation. Upper Shawme Lake is on the 2010 Integrated Waters List for not supporting designated uses as a consequence of excess nutrients and eutrophication as indicated by system biology, and is supposed to be the subject of a TMDL (category 5).

Risk from Future Development

Future development would constitute an increased threat, but the lake is already listed for failing to properly support designated uses, and the key undeveloped lands on the east and west sides of the lake are publicly held.

Assessment Needs

While there has probably been more study of the Shawme Lake system than any other in Sandwich, the specific cause of the biological impairment in Upper Shawme Lake (algal blooms and rooted plant growth) is not completely clear. The thick accumulated muck supports the rooted plants, but the species are not invasive forms and it is not known if the fertility was there when the ponds were formed or was substantially increased by human inputs over time. Cyanobacterial blooms appear linked to high phosphorus with low nitrate, a situation that strongly favors those algae. However, if on-site waste water disposal was the main source, the nitrogen levels should be much higher than they are. Further, phosphorus is adsorbed to soil, even sand, and it would take a very large input to that soil over a very long time to exhaust the removal capacity. That could be the case, but the presence of storm drains with very high phosphorus levels suggests an alternative explanation for algal blooms, one that seems more likely than waste water from review of the available data. Possible release of phosphorus from sediment is yet another potential phosphorus source that would add appreciably less nitrogen and could be a factor in the observed blooms. An investigative study is needed to determine the causative agents and best means of control. A thorough plant survey is also needed.

Management Needs

Upper Shawme Lake needs reduced algae growth, which translates into reduced available phosphorus inputs. It may also need rooted plant control, but in the absence of any recent plant survey, this need is uncertain.

Lower Shawme Lake

Pond Features

Lower Shawme Lake is the downstream part of a two pond complex, and covers about 24 acres to an average depth of 4 ft with a maximum depth of 5.3 ft (Table 1, Figure 16). However, as with Upper Shawme Lake, there are multiple estimates of area and depth from various sources. Area estimates are similar, but some depth estimates are much deeper. However, given the history of the pond as a dammed stream and the presence of considerable accumulated muck sediment (ENSR 2001), much greater depth is unlikely. There are about 1.5 acres of shoreline, some of it wooded, but much in residential backyards. There is a surface water inlet from Upper Shawme Lake, and the outlet is the start of Mill Creek, which runs to the bay with an average flow in excess of 7 cfs. Detention time in Lower Shawme Lake is about 7 days. There is some access through a large public parcel on the southwest side and near the outlet in town, but there are no developed boat launch or beach facilities. Ground water enters from the east and west, but most flow is surface water inflow. A variety of warmwater fish are present and alewife run from the bay into and through Lower Shawme Lake. What was known of Lower Shawme Pond and its watershed was summarized by ENSR in a 2001 letter report, and that information is considerable, but there are few data since that time.

Watershed Features

The watershed of Lower Shawme Lake includes all the drainage area for Upper Shawme Lake plus an additional watershed area of approximately 162 acres. Approximately 55% of the total watershed is forested according to ESS (2001), with about 24% in residential uses and another 8% in other developed uses. The rest is wetland and lake. There is more developed land immediately adjacent to Lower Shawme Lake (Figures 17 and 18), and there are at least four active storm drains discharging to the lake (Figure 3), although two are near the outlet. Soils surrounding the Shawme Lakes are very permeable sandy loams, but with storm water drainage systems associated with developed areas, storm water runoff can be significant.

Pond Condition

Ground water was shown to be the dominant inflow source to Upper Shawme Lake, but seepage into Lower Shawme Lake is much lower, at -5 to 21 L/m^2/day. Lower Shawme Lake therefore also experiences outseepage, and most of its inflow comes from Upper Shawme Lake. This is consistent with land slopes near the pond, which are far less steep than for Upper Shawme Lake. However, there are active storm drains discharging runoff from nearby developed lands and roadways, and these may be significant sources of contaminants if not actual flow.

Water quality is similar to that of Upper Shawme Lake, consistent with that upper lake as the main source of water to the lower lake. Phosphorus remains elevated. One difference is higher ammonium in the lower lake, probably a function of sediment and rooted plant influence on nitrogen forms, but possibly also related to on-site waste water inputs from nearby developed land. Nitrate nitrogen was elevated in the town spring near the outlet, not to an extent that would represent a human health hazard, but to a degree that suggests a different water source than what supplies the lower lake. No oxygen problems have been noted, but with such a shallow pond this is to be expected.

Since at least the late 1980s, the plant community of Lower Shawme Lake has been dense and dominated by water weed (*Elodea canadensis*), with profuse growths of Robbin's pondweed (*Potamogeton robbinsii*), wild celery (*Vallisneria americana*) and bushy pondweed (*Najas flexilis*). Swamp loosestrife (*Decodon verticillatus*), purple loosestrife (*Lythrum salicaria*) and reed grass (*Phragmites sp.*) were observed along the shoreline, the latter two being invasive plant species. No recent study has been conducted, but plant cover is known to still be dense. The fish community of the lower lake is similar to that of the upper lake, with warmwater species and sea-run alewife.

Designated Use Support

Designated uses for Lower Shawme Lake include swimming, boating and fishing, along with aesthetic and passive uses. As a breeding area of sea-run alewife, the lake is also important for fish and wildlife propagation. Lower Shawme Lake is on the 2010 Integrated Waters List for not supporting designated uses as a consequence of excess nutrients and eutrophication as indicated by system biology, and is supposed to be the subject of a TMDL (category 5).

Risk from Future Development

Future development would constitute an increased threat, but the lake is already listed for failing to properly support designated uses, and most developable land near the lake is already developed.

Assessment Needs

While there has probably been more study of the Shawme Lake system than any other in Sandwich, the specific cause of the biological impairment in Lower Shawme Lake (algal blooms and rooted plant growth) is not completely clear. The thick accumulated muck supports the rooted plants, but the species are not invasive forms and it is not known if the fertility was there when the ponds were formed of was substantially increased by human inputs over time. Cyanobacterial blooms appear linked to high phosphorus with low nitrate, a situation that strongly favors those algae. However, if on-site waste water disposal was the main source, the nitrogen levels should be much higher than they are. Further, phosphorus is adsorbed to soil, even sand, and it would take a very large input to that soil over a very long time to exhaust the removal capacity. That could be the case, but the presence of storm drains with very high phosphorus levels suggests an alternative explanation. Possible release from sediment is yet another potential phosphorus source that would add appreciably less nitrogen. An investigative study is needed to determine the causative agents and best means of control. A thorough plant survey is also needed.

Management Needs

Lower Shawme Lake needs reduced algae growth, which translates into reduced available phosphorus inputs. It may also need rooted plant control, but in the absence of any recent plant survey, this need is uncertain.

Waste Water Disposal Impact Assessment

Waste water is an ongoing threat to many Cape Cod ponds, as much waste water is disposed of in on-site systems that discharge to ground water, and ground water constitutes a major input to many ponds. Transport of nitrogen, with dilution as the primary means of concentration reduction, is relatively well understood, but movement of phosphorus is less well understood. Phosphorus levels tend to be very high in waste water, and while removal through adsorption to soil particles is an effective removal mechanism, removal efficiencies are lowest in sand and adsorption capacity can be depleted over time with constant inputs, as with on-site waste water disposal.

The conventional wisdom is that phosphorus will be removed to very low levels within 300 ft of the discharge point when moving through oxygenated soil, but this is a largely untested assumption in many situations. Further, not all pathways from discharge to pond include oxygenated soil, and there have been cases where phosphorus break out has been documented (e.g., Ashumet Pond in Falmouth, and that involved inputs from the MMR that could be a factor in some Sandwich Ponds as well). It is clearly best to directly evaluate ground water loading to ponds to the extent possible. Effective inputs are largely controlled by available iron and oxygen in Cape Cod ponds; if iron is high and oxygen is present, most ground water phosphorus will precipitate and not support algal blooms. But if iron is limiting or oxygen is depleted, the phosphorus will be available and can support algal growth.

With limited data from which to derive a direct analysis of waste water impacts on the assessed Sandwich Ponds, we can still look at qualitative and calculated aspects of waste water loading to get a reasonable impression of the threat of impact posed by waste water to each pond. Generation of waste

Table 5. Ratings of potential impact from specified factors for each assessed pond.

Pond	Waste Water	Storm Water	Internal Recycling	Rooted Plants	Algal Blooms	Preliminary Trophic State Assessment
Lawrence	M	L	M	L	L	Oligo-Meso
Spectacle	H	M	H	L	M	Meso
Triangle	M	L	M	L	H	Meso-Eut
Upper Hog	L	L	L	L	L	Oligo
Lower Hog	L	L	L	L	L	Oligo
Peters	M	M	H	L	M	Meso-Eut
Pimlico	M	M	L	M	L	Meso-Eut
Snake	M	M	M	L	L	Oligo-Meso
Weeks	L	M	L	M	L	Meso
Hoxie	M	L	H	L	M	Meso-Eut
Lower Shawme	M	H	L	H	H	Eut
Upper Shawme	M	H	L	H	H	Eut
H = high, M = moderate, L = low						
Oligo = Oligotrophic, Meso = Mesotrophic, Eut = Eutrophic						

water within 300 ft of each pond in what is understood to be the likely path of ground water flow (Table 1) suggests waste water inputs of 345 to 3050 gallons per day (gpd) which, at roughly 23 mg/gallon, translates into loads of roughly 8 to 70 g/d to the ground water moving toward the lake. For an entire year, this equates to between 2.9 and 25.6 kg/yr. At removal rates that are typically at least 90%, this would result in loads to ponds of 0.3 to 2.6 kg/yr. While pond size will affect concentration, such inputs are not likely to be sufficient by themselves to significantly increase measured phosphorus concentration. However, most of that phosphorus will wind up in the pond sediment, and the build-up over time could fuel substantial internal recycling and related algal blooms.

For waste water to represent a more immediate threat (e.g., within the year of input), the load must be much higher or the removal rate of soil must be much lower. Such conditions can exist where years of loading have exhausted the adsorption capacity of the associated soils and waste water disposal is large (many individual systems or fewer large communal systems). This will most likely require a substantial development within a mile of the pond, probably closer, although larger inputs further away for a longer period of time could be involved. With water movement measured in feet per day, it is less that rate of movement than the adsorption capacity of the soil that will determine phosphorus delivery. Both the actual adsorption capacity (mg P/g soil, which is around 100 mg P/g sand) and the path of the ground water plume containing the waste water (focused vs. diffuse, well mixed vs. segregated) will be important, and site specific conditions must be examined to gain insights in that regard.

For the Sandwich ponds assessed, the potential for waste water impacts is categorized as high (H), moderate (M) or low (L). Key factors include development density (and by extension waste water disposal volume) in the upgradient direction and depth of the pond (deeper ponds can intercept more ground water). Spectacle Pond has the only high rating, although one could make a case for Peters Pond receiving a high rating as well; it would have the highest priority for attention after Spectacle Pond. All the other ponds except Weeks and Upper and Lower Hog Ponds have moderate ratings (Table 5). Over time, even a moderate rating represents a threat of phosphorus accumulation in the pond and a potential internal recycling threat. Consequently, 9 out of 12 ponds warrant additional waste water investigations and consideration of waste water management options.

Storm Water Impact Assessment

The potential for storm water to impact the Sandwich ponds is largely a function of nearby development and routing of water to the ponds by storm water drainage systems. The vast majority of storm water drainage systems in Sandwich are leaching systems, and improvements in some of the direct drainage systems have been made under the town storm water mitigation plan, so storm water is not as big a threat as in many developed areas off the Cape. Upper and Lower Shawme Lakes have multiple direct entry storm drains serving developed areas that have tested high for nutrient levels, making the potential for storm water impact on these ponds high (Table 5). Spectacle, Peters, Pimlico, Snake and Weeks Ponds received moderate ratings, with some storm water issues to be addressed, but these are relatively minor. The remaining ponds have low potential for storm water impacts, although the discharge from the cranberry bog may be a substantial influence on Hoxie Pond, but this is not characterized as a storm water input.

Internal Nutrient Recycling Impact Assessment

Internal loading in Cape Cod ponds is a function of accumulated iron-bound phosphorus and oxygen depletion that leads to the release of that phosphorus. The original sources of that phosphorus are not critical to this assessment, although they may be important to long-term pond management activities. Phosphorus bound to organic matter may also be important in the long-term, as decomposition will release some of that phosphorus, but it is iron-bound phosphorus that is released relatively rapidly under anoxic conditions and fuels algal blooms through that increase in available phosphorus.

We have no data for available sediment phosphorus in any of the assessed ponds, but based on depth and oxygen features, ponds can be sorted into categories of high, moderate or low potential for internal recycling (Table 5). Spectacle, Peters and Hoxie Ponds have high potential for internal recycling, while Lawrence, Triangle and Snake Ponds have more moderate potential. The others have lower potential for internal recycling, but some recycling is still possible. Addition of sample analysis for iron-bound phosphorus would allow considerable refinement of this assessment.

Rooted Plant Issues Assessment

There are not recent surveys of rooted plants in the assessed ponds, but from the available background data and a cursory viewing in fall of 2011, there are few rooted plant issues (Table 5). The Shawme Lakes have dense assemblages that may need some management, but as far as is known, plant populations include only native species. Pimlico and Weeks Ponds have enough vegetation to warrant a high priority for assessment, but only a moderate rating for potential problems. Vegetation in Pimlico Pond may actually be protecting the pond from other influences. Other ponds appear to have a low potential for rooted plant impacts.

Algal Issues Assessment

Increased fertility leads to greater algal production, which can be desirable if the biological structure processes that production and generates desirable features such as abundant gamefish stocks. However, overfertilization often leads to excessive algal production and build-up of algal biomass that may be perceived as a "bloom". Note that there is no official level of algae that constitutes a bloom, but high levels of any algae can cause discoloration of pond water that qualifies as a bloom. Blue-green algae (cyanobacteria) are particularly troublesome, as many have gas vacuoles that allow them to form surface scums. Cyanobacteria often cause taste and odor and can create toxicity in water at high enough densities. Cyanobacteria are also favored by warm temperatures and low N:P ratios common in Cape ponds during summer.

Based on the combination of past reports, water quality, and pond features, potential for algal blooms is projected for the assessed ponds (Table 5). The two Shawme Lakes and Triangle Pond have high potential, while Spectacle, Peters and Hoxie Ponds have moderate potential. The remaining six ponds have low potential, but this could change and some additional data for actual algal communities and more recent nutrient levels would help refine this analysis.

Additional Threats to Pond Condition

In the course of evaluating the Sandwich ponds, no invasive species were encountered. These ponds are not likely to be susceptible to zebra mussels, but there are other mollusks (e.g., Asian clams) and some fish that could invade Cape ponds; none are known from these ponds. Invasive plant species are far more likely, with variable milfoil, fanwort and even hydrilla known from multiple Cape ponds. No invasive plant species are known from the assessed ponds, but a lack of detailed surveys hinders meaningful assessment. It would be worthwhile to perform at least a short survey of each pond to characterize plant communities and detect any major infestations.

Sedimentation is not often a major problem for Cape ponds, as water flow is limited and usually diffuse. Exceptions occur where there are major inlets or where storm drains outlet with no energy dissipation. No serious problems were noted in this pond assessment, but there are indications of erosion and sedimentation at Peters Pond, Pimlico Pond, and the Shawme Ponds in association with storm water inputs. There may be other localized impacts that were not detected at Spectacle, Snake and Weeks Ponds. Mitigation would be desirable.

Management Needs Summary

The greatest management need is really additional information for the ponds of Sandwich. A comprehensive pond sampling program is needed. The Pond And Lake Steward (PALS) program, conducted by volunteers with testing and analysis by the School for Marine Science and Technology at UMASS Dartmouth is an excellent program, and the Town has taken advantage of this where volunteers have been available (most notably in the Three Ponds District over the last four years). Getting and maintaining volunteers has been a challenge, but effort needs to be made to interest residents in the valuable resources represented by the ponds.

The typical PALS approach involves a single sampling at multiple depths (usually surface and bottom, with a mid-depth sample if the pond stratifies) at the deepest location in the pond, usually in August, with testing for temperature, oxygen, pH, alkalinity, phosphorus, nitrogen, chlorophyll and water clarity. For those ponds where algal blooms have developed, samples should also be collected for algal analysis, and water quality sampling should include spring (early to mid-May) and July events as well, to fill in potentially important gaps in data for the growing season. For ponds with more than one basin, as defined by the bathymetric maps, sampling should be extended to each basin.

A plant survey is needed at each pond. This should be conducted by someone with expertise in plant identification and possible management approaches, but volunteers could learn from the process and expand or extend it later. The survey would yield a map of plant distribution and density, with frequency for each species and a description of the plant community, any invasive species, and threats by plants to designated uses.

Samples of surficial bottom sediment should be collected from the ponds and tested for available sediment phosphorus, a key feature that allows assessment of potential internal recycling of phosphorus. All of the ponds would benefit from this assessment, but those that have experienced algal blooms or for which there is documented high phosphorus levels would be especially important to assess. Testing is done by a qualified lab, and samples are normally collected with an Ekman dredge by qualified personnel, although the process is not difficult to learn if volunteers wish to be involved.

No harm would be done by better and more storm water and waste water management, but these tend to be expensive activities best applied with adequate planning that requires more data than are currently available. Proper assessment is an important element of management planning and implementation. While more investigation is needed before management plans can be crafted, the most likely needs for each pond can be summarized as follows:

Lawrence – Protection of undeveloped land.

Spectacle – Management of ground water quality to the northwest.

Triangle – In-pond nutrient control, most likely by mixing or phosphorus inactivation.

Upper Hog – Protection of undeveloped land.

Lower Hog – Protection of undeveloped land.

Peters – In-pond nutrient control, most likely by mixing or phosphorus inactivation.

Pimlico – Storm water mitigation, undeveloped land protection.

Snake – Storm water mitigation, ground water management to the north and west.

Weeks – Storm water mitigation, ground water management to the west.

Hoxie – Cranberry bog best management practices, possible mixing in pond.

Upper Shawme – Storm water and ground water management, possible in-pond nutrient control, possible in-pond rooted plant control.

Lower Shawme – Storm water and ground water management, possible in-pond nutrient control, possible in-pond rooted plant control.

Management Options

Key aspects of pond management are covered in Mattson et al. 2004, and those interested in the management of waterbodies are strongly urged to acquaint themselves with that publication, which can be obtained for free online on the DCR Ponds and Lakes program web page. Based on the information available, it is definitely premature to specify management methods to be applied to the assessed ponds and/or their watersheds. Protection of undeveloped land is a matter of purchase, easement, or regulatory controls. Waste water management consists mainly of diversion or treatment measures, of which there are a variety. Storm water management typically involves detention and/or infiltration, with the details highly dependent on site specific features. In-pond mixing could be accomplished by addition of air or mechanical force, and the choice is largely a matter of economics and pond configuration. Phosphorus inactivation has been performed on Cape Cod previously and has involved addition of aluminum compounds in each case so far. Rooted plant control can involve physical, chemical or biological approaches, but most often will involve herbicides on a localized to lakewide scale or localized mechanical techniques such as bottom barriers (mats laid on top of plants to prevent growth) or forms of harvesting (ranging from simple hand pulling to highly mechanized cut and collection systems). A tabular summary of control options for algae and rooted aquatic plants is provided as an appendix.

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Appendix: Algae management options template

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
WATERSHED CONTROLS				
1)Management for nutrient input reduction	♦ Includes wide range of watershed and lake edge activities intended to eliminate nutrient sources or reduce delivery to lake ♦ Essential component of algal control strategy where internal recycling is not the dominant nutrient source, and desired even where internal recycling is important	♦ Acts against the original source of algal nutrition ♦ Creates sustainable limitation on algal growth ♦ May control delivery of other unwanted pollutants to lake ♦ Facilitates ecosystem management approach which considers more than just algal control	♦ May involve considerable lag time before improvement observed ♦ May not be sufficient to achieve goals without some form of in-lake management ♦ Reduction of overall system fertility may impact fisheries ♦ May cause shift in nutrient ratios which favor less desirable algae	♦
1a) Point source controls	♦ More stringent discharge requirements ♦ May involve diversion ♦ May involve technological or operational adjustments ♦ May involve pollution prevention plans	♦ Often provides major input reduction ♦ Highly efficient approach in most cases ♦ Success easily monitored	♦ May be very expensive in terms of capital and operational costs ♦ May transfer problems to another watershed ♦ Variability in results may be high in some cases	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
1b) Non-point source controls	♦ Reduction of sources of nutrients ♦ May involve elimination of land uses or activities that release nutrients ♦ May involve alternative product use, as with no phosphate fertilizer	♦ Removes source ♦ Limited ongoing costs	♦ May require purchase of land or activity ♦ May be viewed as limitation of "quality of life" ♦ Usually requires education and gradual implementation	♦
1c) Non-point source pollutant trapping	♦ Capture of pollutants between source and lake ♦ May involve drainage system alteration ♦ Often involves wetland treatments (det./infiltration) ♦ May involve storm water collection and treatment as with point sources	♦ Minimizes interference with land uses and activities ♦ Allows diffuse and phased implementation throughout watershed ♦ Highly flexible approach ♦ Tends to address wide range of pollutant loads	♦ Does not address actual sources ♦ May be expensive on necessary scale ♦ May require substantial maintenance	♦
IN-LAKE PHYSICAL CONTROLS				
2) Circulation and destratification	♦ Use of water or air to keep water in motion ♦ Intended to prevent or break stratification ♦ Generally driven by mechanical or pneumatic force	♦ Reduces surface build-up of algal scums ♦ May disrupt growth of blue-green algae ♦ Counteraction of anoxia improves habitat for fish/invertebrates ♦ Can eliminate localized problems without obvious impact on whole lake	♦ May spread localized impacts ♦ May lower oxygen levels in shallow water ♦ May promote downstream impacts	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
3) Dilution and flushing	♦ Addition of water of better quality can dilute nutrients ♦ Addition of water of similar or poorer quality flushes system to minimize algal build-up ♦ May have continuous or periodic additions	♦ Dilution reduces nutrient concentrations without altering load ♦ Flushing minimizes detention; response to pollutants may be reduced	♦ Diverts water from other uses ♦ Flushing may wash desirable zooplankton from lake ♦ Use of poorer quality water increases loads ♦ Possible downstream impacts	♦
4) Drawdown	♦ Lowering of water over autumn period allows oxidation, desiccation and compaction of sediments ♦ Duration of exposure and degree of dewatering of exposed areas are important ♦ Algae are affected mainly by reduction in available nutrients.	♦ May reduce available nutrients or nutrient ratios, affecting algal biomass and composition ♦ Opportunity for shoreline clean-up/structure repair ♦ Flood control utility ♦ May provide rooted plant control as well	♦ Possible impacts on non-target resources ♦ Possible impairment of water supply ♦ Alteration of downstream flows and winter water level ♦ May result in greater nutrient availability if flushing inadequate	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
5) Dredging	♦ Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering ♦ Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system ♦ Nutrient reserves are removed and algal growth can be limited by nutrient availability	♦ Can control algae if internal recycling is main nutrient source ♦ Increases water depth ♦ Can reduce pollutant reserves ♦ Can reduce sediment oxygen demand ♦ Can improve spawning habitat for many fish species ♦ Allows complete renovation of aquatic ecosystem	♦ Temporarily removes benthic invertebrates ♦ May create turbidity ♦ May eliminate fish community (complete dry dredging only) ♦ Possible impacts from containment area discharge ♦ Possible impacts from dredged material disposal ♦ Interference with recreation or other uses during dredging	♦
5a) "Dry" excavation	♦ Lake drained or lowered to maximum extent practical ♦ Target material dried to maximum extent possible ♦ Conventional excavation equipment used to remove sediments	♦ Tends to facilitate a very thorough effort ♦ May allow drying of sediments prior to removal ♦ Allows use of less specialized equipment	♦ Eliminates most aquatic biota unless a portion left undrained ♦ Eliminates lake use during dredging	♦
5b) "Wet" excavation	♦ Lake level may be lowered, but sediments not substantially exposed ♦ Draglines, bucket dredges, or long-reach backhoes used to remove sediment	♦ Requires least preparation time or effort, tends to be least cost dredging approach ♦ May allow use of easily acquired equipment ♦ May preserve aquatic biota	♦ Usually creates extreme turbidity ♦ Normally requires intermediate containment area to dry sediments prior to hauling ♦ May disrupt ecological function ♦ Use disruption	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
5c) Hydraulic removal	♦ Lake level not reduced ♦ Suction or cutterhead dredges create slurry which is hydraulically pumped to containment area ♦ Slurry is dewatered; sediment retained, water discharged	♦ Creates minimal turbidity and impact on biota ♦ Can allow some lake uses during dredging ♦ Allows removal with limited access or shoreline disturbance	♦ Often leaves some sediment behind ♦ Cannot handle coarse or debris-laden materials ♦ Requires sophisticated and more expensive containment area	♦
6) Light-limiting dyes and surface covers	♦ Creates light limitation	♦ Creates light limit on algal growth without high turbidity or great depth ♦ May achieve some control of rooted plants as well	♦ May cause thermal stratification in shallow ponds ♦ May facilitate anoxia at sediment interface with water	♦
6.a) Dyes	♦ Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting algal growth ♦ Dyes remain in solution until washed out of system.	♦ Produces appealing color ♦ Creates illusion of greater depth	♦ May not control surface bloom-forming species ♦ May not control growth of shallow water algal mats ♦ Altered thermal regime	♦
6.b) Surface covers	♦ Opaque sheet material applied to water surface	♦ Minimizes atmospheric and wildlife pollutant inputs	♦ Minimizes atmospheric gas exchange ♦ Limits recreation	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
7) Mechanical removal	♦ Filtering of pumped water for water supply purposes ♦ Collection of floating scums or mats with booms, nets, or other devices ♦ Continuous or multiple applications per year usually needed	♦ Algae and associated nutrients can be removed from system ♦ Surface collection can be applied as needed ♦ May remove floating debris ♦ Collected algae dry to minimal volume	♦ Filtration requires high backwash and sludge handling capability ♦ Labor and/or capital intensive ♦ Variable collection efficiency ♦ Possible impacts on non-target organisms	♦
8) Selective withdrawal	♦ Discharge of bottom water which may contain (or be susceptible to) low oxygen and higher nutrient levels ♦ May be pumped or utilize passive head differential	♦ Removes targeted water from lake efficiently ♦ May prevent anoxia and phosphorus build up in bottom water ♦ May remove initial phase of algal blooms which start in deep water ♦ May create coldwater conditions downstream	♦ Possible downstream impacts of poor water quality ♦ May promote mixing of remaining poor quality bottom water with surface waters ♦ May cause unintended drawdown if inflows are low	♦
9) Sonication	♦ Sound waves disrupt algal cells	♦ Supposedly affects only algae (new technique) ♦ Applicable in localized areas	♦ Unknown effects on non-target organisms ♦ May release cellular toxins or other undesirable contents into water column	♦
IN-LAKE CHEMICAL CONTROLS				
10) Hypolimnetic aeration or oxygenation	♦ Addition of air or oxygen provides oxic conditions ♦ Maintains stratification ♦ Can also withdraw water, oxygenate, then replace	♦ Oxic conditions reduce P availability ♦ Oxygen improves habitat ♦ Oxygen reduces build-up of reduced cpds	♦ May disrupt thermal layers important to fish community ♦ Theoretically promotes supersaturation with gases harmful to fish	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
11) Algaecides	♦ Liquid or pelletized algaecides applied to target area ♦ Algae killed by direct toxicity or metabolic interference ♦ Typically requires application at least once/yr, often more frequently	♦ Rapid elimination of algae from water column , normally with increased water clarity ♦ May result in net movement of nutrients to bottom of lake	♦ Possible toxicity to non-target species ♦ Restrictions on water use for varying time after treatment ♦ Increased oxygen demand and possible toxicity ♦ Possible recycling of nutrients	♦
11a) Forms of copper	♦ Cellular toxicant, disruption of membrane transport ♦ Applied as wide variety of liquid or granular formulations	♦ Effective and rapid control of many algae species ♦ Approved for use in most water supplies	♦ Possible toxicity to aquatic fauna ♦ Accumulation of copper in system ♦ Resistence by certain green and blue-green nuisance species ♦ Lysing of cells releases nutrients and toxins	♦
11b) Peroxides	♦ Disrupts most cellular functions, tends to attack membranes ♦ Applied as a liquid or solid. ♦ Typically requires application at least once/yr, often more frequently	♦ Rapid action ♦ Oxidizes cell contents, may limit oxygen demand and toxicity	♦ Much more expensive than copper ♦ Limited track record ♦ Possible recycling of nutrients	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
11c) Synthetic organic algaecides	♦ Absorbed or membrane-active chemicals which disrupt metabolism ♦ Causes structural deterioration	♦ Used where copper is ineffective ♦ Limited toxicity to fish at recommended dosages ♦ Rapid action	♦ Non-selective in treated area ♦ Toxic to aquatic fauna (varying degrees by formulation) ♦ Time delays on water use	♦
12) Phosphorus inactivation	♦ Typically salts of aluminum, iron or calcium are added to the lake, as liquid or powder ♦ Phosphorus in the treated water column is complexed and settled to the bottom of the lake ♦ Phosphorus in upper sediment layer is complexed, reducing release from sediment ♦ Permanence of binding varies by binder in relation to redox potential and pH	♦ Can provide rapid, major decrease in phosphorus concentration in water column ♦ Can minimize release of phosphorus from sediment ♦ May remove other nutrients and contaminants as well as phosphorus ♦ Flexible with regard to depth of application and speed of improvement	♦ Possible toxicity to fish and invertebrates, especially by aluminum at low pH ♦ Possible release of phosphorus under anoxia or extreme pH ♦ May cause fluctuations in water chemistry, especially pH, during treatment ♦ Possible resuspension of floc in shallow areas ♦ Adds to bottom sediment, but typically an insignificant amount	♦
13) Sediment oxidation	♦ Addition of oxidants, binders and pH adjustors to oxidize sediment ♦ Binding of phosphorus is enhanced ♦ Denitrification is stimulated	♦ Can reduce phosphorus supply to algae ♦ Can alter N:P ratios in water column ♦ May decrease sediment oxygen demand	♦ Possible impacts on benthic biota ♦ Longevity of effects not well known ♦ Possible source of nitrogen for blue-green algae	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
14) Settling agents	♦ Closely aligned with phosphorus inactivation, but can be used to reduce algae directly too ♦ Lime, alum or polymers applied, usually as a liquid or slurry ♦ Creates a floc with algae and other suspended particles ♦ Floc settles to bottom of lake ♦ Re-application typically necessary at least once/yr	♦ Removes algae and increases water clarity without lysing most cells ♦ Reduces nutrient recycling if floc sufficient ♦ Removes non-algal particles as well as algae ♦ May reduce dissolved phosphorus levels at the same time	♦ Possible impacts on aquatic fauna ♦ Possible fluctuations in water chemistry during treatment ♦ Resuspension of floc possible in shallow, well-mixed waters ♦ Promotes increased sediment accumulation	♦
15) Selective nutrient addition	♦ Ratio of nutrients changed by additions of selected nutrients ♦ Addition of non-limiting nutrients can change composition of algal community ♦ Processes such as settling and grazing can then reduce algal biomass	♦ Can reduce algal levels where control of limiting nutrient not feasible ♦ Can promote non-nuisance forms of algae ♦ Can improve productivity of system without increased standing crop of algae	♦ May result in greater algal abundance through uncertain biological response ♦ May require frequent application to maintain desired ratios ♦ Possible downstream effects	♦
IN-LAKE BIOLOGICAL CONTROLS				
16) Enhanced grazing	♦ Manipulation of biological components of system to achieve grazing control over algae ♦ Typically involves alteration of fish community to promote growth of grazing zooplankton	♦ May increase water clarity by changes in algal biomass or cell size without reduction of nutrient levels ♦ Can convert unwanted algae into fish ♦ Harnesses natural processes	♦ May involve introduction of exotic species ♦ Effects may not be controllable or lasting ♦ May foster shifts in algal composition to even less desirable forms	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
16.a) Herbivorous fish	♦ Stocking of fish that eat algae	♦ Converts algae directly into potentially harvestable fish ♦ Grazing pressure can be adjusted through stocking rate	♦ Typically requires introduction of non-native species ♦ Difficult to control over long term ♦ Smaller algal forms may be benefited and bloom	♦
16.b) Herbivorous zooplankton	♦ Reduction in planktivorous fish to promote grazing pressure by zooplankton ♦ May involve stocking piscivores or removing planktivores ♦ May also involve stocking zooplankton or establishing refugia	♦ Converts algae indirectly into harvestable fish ♦ Zooplankton response to increasing algae can be rapid ♦ May be accomplished without introduction of non-native species ♦ Generally compatible with most fishery management goals	♦ Highly variable response expected; temporal and spatial variability may be high ♦ Requires careful monitoring and management action on 1-5 yr basis ♦ Larger or toxic algal forms may be benefitted and bloom	♦
17) Bottom-feeding fish removal	♦ Removes fish that browse among bottom deposits, releasing nutrients to the water column by physical agitation and excretion	♦ Reduces turbidity and nutrient additions from this source ♦ May restructure fish community in more desirable manner	♦ Targeted fish species are difficult to control ♦ Reduction in fish populations valued by some lake users (human/non-human)	♦
18) Microbial competition	♦ Addition of microbes, often with oxygenation, can tie up nutrients and limit algal growth ♦ Tends to control N more than P	♦ Shifts nutrient use to organisms that do not form scums or impair uses to same extent as algae ♦ Harnesses natural processes ♦ May decrease sediment	♦ Minimal scientific evaluation ♦ N control may still favor cyanobacteria ♦ May need aeration system to get acceptable results	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
19) Pathogens	♦ Addition of inoculum to initiate attack on algal cells ♦ May involve fungi, bacteria or viruses	♦ May create lakewide "epidemic" and reduction of algal biomass ♦ May provide sustained control through cycles ♦ Can be highly specific to algal group or genera	♦ Largely experimental approach at this time ♦ May promote resistant nuisance forms ♦ May cause high oxygen demand or release of toxins by lysed algal cells ♦ Effects on non-target organisms uncertain	♦
20) Competition and allelopathy by plants	♦ Plants may tie up sufficient nutrients to limit algal growth ♦ Plants may create a light limitation on algal growth ♦ Chemical inhibition of algae may occur through substances released by other organisms	♦ Harnesses power of natural biological interactions ♦ May provide responsive and prolonged control	♦ Some algal forms appear resistant ♦ Use of plants may lead to problems with vascular plants ♦ Use of plant material may cause depression of oxygen levels	♦
19a) Plantings for nutrient control	♦ Plant growths of sufficient density may limit algal access to nutrients ♦ Plants can exude allelopathic substances which inhibit algal growth ♦ Portable plant "pods" , floating islands, or other structures can be installed	♦ Productivity and associated habitat value can remain high without algal blooms ♦ Can be managed to limit interference with recreation and provide habitat ♦ Wetland cells in or adjacent to the lake can minimize nutrient inputs	♦ Vascular plants may achieve nuisance densities ♦ Vascular plant senescence may release nutrients and cause algal blooms ♦ The switch from algae to vascular plant domination of a lake may cause unexpected or undesirable changes	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
19b) Plantings for light control	♦ Plant species with floating leaves can shade out many algal growths at elevated densities	♦ Vascular plants can be more easily harvested than most algae ♦ Many floating species provide waterfowl food	♦ Floating plants can be a recreational nuisance ♦ Low surface mixing and atmospheric contact promote anoxia	♦
19c) Addition of barley straw	♦ Input of barley straw can set off a series of chemical reactions which limit algal growth ♦ Release of allelopathic chemicals can kill algae ♦ Release of humic substances can bind phosphorus	♦ Materials and application are relatively inexpensive ♦ Decline in algal abundance is more gradual than with algaecides, limiting oxygen demand and the release of cell contents	♦ Success appears linked to uncertain and potentially uncontrollable water chemistry factors ♦ Depression of oxygen levels may result ♦ Water chemistry may be altered in other ways unsuitable for non-target organisms	♦

Appendix: Rooted plant management options template

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
Physical Controls				
1) Benthic barriers	♦ Mat of variable composition laid on bottom of target area, preventing growth ♦ Can cover area for as little as several months or permanently ♦ Maintenance improves effectiveness	♦ Highly flexible control ♦ Reduces turbidity from soft bottoms ♦ Can cover undesirable substrate ♦ Can improve fish habitat by creating edge effects	♦ May cause anoxia at sediment-water interface ♦ May limit benthic invertebrates ♦ Non-selective interference with plants in target area ♦ May inhibit spawning/feeding by some fish species	♦
1.a) Porous or loose-weave synthetic materials	♦ Laid on bottom and usually anchored by weights or stakes ♦ Removed and cleaned or flipped and repositioned at least once per year for maximum effect	♦ Allows some escape of gases which may build up underneath ♦ Panels may be flipped in place or removed for relatively easy cleaning or repositioning	♦ Allows some growth through pores ♦ Gas may still build up underneath in some cases, lifting barrier from bottom	♦
1.b) Non-porous or sheet synthetic materials	♦ Laid on bottom and anchored by many stakes, anchors or weights, or by layer of sand ♦ Not typically removed, but may be swept or "blown" clean periodically	♦ Prevents all plant growth until buried by sediment ♦ Minimizes interaction of sediment and water column	♦ Gas build up may cause barrier to float upwards ♦ Strong anchoring makes removal difficult and can hinder maintenance	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
1.c) Sediments of a desirable composition	♦ Sediments may be added on top of existing sediments or plants. ♦ Use of sand or clay can limit plant growths and alter sediment-water interactions. ♦ Sediments can be applied from the surface or suction dredged from below muck layer (reverse layering technique)	♦ Plant biomass and propagules can be buried ♦ Sediment can be made less hospitable ♦ Nutrient release from sediments may be reduced ♦ Surface sediment can be made more appealing to humans ♦ Reverse layering requires no addition or removal of sediment	♦ Lake depth may decline ♦ Sediments may mix with underlayment ♦ Permitting for added sediment difficult ♦ Addition of sediment may cause initial turbidity ♦ New sediment may contain nutrients or other contaminants ♦ Generally too expensive for large scale application	♦
2) Dredging	♦ Sediment is physically removed by wet or dry excavation, with deposition in a containment area ♦ Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system ♦ Plants and seed beds are removed and re-growth can be limited by light and/or substrate limitation	♦ Plant removal with some flexibility ♦ Increases water depth ♦ Can reduce pollutant reserves ♦ Can reduce sediment oxygen demand ♦ Can improve spawning habitat for many fish species ♦ Allows complete renovation of aquatic ecosystem	♦ Temporarily removes benthic invertebrates ♦ May create turbidity ♦ May eliminate fish community (complete dry dredging only) ♦ Possible impacts from containment area discharge ♦ Possible impacts from dredged material disposal ♦ Interference with uses during dredging ♦ Usually very expensive	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
2.a) "Dry" excavation	♦ Lake drained or lowered to maximum extent practical ♦ Target material dried to maximum extent possible ♦ Conventional excavation equipment used to remove sediments	♦ Tends to facilitate a very thorough effort ♦ May allow drying of sediments prior to removal ♦ Allows use of less specialized equipment	♦ Eliminates most aquatic biota unless a portion left undrained ♦ Eliminates lake use during dredging	♦
2.b) "Wet" excavation	♦ Lake level may be lowered, but sediments not substantially dewatered ♦ Draglines, bucket dredges, or long-reach backhoes used to remove sediment	♦ Tends to require less preparation and be less costly than dry dredging ♦ May allow use of easily acquired equipment ♦ May preserve most aquatic biota	♦ Usually creates extreme turbidity ♦ Sediment deposits in surrounding area ♦ Normally requires containment area to dry sediments prior to hauling ♦ Severe disruption of ecological function ♦ Lake uses impaired during dredging	♦
2.c) Hydraulic (or pneumatic) removal	♦ Lake level not reduced ♦ Suction or cutterhead dredges create slurry which is hydraulically pumped to containment area ♦ Slurry is dewatered; sediment retained, water discharged	♦ Creates minimal turbidity and limits impact on biota ♦ Can allow some lake uses during dredging ♦ Allows removal with limited access or shoreline disturbance	♦ Often leaves some sediment behind ♦ Cannot handle extremely coarse or debris-laden materials ♦ Requires advanced and more expensive containment area ♦ Requires overflow discharge from containment area	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
3) Dyes and surface covers	♦ Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting plant growth ♦ Dyes remain in solution until washed out of system. ♦ Opaque sheet material applied to water surface	♦ Light limit on plant growth without high turbidity or great depth ♦ May achieve some control of algae as well ♦ May achieve some selectivity for species tolerant of low light	♦ May not control peripheral or shallow water rooted plants ♦ May cause thermal stratification in shallow ponds ♦ May facilitate anoxia at sediment interface with water ♦ Covers inhibit gas exchange with atmosphere	♦
4) Mechanical removal ("harvesting")	♦ Plants reduced by mechanical means, possibly with disturbance of soils ♦ Collected plants may be composted otherwise disposed ♦ Wide range of techniques employed, from manual to highly mechanized ♦ Application once or twice per year usually needed	♦ Highly flexible control ♦ May remove other debris ♦ Can balance habitat and recreational needs	♦ Possible impacts on aquatic fauna ♦ Non-selective removal of plants in treated area ♦ Possible spread of undesirable species by fragmentation ♦ Possible generation of turbidity	♦
4.a) Hand pulling	♦ Plants uprooted by hand ("weeding") and preferably removed	♦ Highly selective technique	♦ Labor intensive ♦ Difficult to perform in dense stands	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
4.b) Cutting (without collection)	♦ Plants cut in place above roots without being harvested	♦ Generally efficient and less expensive than complete harvesting	♦ Leaves root systems and part of plant for re-growth ♦ Leaves cut vegetation to decay or to re-root ♦ Not selective within applied area	♦
4.c) Harvesting (with collection)	♦ Plants cut at depth of 2-10 feet and collected for removal from lake	♦ Allows plant removal on greater scale	♦ Limited depth of operation ♦ Usually leaves fragments which may re-root and spread infestation ♦ May impact lake fauna ♦ Not selective within applied area ♦ More expensive than cutting	♦
4.d) Rototilling	♦ Plants, root systems, and surrounding sediment disturbed with mechanical blades	♦ Can thoroughly disrupt entire plant	♦ Usually leaves fragments which may re-root and spread infestation ♦ May impact lake fauna ♦ Not selective within applied area ♦ Creates substantial turbidity ♦ More expensive than harvesting	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
4.e) Hydroraking	♦ Plants, root systems and surrounding sediment and debris disturbed with mechanical rake, part of material usually collected and removed from lake	♦ Can thoroughly disrupt entire plant ♦ Also allows removal of stumps or other obstructions	♦ Usually leaves fragments which may re-root and spread infestation ♦ May impact fauna ♦ Not selective within applied area ♦ Creates substantial turbidity ♦ More expensive than harvesting	♦
5) Water level control	♦ Lowering or raising the water level to lower suitability for aquatic plants ♦ Disrupts plant life cycle by drying/ freezing, or light limitation	♦ Requires only outlet control to affect large area ♦ Provides widespread control in increments of water depth ♦ Complements dredging and flushing	♦ Potential issues with water supply ♦ Potential issues with flooding ♦ Potential impacts to non-target flora and fauna	♦
5.a) Drawdown	♦ Lowering of water over winter period allows desiccation, freezing, and physical disruption of plants, roots and seed beds ♦ Timing and duration of exposure and degree of dewatering are critical aspects ♦ Variable species tolerance	♦ Control with some flexibility ♦ Opportunity for shoreline clean-up/structure repair ♦ Flood control utility ♦ Impacts vegetative propagation species with limited impact to seed producing populations	♦ Possible impacts on emergent wetlands ♦ Possible effects on overwintering vertebrates ♦ Reduction in potential supply ♦ Alteration of downstream flows ♦ Possible overwinter water level variation ♦ May result in greater nutrient availability for algae	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
5.b) Flooding	♦ Higher water level in the spring can inhibit seed germination and plant growth ♦ Higher flows which are normally associated with elevated water levels can flush seed and plant fragments from system	♦ Where water is available, this can be an inexpensive technique ♦ Plant growth need not be eliminated, merely retarded or delayed ♦ Timing of water level control can selectively favor certain desirable species	♦ Water for raising the level may not be available ♦ Potential peripheral flooding ♦ Possible downstream impacts ♦ Many species may not be affected, and some may be benefitted ♦ Algal nuisances may increase where nutrients are available	♦
Chemical controls				
6) Herbicides	♦ Liquid or pelletized herbicides applied to target area or to plants directly ♦ Contact or systemic poisons kill plants or limit growth ♦ Typically requires application every 1-5 yrs	♦ Wide range of control is possible ♦ May be able to selectively eliminate species ♦ May achieve some algae control as well	♦ Possible toxicity to non-target species ♦ Possible impacts downstream ♦ Restrictions of water use for varying time after treatment ♦ Increased oxygen demand from decaying vegetation ♦ Possible recycling of nutrients to allow other growths	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
6.a) Forms of copper	♦ Contact herbicide ♦ Cellular toxicant, suspected membrane transport disruption ♦ Applied as wide variety of liquid or granular formulations	♦ Moderately effective control of some submersed plant species ♦ More often an algal control agent	♦ Toxic to aquatic fauna as a function of concentration, formulation, and water chemistry ♦ Ineffective at colder temperatures ♦ Copper ion persistent; accumulates in sediments	♦
6.b) Forms of endothall (7-oxabicyclo [2.2.1] heptane-2,3-dicarboxylic acid)	♦ Contact herbicide with limited translocation potential ♦ Membrane-active chemical which inhibits protein synthesis ♦ Causes structural deterioration ♦ Applied as liquid or granules	♦ Moderate control of some emersed plant species, moderately to highly effective control of floating and submersed species ♦ Limited toxicity to fish at recommended dosages ♦ Rapid action	♦ Non-selective in treated area ♦ Toxic to aquatic fauna (varying degrees by formulation) ♦ Time delays on use for water supply, agriculture and recreation ♦ Safety hazards for applicators	♦
6.c) Forms of diquat (6,7-dihydropyrido [1,2-2',1'-c] pyrazinediium dibromide)	♦ Contact herbicide ♦ Absorbed by foliage but not roots ♦ Strong oxidant; disrupts most cellular functions ♦ Applied as a liquid, sometimes in conjunction with copper	♦ Moderate control of some emersed plant species, moderately to highly effective control of floating or submersed species ♦ Limited toxicity to fish at recommended dosages ♦ Rapid action	♦ Non-selective in treated area ♦ Toxic to zooplankton at recommended dosage ♦ Inactivated by suspended particles ♦ Time delays on use for water supply, agriculture and recreation	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
6.d) Forms of glyphosate (N-[phosphonomethyl glycine)	♦ Contact herbicide ♦ Absorbed through foliage, disrupts enzyme formation and function in uncertain manner ♦ Applied as liquid spray	♦ Moderately to highly effective control of emersed and floating plant species ♦ Can be used selectively, based on application to individual plants ♦ Rapid action ♦ Low toxicity to aquatic fauna at recommended dosages ♦ No time delays for use of treated water	♦ Non-selective in treated area ♦ Inactivation by suspended particles; ineffective in muddy waters ♦ Not for use within 0.5 miles of potable water intakes ♦ Highly corrosive; storage precautions necessary	♦
6.e) Forms of 2,4-D (2,4-dichlorophenoxyl acetic acid)	♦ Systemic herbicide ♦ Readily absorbed and translocated throughout plant ♦ Inhibits cell division in new tissue, stimulates growth in older tissue, resulting in gradual cell disruption ♦ Applied as liquid or granules, frequently as part of more complex formulations, preferably during early growth phase of plants	♦ Moderately to highly effective control of a variety of emersed, floating and submersed plants ♦ Can achieve some selectivity through application timing and concentration ♦ Fairly fast action	♦ Variable toxicity to aquatic fauna, depending upon formulation and ambient water chemistry ♦ Time delays for use of treated water for agriculture and recreation ♦ Not for use in water supplies	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
6.f) Forms of fluridone (1-methyl-3-phenyl-5-[-3-{trifluoromethyl} phenyl]-4[IH]-pyridinone)	♦ Systemic herbicide ♦ Inhibits carotenoid pigment synthesis and impacts photosynthesis ♦ Best applied as liquid or granules during early growth phase of plants	♦ Can be used selectively, based on concentration ♦ Gradual deterioration of affected plants limits impact on oxygen level (BOD) ♦ Effective against several difficult-to-control species ♦ Low toxicity to fauna	♦ Impacts on non-target plant species possible at higher doses ♦ Extremely soluble and mixable; difficult to perform partial lake treatments ♦ Requires extended contact time	♦
6.g Amine salt of triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid)	♦ Systemic herbicide ♦ Readily absorbed by foliage, translocated throughout plant ♦ Disrupts enzyme systems specific to plants ♦ Applied as liquid spray or subsurface injected liquid	♦ Effectively controls many floating and submersed plant species ♦ Selectively effective against dicot plant species, including many nuisance species ♦ Effective against several difficult-to-control species ♦ Low toxicity to fauna ♦ Fast action	♦ Impacts on non-target plant species possible at higher doses ♦ Current time delay of 30 days on consumption of fish from treated areas ♦ Necessary restrictions on use of treated water for supply or recreation not yet certain	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
Biological Controls				
7) Biological introductions	♦ Fish, insects or pathogens which feed on or parasitize plants are added to system to affect control ♦ Grass carp most commonly used, but the larvae of several insects have been used and viruses are being tested	♦ Provides potentially continuing control with one treatment ♦ Harnesses biological interactions to produce desired conditions ♦ May produce potentially useful fish biomass as an end product	♦ Typically involves introduction of non-native species ♦ Effects may not be controllable ♦ Plant selectivity may not match desired target species ♦ May adversely affect indigenous species	♦
7.a) Herbivorous fish	♦ Sterile juveniles stocked at density which allows control over multiple years ♦ Growth of individuals offsets losses or may increase herbivorous pressure	♦ May greatly reduce plant biomass in single season ♦ May provide multiple years of control from single stocking ♦ Sterility intended to prevent population perpetuation and allow later adjustments	♦ May eliminate all plant biomass, or impact non-target species ♦ Funnels energy into algae ♦ Alters habitat ♦ May escape lake ♦ Population control issues	♦

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO SANDWICH PONDS
7.b) Herbivorous insects	♦ Larvae or adults stocked at density intended to allow control with limited growth ♦ Intended to selectively control target species ♦ Milfoil weevil is best known, but still experimental	♦ Involves species native to region, or even targeted lake ♦ Expected to have no negative effect on non-target species ♦ May facilitate longer term control with limited management	♦ Incomplete control likely; oscillating cycle of control and re-growth expected ♦ Predation by fish may complicate control ♦ Other lake mgmt actions may interfere	♦
7.c) Fungal/bacterial/ viral pathogens	♦ Inoculum used to seed lake or target plant patch ♦ Growth of pathogen population expected to achieve control over target species	♦ May be highly species specific ♦ May provide substantial control after minimal inoculation effort	♦ Effectiveness and longevity of control not well known ♦ Infection ecology suggests incomplete control likely	♦
7.d) Selective plantings	♦ Establishment of plant assemblage resistant to undesirable species ♦ Plants introduced as seeds, cuttings or whole plants	♦ Can restore native assemblage ♦ Can encourage assemblage most suitable to lake uses ♦ Supplements targeted species removal effort	♦ Largely experimental ♦ May not prevent nuisance species from returning ♦ Introduced species may become nuisances	♦

Appendix B

WRIGHT-PIERCE

Engineering a Better Environment

University of Massachusetts Dartmouth
The School for Marine Science and Technology

Massachusetts Department of Environmental Protection

Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Three Bays System Barnstable, Massachusetts

Executive Summary

1. Background

This report presents the results generated from the implementation of the Massachusetts Estuaries Project's Linked Watershed-Embayment Approach to the Three Bays embayment system, a coastal embayment within the Town of Barnstable, Massachusetts. Analyses of the Three Bays embayment system was performed to assist the Town with up-coming nitrogen management decisions associated with the Towns' current and future wastewater planning efforts, as well as wetland restoration, anadromous fish runs, shell fishery, open-space, and harbor maintenance programs. As part of the MEP approach, habitat assessment was conducted on the embayment based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. Nitrogen loading thresholds for use as goals for watershed nitrogen management are the major product of the MEP effort. In this way, the MEP offers a science-based management approach to support the Town of Barnstable resource planning and decision-making process. The primary products of this effort are: (1) a current quantitative assessment of the nutrient related health of the Three Bays embayment, (2) identification of all nitrogen sources (and their respective N loads) to embayment waters, (3) nitrogen threshold levels for maintaining Massachusetts Water Quality Standards within embayment waters, (4) analysis of watershed nitrogen loading reduction to achieve the N threshold concentrations in embayment waters, and (5) a functional calibrated and validated Linked Watershed-Embayment modeling tool that can be readily used for evaluation of nitrogen management alternatives (to be developed by the Town) for the restoration of the Three Bays embayment system.

Wastewater Planning: As increasing numbers of people occupy coastal watersheds, the associated coastal waters receive increasing pollutant loads. Coastal embayments throughout the Commonwealth of Massachusetts (and along the U.S. eastern seaboard) are becoming nutrient enriched. The elevated nutrient levels are primarily related to the land use impacts associated with the increasing population within the coastal zone over the past half-century.

The regional effects of both nutrient loading and bacterial contamination span the spectrum from environmental to socio-economic impacts and have direct consequences to the culture, economy, and tax base of Massachusetts's coastal communities. The primary nutrient causing the increasing impairment of our coastal embayments is nitrogen, with its primary sources being wastewater disposal, and nonpoint source runoff that carries nitrogen (e.g. fertilizers) from a range of other sources. Nitrogen related water quality decline represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their shallow nature and large shoreline area, are generally the first coastal systems to show the effect of nutrient pollution from terrestrial sources.

In particular, the Three Bays embayment system within the Town of Barnstable is at risk of eutrophication (over enrichment) from enhanced nitrogen loads entering through groundwater from the increasingly developed watershed to this coastal system. Eutrophication is a process that occurs naturally and gradually over a period of tens or hundreds of years. However, human-related (anthropogenic) sources of nitrogen may be introduced into ecosystems at an accelerated rate that cannot be easily absorbed, resulting in a phenomenon known as cultural eutrophication. In both marine and freshwater systems, cultural eutrophication results in degraded water quality, adverse impacts to ecosystems, and limits on the use of water resources.

The Town of Barnstable has recognized the severity of the problem of eutrophication and the need for watershed nutrient management and is currently developing a Comprehensive Wastewater Management Plan, which it plans to rapidly implement. The Town of Barnstable has also completed and implemented wastewater planning in other regions of the Town not associated with the Three Bays embayment system. The Town has nutrient management activities related to their tidal embayments, which have been associated with the MEP effort in the Centerville River/Harbor and the Lewis Bay embayment systems. The Town of Barnstable and work groups have recognized that a rigorous scientific approach yielding site-specific nitrogen loading targets was required for decision-making and alternatives analysis. The completion of this multi-step process has taken place under the programmatic umbrella of the Massachusetts Estuaries Project, which is a partnership effort between all MEP collaborators and the Town. The modeling tools developed as part of this program provide the quantitative information necessary for the Towns' nutrient management groups to predict the impacts on water quality from a variety of proposed management scenarios.

Nitrogen Loading Thresholds and Watershed Nitrogen Management: Realizing the need for scientifically defensible management tools has resulted in a focus on determining the aquatic system's assimilative capacity for nitrogen. The highest-level approach is to directly link the watershed nitrogen inputs with embayment hydrodynamics to produce water quality results that can be validated by water quality monitoring programs. This approach when linked to state-of-the-art habitat assessments yields accurate determination of the "allowable N concentration increase" or "threshold nitrogen concentration". These determined nitrogen concentrations are then directly relatable to the watershed nitrogen loading, which also accounts for the spatial distribution of the nitrogen sources, not just the total load. As such, changes in nitrogen load from differing parts of the embayment watershed can be evaluated relative to the degree to which those load changes drive embayment water column nitrogen concentrations toward the "threshold" for the embayment system. To increase certainty, the "Linked" Model is independently calibrated and validated for each embayment.

Massachusetts Estuaries Project Approach: The Massachusetts Department of Environmental Protection (DEP), the University of Massachusetts – Dartmouth School of Marine Science and Technology (SMAST), and others including the Cape Cod Commission (CCC) have undertaken the task of providing a quantitative tool to communities throughout southeastern Massachusetts (the Linked Watershed-Embayment Management Model) for nutrient management in their coastal embayment systems. Ultimately, use of the Linked Watershed-Embayment Management Model tool by municipalities in the region results in effective screening of nitrogen reduction approaches and eventual restoration and protection of valuable coastal resources. The MEP provides technical guidance in support of policies on nitrogen loading to embayments, wastewater management decisions, and establishment of nitrogen Total Maximum Daily Loads (TMDLs). A TMDL represents the greatest amount of a pollutant that a waterbody can accept and still meet water quality standards for protecting public health and maintaining the designated beneficial uses of those waters for drinking, swimming, recreation and fishing. The MEP modeling approach assesses available options for meeting selected nitrogen goals that are protective of embayment health and achieve water quality standards.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach, which links watershed inputs with embayment circulation and nitrogen characteristics.

The Linked Model builds on well-accepted basic watershed nitrogen loading approaches such as those used in the Buzzards Bay Project, the CCC models, and other relevant models. However, the Linked Model differs from other nitrogen management models in that it:

- requires site-specific measurements within each watershed and embayment;
- uses realistic "best-estimates" of nitrogen loads from each land-use (as opposed to loads with built-in "safety factors" like Title 5 design loads);
- spatially distributes the watershed nitrogen loading to the embayment;
- accounts for nitrogen attenuation during transport to the embayment;
- includes a 2D or 3D embayment circulation model depending on embayment structure;
- accounts for basin structure, tidal variations, and dispersion within the embayment;
- includes nitrogen regenerated within the embayment;
- is validated by both independent hydrodynamic, nitrogen concentration, and ecological data;
- is calibrated and validated with field data prior to generation of "what if" scenarios.

The Linked Model Approach's greatest assets are its ability to be clearly calibrated and validated, and its utility as a management tool for testing "what if" scenarios for evaluating watershed nitrogen management options.

For a comprehensive description of the Linked Model, please refer to the *Full Report: Nitrogen Modeling to Support Watershed Management: Comparison of Approaches and Sensitivity Analysis*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm. A more basic discussion of the Linked Model is also provided in Appendix F of the *Massachusetts Estuaries Project Embayment Restoration Guidance for Implementation Strategies*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm. The Linked Model suggests which management solutions will adequately protect or restore embayment water quality by enabling towns to test specific management scenarios and weigh the resulting water quality impact against the cost of that approach. In addition to the management scenarios modeled for this report, the Linked Model can be used to evaluate additional management scenarios and may be

updated to reflect future changes in land-use within an embayment watershed or changing embayment characteristics. In addition, since the Model uses a holistic approach (the entire watershed, embayment and tidal source waters), it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries. Unlike many approaches, the Linked Model accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics and accommodates the spatial distribution of these processes. For an overview of several management scenarios that may be employed to restore embayment water quality, see *Massachusetts Estuaries Project Embayment Restoration Guidance for Implementation Strategies*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm.

Application of MEP Approach: The Linked Model was applied to the Three Bays embayment system by using site-specific data collected by the MEP and water quality data from the Water Quality Monitoring Program conducted by Three Bays Preservation in partnership with the Town of Barnstable, with technical guidance from the Coastal Systems Program at SMAST (see Chapter 2). Evaluation of upland nitrogen loading was conducted by the MEP, data was provided by the Town of Barnstable Planning Department, and watershed boundaries delineated by USGS. This land-use data was used to determine watershed nitrogen loads within the Three Bays embayment system and each of the systems sub-embayments as appropriate (current and build-out loads are summarized in Table IV-5). Water quality within a sub-embayment is the integration of nitrogen loads with the site-specific estuarine circulation. Therefore, water quality modeling of this tidally influenced estuary included a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Once the hydrodynamics of the system was quantified, transport of nitrogen was evaluated from tidal current information developed by the numerical models.

A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents and water elevations was employed for the Three Bays embayment system. Once the hydrodynamic properties of the estuarine system were computed, two-dimensional water quality model simulations were used to predict the dispersion of the nitrogen at current loading rates. Using standard dispersion relationships for estuarine systems of this type, the water quality model and the hydrodynamic model was then integrated in order to generate estimates regarding the spread of total nitrogen from the site-specific hydrodynamic properties. The distributions of nitrogen loads from watershed sources were determined from land-use analysis. Boundary nutrient concentrations in Vineyard Sound source waters were taken from water quality monitoring data. Measurements of current salinity distributions throughout the estuarine waters of the Three Bays embayment system was used to calibrate the water quality model, with validation using measured nitrogen concentrations (under existing loading conditions). The underlying hydrodynamic model was calibrated and validated independently using water elevations measured in time series throughout the embayments.

MEP Nitrogen Thresholds Analysis: The threshold nitrogen level for an embayment represents the average water column concentration of nitrogen that will support the habitat quality being sought. The water column nitrogen level is ultimately controlled by the watershed nitrogen load and the nitrogen concentration in the inflowing tidal waters (boundary condition). The water column nitrogen concentration is modified by the extent of sediment regeneration. Threshold nitrogen levels for the embayment systems in this study were developed to restore or maintain SA waters or high habitat quality. High habitat quality was defined as supportive of

eelgrass and infaunal communities. Dissolved oxygen and chlorophyll a were also considered in the assessment.

The nitrogen thresholds developed in Section VIII-2 were used to determine the amount of total nitrogen mass loading reduction required for restoration of eelgrass and infaunal habitats in the Rushy Marsh system. Tidally averaged total nitrogen thresholds derived in Section VIII.1 were used to adjust the calibrated constituent transport model developed in Section VI. Watershed nitrogen loads were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold level at the sentinel station chosen for the Three Bays system. It is important to note that load reductions can be produced by reduction of any or all sources or by increasing the natural attenuation of nitrogen within the freshwater systems to the embayment. The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the community. The presentation is to establish the general degree and spatial pattern of reduction that will be required for restoration of this nitrogen impaired embayment.

The Massachusetts Estuaries Project's thresholds analysis, as presented in this technical report, provides the site-specific nitrogen reduction guidelines for nitrogen management of the Three Bays embayment system in the Town of Barnstable. Future water quality modeling scenarios should be run which incorporate the spectrum of strategies that result in nitrogen loading reduction to the embayment. The MEP analysis has initially focused upon nitrogen loads from on-site septic systems as a test of the potential for achieving the level of total nitrogen reduction for restoration of each embayment system. The concept was that since septic system nitrogen loads generally represent 85% - 90% of the controllable watershed load to the Three Bays embayment system and are more manageable than other of the nitrogen sources, the ability to achieve needed reductions through this source is a good gauge of the feasibility for restoration of these systems.

2. Problem Assessment (Current Conditions)

A habitat assessment was conducted throughout The Three Bays system based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. At present, the Three Bays system is showing significantly impaired to severely degraded habitat quality in the Prince's Cove and Warren's Cove sub-embayments as well as the upper portion of North Bay. The lower portion of North Bay as well as Eel River are showing indications of moderate bordering on significant impairment while Cotuit Bay and West Bay are both showing signs of moderate impairment. All of the habitat indicators are consistent with this evaluation of the whole of system (Chapter VII).

The effect of nitrogen enrichment is to cause oxygen depletion; however, with increased phytoplankton (or epibenthic algae) production, oxygen levels will rise in daylight to above atmospheric equilibration levels in shallow systems (generally ~7-8 mg L^{-1} at the mooring sites). The clear evidence of oxygen levels above atmospheric equilibration indicates that the Three Bays system is eutrophic.

The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate highly nutrient enriched waters and impaired habitat quality within the estuary. The major sub-embayments to the Three Bays system (Cotuit Bay, West Bay, North Bay and Prince's Cove) are currently under seasonal oxygen stress, consistent with nitrogen enrichment (Chapter VII). That the cause is nitrogen enrichment is supported by

parallel observations of chlorophyll a (Table VII-2). Oxygen conditions and chlorophyll a levels generally improved with decreasing distance to the tidal inlet, although all basins showed oxygen depletions to <4 mg L^{-1}. There was also a clear gradient in chlorophyll a, with highest levels in the uppermost reaches and lowest levels near the tidal inlet to Nantucket Sound. The results of the summer oxygen and chlorophyll a studies are consistent with the absence of eelgrass throughout the Three Bays System and the near absence of animal communities throughout the upper basins where oxygen depletions routinely dropped below 3 mg/L.

Currently, there are no remaining eelgrass beds within the Three Bays System. However, it appears that all of the major sub-embayments had water quality conditions capable of supporting eelgrass (except in the deeper channels and basin depths) in 1951. However, eelgrass appears to have been restricted to the shallows (North and Cotuit Bays) or to Prince's Cove and West Bay basins. If the issue in 1951 was nitrogen enrichment, the pattern of the beds would have been very different, with more eelgrass in lower Cotuit Bay and West Bay and much less in Prince's Cove and North Bay (except in the very shallows). Instead, it is likely that disturbance related to activities in North and Cotuit Bays associated with training during WWII played a role in the North and Cotuit Bay pattern of beds in the 1951 assessment. Whatever the cause, it is clear that in the recent past, the Three Bays system was capable of supporting eelgrass within each of its major sub-embayments. It also appears that the recent losses (post 1951) are associated with nitrogen enrichment, as in virtually every other embayment in southeastern Massachusetts. The absence of eelgrass in each basin and the fact that they supported eelgrass in the recent past classifies each basins eelgrass habitat as "significantly impaired" (Table VIII-1).

The current absence of eelgrass in each of the major sub-embayments of the Three Bays System is consistent with the observed oxygen depletions in each basin and the high chlorophyll levels in the upper regions. The greater depths in the Three Bays Estuary also makes oxygen depletions more likely than in shallow basins with the same nitrogen levels. This results from the fact that deeper systems are more likely to periodically stratify. The central deep basins in North Bay and Prince's Cove are particularly sensitive to eelgrass loss as it takes less intense phytoplankton blooms to reduce light penetration to the bottom, and thereby prevent eelgrass growth. In addition, the basins are sensitive to periodic oxygen depletion. At this time, it is not clear if these regions have historically (100 years) supported eelgrass. However, eelgrass beds fringing these basins are well documented. As regards the lack of eelgrass within the lowermost portion of Cotuit Bay and the Seapuit River, it is likely associated with the documented highly dynamic coastal processes in this area. The level of natural disturbance in this region is very high (sand transport, overwash, etc). Physical stability is important to the ability of eelgrass beds to form and persist.

The Infauna Study indicated that most of the upper areas of the Three Bays system are presently significantly impaired to severely degraded by nitrogen enrichment (Prince's Cove, Warren's Cove and portions of North Bay), while the lower basins of Cotuit Bay and West Bay are moderately impaired (Table VII-4). Prince's Cove, Warren's Cove and 2 of 3 sites in North Bay are virtually devoid of infaunal animal communities. The central region of North Bay currently supports a transitional community dominated by amphipods, indicative of organic matter enrichment. In contrast, Cotuit and West Bays generally have ~500-2000 individuals per grab and 16-26 species. While there are stress indicator species (generally *Capitella* or *Streblospio*) in numbers at these locations there are also other species indicative of a healthy environment and overall high diversity. Overall, the pattern of infaunal community quality is consistent with the pattern of oxygen depletion and chlorophyll a during summer and the

absence of eelgrass. All sites showed some level of degradation, either in number of individuals, diversity or the presence of stress indicator species.

3. Conclusions of the Analysis

The threshold nitrogen level for an embayment represents the average watercolumn concentration of nitrogen that will support the habitat quality being sought. The watercolumn nitrogen level is ultimately controlled by the integration of the watershed nitrogen load, the nitrogen concentration in the inflowing tidal waters (boundary condition) and dilution and flushing via tidal flows. The water column nitrogen concentration is modified by the extent of sediment regeneration and by direct atmospheric deposition.

Threshold nitrogen levels for this embayment system were developed to restore or maintain SA waters or high habitat quality. In this system, high habitat quality was defined as possibly supportive of eelgrass and supportive of diverse benthic animal communities. Dissolved oxygen and chlorophyll *a* were also considered in the assessment.

Watershed nitrogen loads (Tables ES-1 and ES-2) for the Town of Barnstable Three Bays embayment system was comprised primarily of wastewater nitrogen. Land-use and wastewater analysis found that generally about 80% - 85% of the controllable watershed nitrogen load to the embayment was from wastewater.

A major finding of the MEP clearly indicates that a single total nitrogen threshold can not be applied to Massachusetts' estuaries, based upon the results of the Great, Green and Bournes Pond Systems, Popponesset Bay System, the Hamblin / Jehu Pond / Quashnet River analysis in eastern Waquoit Bay, the analysis of the adjacent Rushy Marsh system and the Pleasant Bay and Nantucket Sound embayments associated with the Town of Chatham. This is almost certainly going to be true for the other embayments within the MEP area, as well.

The threshold nitrogen levels for the Three Bays embayment system in Barnstable were determined as follows:

Three Bays Threshold Nitrogen Concentrations

- Following the MEP protocol, the restoration target for the Three Bays system should reflect both recent pre-degradation habitat quality and be reasonably achievable. Based upon the assessment data (Chapter VII), eelgrass bed restoration within Cotuit Bay and West Bay, with restoration of marginal beds in North Bay and Prince's Cove is supportable. In addition, in the central basins of North Bay and Prince's Cove, where eelgrass habitat has not been documented, as well as in Warren's Cove, restoration of infaunal habitat is necessary. Achieving these habitat quality targets will also result in mitigation of the present macroalgal accumulation problem in Warren's Cove. To achieve these habitat restoration targets, for the Three Bays system a single sentinel location was selected with secondary criteria that must be achieved at other locations. The secondary criteria serve only as checks to make sure that the targets are achieved when the nitrogen threshold at the sentinel station has been reached.
- The target nitrogen concentration for restoration of eelgrass in this system was determined to be 0.38 mg TN L^{-1} at the sentinel location and 0.40 mg TN L^{-1} within the marginal regions (shallows) of North Bay. This secondary level to check restoration of marginal beds in North Bay (O.40 mg TN L^{-1}) is consistent with the analysis of

restoration of fringing eelgrass beds in nearby Great Pond, and analysis where eelgrass beds in deep waters could not be supported at a tidally averaged TN of 0.412 mg TN L^{-1} at depths of 2 m. Similarly prior MEP analysis in Bournes Pond indicated that tidally averaged TN levels of 0.42 mg TN L^{-1} excluded beds from all but the shallowest water. The MEP Technical Team cannot specify the exact extent of marginal beds to be restored in the upper deep basins. At tidally averaged TN levels of 0.42 mg TN L^{-1} the eelgrass habitat would be restricted to very shallow waters, while at 0.40 mg TN L^{-1} the eelgrass habitat should reach to 1-2 meters depth, based upon the data from nearby systems. In addition, the persistence of eelgrass beds through 1995-2001 in the shallow waters of south Windmill Cove, but in a stable physical setting, were at nitrogen levels (tidally averaged TN ~0.40 mg L-1).

- Since infaunal animal habitat is also a critical resource to the Three Bays System, the secondary metric for a successful restoration (after eelgrass) will be to restore the significantly impaired/severely degraded habitats in the Prince's Cove/Warren's Cove and North Bay basins. In the upper more muddy basins of other nearby systems, healthy infaunal habitat is associated with nitrogen levels of TN <0.5 mg TN L^{-1}. This was found for Popponesset Bay where based upon the infaunal analysis coupled with the nitrogen data (measured and modeled), nitrogen levels on the order of 0.4 to 0.5 mg TN L-1 were found supportive of high infaunal habitat quality in this system. In the Three Bays System, present healthy infaunal areas are found at nitrogen levels of TN <0.42 mg TN L^{-1} (Cotuit Bay and West Bay) However, the impaired areas are at nitrogen levels of TN >0.5 mg TN L^{-1} (North Bay) and are severely degraded at nitrogen levels of TN >0.6 mg TN L^{-1}. This is consistent with the findings discussed above from other systems and fully supports a secondary nitrogen criteria for the upper muddy basins of 0.5 mg TN L^{-1}.

It is important to note that the analysis of future nitrogen loading to the Three Bays estuarine system focuses upon additional shifts in land-use from forest/grasslands to residential and commercial development. However, the MEP analysis indicates that significant increases in nitrogen loading can occur under present land-uses, due to shifts in occupancy, shifts from seasonal to year-round useage and increasing use of fertilizers (presently less than half of the parcels use lawn fertilizers). Therefore, watershed-estuarine nitrogen management must include management approaches to prevent increased nitrogen loading from both shifts in land-uses (new sources) and from loading increases of current land-uses. The overarching conclusion of the MEP analysis of the Three Bays estuarine system is that restoration will necessitate a reduction in the present (2004) nitrogen inputs and management options to negate additional future nitrogen inputs.

Table ES-1. Existing total and sub-embayment nitrogen loads to the estuarine waters of the Three Bays system, observed nitrogen concentrations, and sentinel system threshold nitrogen concentrations. Loads to estuarine waters of the Three Bays system include both upper watershed regions contributing to the major surface water inputs (Marstons Mills River and Little River).

Sub-embayments	Natural Background Watershed Load [1] (kg/day)	Present Land Use Load [2] (kg/day)	Present Septic System Load (kg/day)	Present WWTF Load [3] (kg/day)	Present Watershed Load [4] (kg/day)	Direct Atmospheric Deposition [5] (kg/day)	Present Net Benthic Flux (kg/day)	Present Total Load [6] (kg/day)	Observed TN Conc. [7] (mg/L)	Threshold TN Conc. (mg/L)
THREE BAYS SYSTEM										
Cotuit Bay [a]	2.447	5.515	20.225	--	25.740	5.786	-54.443	-22.917	0.39-0.44	--
West Bay	1.170	3.578	15.490	--	19.068	4.233	3.815	27.117	0.38-0.48	--
Seapuit River	0.452	0.847	2.921	0.016	3.767	0.452	-5.418	-1.199	0.32	--
North Bay	1.970	4.468	24.978	--	29.447	3.953	67.522	100.922	0.50-0.52	--
Prince's Cove [a]	3.964	10.337	24.836	0.092	35.173	1.230	0.512	36.914	0.60-0.70	--
Warren Cove	1.945	5.052	6.975	--	12.027	--	8.830	20.857	0.64	--
Prince's Cove Channel	0.515	0.770	4.767	--	5.537	--	2.345	7.882	0.64	--
Three Bays System Total	12.463	30.567	100.192	0.108	130.759	15.655	23.162	169.576	**0.32-0.70**	0.38

[1] assumes entire watershed is forested (i.e., no anthropogenic sources)
[2] composed of non-wastewater loads, e.g. fertilizer and runoff and natural surfaces and atmospheric deposition to lakes
[3] existing wastewater treatment facility discharges to groundwater
[4] composed of combined natural background, fertilizer, runoff, and septic system loadings
[5] atmospheric deposition to embayment surface only. Warren Cove and Prince's Cove Channel atmospheric loads are included with the Prince's Cove Load.
[6] composed of natural background, fertilizer, runoff, septic system atmospheric deposition and benthic flux loadings
[7] average of 1999 – 2004 data, ranges show the upper to lower regions (highest-lowest) of a sub-embayment.
[8] Eel grass threshold for sentinel site located at "The Narrows" between North Bay and Cotuit Bay (0.38 mg/L TN), and infaunal target for Prince's Cove of 0.50 mg/L TN.
[a] Include loads from surface water sources (i.e., Marstons Mills River to Prince's Cove and Little River to Cotuit Bay).

Table ES-2. Present Watershed Loads, Threshold Loads and the percent reductions necessary to achieve the Threshold Loads for the Three Bays system.

Sub-embayments	Present Watershed Load [1] (kg/day)	Target Threshold Watershed Load [2] (kg/day)	Direct Atmospheric Deposition (kg/day)	Benthic Flux Net [3] (kg/day)	Percent watershed reductions needed to achieve threshold load levels
THREE BAYS SYSTEM					
Cotuit Bay	25.740	22.335	5.786	-45.788	-13.2%
West Bay	19.068	15.970	4.233	3.469	-16.2%
Seapuit River	3.767	3.767	0.452	-5.371	0.0%
North Bay	29.447	4.468	3.953	45.202	-84.8%
Prince's Cove	35.173	17.890	1.230	0.323	-49.1%
Warren Cove	12.027	5.052	--	6.225	-58.0%
Prince's Cove Channel	5.537	0.770	--	1.541	-86.1%
Three Bays System Total	130.759	70.254	15.655	5.602	-46.3%

(1) Composed of combined natural background, fertilizer, runoff, and septic system loadings.
(2) Target Threshold Watershed Load is the load from the watershed needed to meet the embayment threshold concentration identified in Table ES-1.
(3) Projected future flux (present rates reduced approximately proportional to watershed load reductions).

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The regional effects of both nutrient loading and bacterial contamination span the spectrum from environmental to socio-economic impacts and have direct consequences to the culture, economy, and tax base of Massachusetts's coastal communities. The primary nutrient causing the increasing impairment of our coastal embayments is nitrogen, with its primary sources being wastewater disposal, and nonpoint source runoff that carries nitrogen (e.g. fertilizers) from a range of other sources. Nitrogen related water quality decline represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their shallow nature and large shoreline area, are generally the first coastal systems to show the effect of nutrient pollution from terrestrial sources.

In particular, the Popponesset Bay System within the Towns of Mashpee and Barnstable is at risk of eutrophication (over enrichment) from enhanced nitrogen loads entering through groundwater and surface water from its increasingly developed watersheds. Eutrophication is a process that occurs naturally and gradually over a period of tens or hundreds of years. However, human-related (anthropogenic) sources of nitrogen may be introduced into ecosystems at an accelerated rate that cannot be easily absorbed, resulting in a phenomenon known as cultural eutrophication. In both marine and freshwater systems, cultural eutrophication results in degraded water quality, adverse impacts to ecosystems, and limits on the use of water resources.

The Town of Mashpee has recognized the severity of the problem of eutrophication and the need for watershed nutrient management and is currently developing a Comprehensive Wastewater Management Plan, which it plans to rapidly implement. The Town of Barnstable has already completed and implemented wastewater planning in other regions of the Town not associated with Popponesset Bay. Both Towns have nutrient management activities related to their tidal embayments, which have been associated with the MEP effort in Popponesset Bay. These groups have recognized that a rigorous scientific approach yielding site-specific nitrogen loading targets was required for decision-making and alternatives analysis. The completion of this multi-step process has taken place under the programmatic umbrella of the Massachusetts Estuaries Project, which is a partnership effort between all MEP collaborators and the Towns. The modeling tools developed as part of this program provide the quantitative information necessary for the Towns' nutrient management groups to predict the impacts on water quality from a variety of proposed management scenarios.

Nitrogen Loading Thresholds and Watershed Nitrogen Management: Realizing the need for scientifically defensible management tools has resulted in a focus on determining the aquatic system's assimilative capacity for nitrogen. The highest-level approach is to directly link the watershed nitrogen inputs with embayment hydrodynamics to produce water quality results that can be validated by water quality monitoring programs. This approach when linked to state-of-the-art habitat assessments yields accurate determination of the "allowable N concentration increase" or "threshold nitrogen concentration". These determined nitrogen concentrations are then directly relatable to the watershed nitrogen loading, which also accounts for the spatial distribution of the nitrogen sources, not just the total load. As such, changes in nitrogen load from differing parts of the embayment watershed can be evaluated relative to the degree to which those load changes drive embayment water column nitrogen concentrations toward the "threshold" for the embayment system. To increase certainty, the "Linked" Model is independently calibrated and validated for each embayment.

Massachusetts Estuaries Project Approach: The Massachusetts Department of Environmental Protection (DEP), the University of Massachusetts – Dartmouth School of Marine Science and Technology (SMAST), and others including the Cape Cod Commission (CCC)

have undertaken the task of providing a quantitative tool to communities throughout southeastern Massachusetts (the Linked Watershed-Embayment Management Model) for nutrient management in their coastal embayment systems. Ultimately, use of the Linked Watershed-Embayment Management Model tool by municipalities in the region results in effective screening of nitrogen reduction approaches and eventual restoration and protection of valuable coastal resources. The MEP provides technical guidance in support of policies on nitrogen loading to embayments, wastewater management decisions, and establishment of nitrogen Total Maximum Daily Loads (TMDLs). A TMDL represents the greatest amount of a pollutant that a waterbody can accept and still meet water quality standards for protecting public health and maintaining the designated beneficial uses of those waters for drinking, swimming, recreation and fishing. The MEP modeling approach assesses available options for meeting selected nitrogen goals that are protective of embayment health and achieve water quality standards.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach, which links watershed inputs with embayment circulation and nitrogen characteristics.

The Linked Model builds on well-accepted basic watershed nitrogen loading approaches such as those used in the Buzzards Bay Project, the CCC models, and other relevant models. However, the Linked Model differs from other nitrogen management models in that it:

- requires site-specific measurements within each watershed and embayment;
- uses realistic "best-estimates" of nitrogen loads from each land-use (as opposed to loads with built-in "safety factors" like Title 5 design loads);
- spatially distributes the watershed nitrogen loading to the embayment;
- accounts for nitrogen attenuation during transport to the embayment;
- includes a 2D or 3D embayment circulation model depending on embayment structure;
- accounts for basin structure, tidal variations, and dispersion within the embayment;
- includes nitrogen regenerated within the embayment;
- is validated by both independent hydrodynamic, nitrogen concentration, and ecological data;
- is calibrated and validated with field data prior to generation of "what if" scenarios.

The Linked Model Approach's greatest assets are its ability to be clearly calibrated and validated, and its utility as a management tool for testing "what if" scenarios for evaluating watershed nitrogen management options.

For a comprehensive description of the Linked Model, please refer to the *Full Report: Nitrogen Modeling to Support Watershed Management: Comparison of Approaches and Sensitivity Analysis*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm. A more basic discussion of the Linked Model is also provided in Appendix F of the *Massachusetts Estuaries Project Embayment Restoration Guidance for Implementation Strategies*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm. The Linked Model suggests which management solutions will adequately protect or restore embayment water quality by enabling towns to test specific management scenarios and weigh the resulting water quality impact against the cost of that approach. In addition to the management scenarios modeled for this report, the Linked Model can be used to evaluate additional management scenarios and may be updated to reflect future changes in land-use with an embayment watershed or changing embayment characteristics. In addition, since the Model uses a holistic approach (the entire watershed, embayment and tidal source waters), it can be used to evaluate all projects as they

relate directly or indirectly to water quality conditions within its geographic boundaries. Unlike many approaches, the Linked Model accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics and accommodates the spatial distribution of these processes. For an overview of several management scenarios that may be employed to restore embayment water quality, see *Massachusetts Estuaries Project Embayment Restoration Guidance for Implementation Strategies*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm.

Application of MEP Approach: The Linked Model was applied to the Popponesset Bay embayment system using site-specific data collected by the MEP and water quality data from the Popponesset Bay Water Quality Monitoring Program (see Chapter 2). Evaluation of upland nitrogen loading was conducted by the MEP, data was provided by the Town of Mashpee Planning Department and Town of Barnstable, and watershed boundaries delineated by USGS. This land-use data was used to determine watershed nitrogen loads within Popponesset Bay and its sub-embayments (current and build-out loads are summarized in Table IV-3). Water quality within each sub-embayment is the integration of nitrogen loads with the site-specific estuarine circulation. Therefore, water quality modeling of these tidally influenced estuaries included a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Once the hydrodynamics of the system was quantified, transport of nitrogen was evaluated from tidal current information developed by the numerical models.

A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents and water elevations was employed for the Popponesset Bay embayment system. Once the hydrodynamic properties of the estuarine system was computed, two-dimensional water quality model simulations were used to predict the dispersion of the nitrogen at current loading rates. Using standard dispersion relationships for estuarine systems of this type, the water quality model and the hydrodynamic model was then integrated in order to generate estimates regarding the spread of total nitrogen from the site-specific hydrodynamic properties. The distributions of nitrogen loads from watershed sources were determined from land-use analysis while nitrogen entering Mashpee's coastal embayment was quantified by direct measurement of stream nutrient concentrations and freshwater flow, predominantly groundwater, in streams discharging directly to the embayment. Boundary nutrient concentrations in Nantucket Sound source waters were taken from water quality monitoring data. Measurements of current salinity distributions throughout the estuarine waters of Popponesset Bay were used to calibrate the water quality model, with validation using measured nitrogen concentrations (under existing loading conditions). The underlying hydrodynamic model was calibrated and validated independently using water elevations measured in time series throughout the embayment.

MEP Nitrogen Thresholds Analysis: The threshold nitrogen level for an embayment represents the average water column concentration of nitrogen that will support the habitat quality being sought. The water column nitrogen level is ultimately controlled by the watershed nitrogen load and the nitrogen concentration in the inflowing tidal waters (boundary condition). The water column nitrogen concentration is modified by the extent of sediment regeneration. Threshold nitrogen levels for the embayment systems in this study were developed to restore or maintain SA waters or high habitat quality. High habitat quality was defined as supportive of eelgrass and infaunal communities. Dissolved oxygen and chlorophyll a were also considered in the assessment.

The tidally averaged total nitrogen thresholds derived in Section VIII-2 of this report were used to adjust the calibrated constituent transport model developed in Section V of this report. Watershed nitrogen loads were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold levels in each sentinel system within the embayment of interest. Water quality modeling results help to analyze whether a nutrient reduction approach will be effective in meeting a nutrient threshold for a specific embayment. However, the approach for any specific embayment discussed in this report serves as only one manner of achieving the selected threshold level for the sentinel sub-embayment within the estuarine system. The specific examples presented herein do not represent the only method for achieving this goal. It is certain that a more targeted nitrogen reduction program that incorporates more localized wastewater treatment and use of natural attenuation processes will result in the most cost-effective plan for restoring the Popponesset Bay embayment.

The Massachusetts Estuaries Project's thresholds analysis, as presented in this technical report, provides the site-specific nitrogen reduction guidelines for nitrogen management of the Popponesset Bay embayment in the Towns of Mashpee and Barnstable. Future water quality modeling scenarios should be run which incorporate the spectrum of strategies that result in nitrogen loading reduction to the embayment. The MEP analysis has initially focused upon nitrogen loads from on-site septic systems as a test of the potential for achieving the level of total nitrogen reduction for restoration of each embayment system. The concept was that since septic system nitrogen loads generally represent 75%-80% of the watershed load to the Popponesset Bay System and are more manageable than other of the nitrogen sources, the ability to achieve needed reductions through this source is a good gauge of the feasibility for restoration of these systems.

2. Problem Assessment (Current Conditions)

Habitat assessments were conducted on each sub-embayment to Popponesset Bay based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. The Popponesset Bay System and its sub-embayments (Pinquickset Cove, Ockway Bay, Shoestring Bay, Mashpee River, Popponesset Bay central basin) showed variations in habitat quality, both between sub-embayments and along the longitudinal axis of the larger sub-embayments such as Shoestring Bay. In general, sub-embayments show declining habitat quality moving from the inlet to the inland-most tidal reach. This trend is seen in both the nitrogen levels (highest inland), eelgrass distribution, infaunal community stress indicators and community properties, as well as summer dissolved oxygen and chlorophyll a records. The following is a brief synopsis of the present habitat quality within each of the sub-embayments. The underlying quantitative data is presented on nitrogen (Section VI.1.3), oxygen and chlorophyll *a* (Section VII.2), eelgrass (Section VII.3), and benthic infauna (Section VII.4).

Combining the dissolved oxygen and chlorophyll a data yields a clear pattern of nutrient related habitat quality (based on these parameters only). At present, the central basin of Popponesset Bay supports relatively healthy habitat conditions, with consistently high bottom water dissolved oxygen and only modest phytoplankton blooms during summer. In contrast, the other regions of the System have moderate to high levels of nitrogen related impairment. Shoestring Bay shows both periodic oxygen declines and significant phytoplankton blooms, while Ockway Bay has similar oxygen declines, but apparently less phytoplankton biomass. Farther along the gradient in nutrient enrichment is the estuarine region of the Mashpee River, which has extreme oxygen excursions and night-time oxygen depletion on a consistent basis and significant phytoplankton blooms. The major issue with the Mashpee River is the extent to

which its structure as a salt marsh system ameliorates the impact of these water quality features. However, even as a salt marsh these levels of chlorophyll a and oxygen excursion indicate a moderate level of impairment. Based upon the dissolved oxygen and chlorophyll data the ranking of the Popponesset Bay System components is as follows:

- Popponesset Bay Central Basin -- high quality
- Popponesset Bay upper/confluence, Shoestring & Ockway Bays
  --significantly impaired
- Mashpee River
  -- significantly impaired to degraded (relative to embayments)
  -- moderately to significantly impaired (relative to salt marshes)

At present, the Popponesset Bay System does not support eelgrass. In addition, to the DEP mapping, this has been confirmed during the various MEP surveys for infauna and sediment sampling and the moored instrument studies. The current lack of eelgrass is expected, given the high chlorophyll a and low dissolved oxygen levels and the watercolumn nitrogen concentrations within this system. However, it appears that a substantial area of the central basin did support an extensive eelgrass bed in 1951. In addition, there were smaller beds within the upper region of the main basin, at the mouth to Shoestring Bay. The spatial distribution of these beds is consistent with the pattern of nitrogen related habitat quality, which is currently observed within the System. However, the 1951 nitrogen levels would have been much lower than present levels given the difference in projected watershed nitrogen loading from 1951 versus 2003 population. It appears that as the Bay became nutrient enriched, that the Popponesset Bay basin could no longer support eelgrass. However, it is likely that if nitrogen loading were to decrease that eelgrass could first be restored in the lower portion of the main basin and with further reductions, be restored to the 1951 pattern.

It is significant that eelgrass was not detected Shoestring Bay and Ockway Bay in the 1951 data. It appears that these sub-embayments are not supportive of this type of habitat. Given the structure of these sub-embayments and their sediment types, it appears that they are natural depositional basins and may not be conducive to supporting rooted macrophytes. The lack of eelgrass in the Mashpee River is consistent with its role as a salt marsh system, which drains completely at low tide in some regions and which is “naturally” organic rich. For these reasons, salt marshes typically do not support eelgrass beds within their main channels.

The Infauna Study indicated that all areas but the lower station within the central basin of Popponesset Bay are presently moderately to severely degraded (Table VII-5). Upper Ockway Bay was found to support the poorest infaunal communities within the System. This is based upon the very low number of species and individuals observed in the sediments of Ockway Bay. Although the 2 species that were found (compared to 31 in the central basin) were indicative of healthy conditions, the low numbers (20’s compared to 400-500 typically) indicated that this system is not presently supporting a viable community. The Mashpee River sites supported a higher quality habitat related to its function as a riverine salt marsh. The stress indicator species present were dominated by *Cyathura polita,* which is tolerant of the natural salinity stress that helps to define to this marsh system. However, the total numbers of individuals and diversity was low, indicative of a significantly impaired resource, even as a salt marsh. Shoestring Bay and the uppermost portion of the Popponesset Bay central basin both showed a resource between moderate and significant impairment. The numbers of individuals was generally high (500-600 per 0.018 m^2) representing a moderate number of species. Diversity was also moderate to high and distributed between indicators of healthy and stressed conditions (Table VII-6), again indicative of moderate impairment. In contrast the Lower Popponesset Bay station

supports a relatively healthy infaunal community, with nearly double the species of other sites and high numbers of individuals (~500 per 0.018 m^2). The high diversity (H') and general eveness (E) are consistent with a healthy community. The indication of moderate impairment stems from the presence of stress indicator species. The overall results indicate a system capable of supporting diverse healthy communities in the region nearest the tidal inlet with most of the system having infaunal habitat that is significantly impaired under present nitrogen loading conditions.

3. Conclusions of the Analysis

The threshold nitrogen level for an embayment represents the average watercolumn concentration of nitrogen that will support the habitat quality being sought. The watercolumn nitrogen level is ultimately controlled by the integration of the watershed nitrogen load, the nitrogen concentration in the inflowing tidal waters (boundary condition) and dilution and flushing via tidal flows. The water column nitrogen concentration is modified by the extent of sediment regeneration and by direct atmospheric deposition.

Threshold nitrogen levels for each of the sub-embayment systems in this study were developed to restore or maintain SA waters or high habitat quality. In these systems, high habitat quality was defined as supportive of eelgrass and diverse benthic benthos animal communities. Dissolved oxygen and chlorophyll *a* were also considered in the assessment.

Watershed nitrogen loads (Tables ES-1 and ES-2) for the Towns of Mashpee and Barnstable Popponesset Bay embayment system was comprised primarily of wastewater nitrogen. Land-use and wastewater analysis found that generally about 75%-80% of the watershed nitrogen load to an embayment was from wastewater.

A major finding of the MEP is clearly not a single total nitrogen threshold that can be applied to Massachusetts' estuaries, based upon the results of the Popponesset Bay System and the Pleasant Bay and Nantucket Sound embayments associated with the Town of Chatham. This is almost certainly going to be true for the other embayments within the MEP area, as well.

The threshold nitrogen levels for the Popponesset Bay embayment system was determined as follows:

- The target nitrogen concentration for restoration of eelgrass in this system was determined to be 0.38 mg TN L^{-1}. The value stems from (1) the analysis of Stage Harbor, Chatham which also exchanges tidal water with Nantucket Sound and for which a MEP target has already been set), (2) analysis of nitrogen levels within the vestigial eelgrass bed in adjacent Waquoit Bay, near the inlet (measured TN of 0.395 mg N L^{-1}, tidally corrected <0.38 mg N L^{-1}), and (3) a similar analysis in West Falmouth Harbor. Threshold values relating to eelgrass restoration was based upon these other Cape Cod systems with similar nitrogen dynamics, since there are presently no remaining eelgrass beds within Popponesset Bay (or even adjacent Three Bays).

- The sentinel station was located within the upper region of the central basin to Popponesset Bay and the mouth of Shoestring Bay, at the uppermost eelgrass bed detected in the 1951 data. Under present loading conditions the sentinel station supports a measured nitrogen level at mid-ebb tide of 0.581 mg TN L^{-1} and a tidally corrected average concentration of 0.451 mg TN L^{-1}. This location was selected as a

sentinel station because: (1) it was the upper extent of the eelgrass coverage in 1951, (2) restoration of nitrogen conditions supportive of eelgrass at this location will necessarily result in even higher quality conditions throughout the whole of the central basin, and (3) restoration of nitrogen concentrations at this site should result in conditions similar to 1951 within Shoestring and Ockway Bays. Shoestring Bay and Ockway Bay should then be supportive of high quality habitat for benthic infaunal communities

- Based upon sequential reductions in watershed nitrogen loading in the analysis described in the Section VIII-3, the sentinel station achieved an average TN level of 0.371 mg L^{-1} , the mouth of Ockway Bay, 0.376 mg TN L^{-1} and the whole of the Popponesset Bay basin <0.331 mg TN L^{-1}.

The data suggest that there is likely a range of total nitrogen which can support healthy infauna within this system. Since Shoestring and Ockway Bays did not support eelgrass in the 1951 data, evaluation was based upon benthic animal habitat.

- Based upon current conditions, the infaunal analysis (Chapter VII) coupled with the nitrogen data (measured and modeled), indicated that nitrogen levels on the order of 0.4 to 0.5 mg TN L-1 are supportive of high quality infauna habitat within the Popponesset Bay System.

- The results of the Linked Watershed-Embayment modeling indicated that when the nitrogen threshold level is attained at the sentinel station (Section VIII-3), TN levels in Shoestring and Ockway Bays are consistent with high quality infauna habitat; upper to lower Shoestring Bay, 0.522 to 0.412 mg TN L^{-1}; upper Ockway Bay, 0.421 mg TN L^{-1}; and mid to lower Mashpee River, 0.525 to 0.422 mg TN L^{-1}.

- It appears that achieving the nitrogen target at the sentinel station will be restorative of eelgrass habitat throughout the Popponesset Bay central basin and restorative of infaunal habitat throughout Shoestring and Ockway Bays and the lower portion of the Mashpee River.

It is important to note that the analysis of future nitrogen loading to the Popponesset Bay Estuarine system focuses upon additional shifts in land-use from forest/grasslands to residential and commercial development. However, the MEP analysis indicates that significant increases in nitrogen loading can occur under present land-uses, due to shifts in occupancy, shifts from seasonal to year-round useage and increasing use of fertilizers (presently less than half of the parcels use lawn fertilizers). Therefore, watershed-estuarine nitrogen management must include management approaches to prevent increased nitrogen loading from both shifts in land-uses (new sources) and from loading increases of current land-uses. The overarching conclusion of the MEP analysis of the Popponesset Bay Estuarine System is that restoration will necessitate a reduction in the present (2002) nitrogen inputs and management options to negate additional future nitrogen inputs.

Table ES-1. Existing total and sub-embayment nitrogen loads to the estuarine waters of the Popponesset Bay System, observed nitrogen concentrations, and sentinel system threshold nitrogen concentrations. Loads to estuarine waters of Mashpee River and Shoestring Bay include both upper watershed regions contributing to the major rivers (Mashpee River, Santuit River, Quaker Run)and groundwater dominated lower regions.

Sub-embayments	Natural (unaltered) Watershed Load [1] (kg/day)	Present Land Use Load [2] (kg/day)	Present Septic System Load (kg/day)	Present WWTF Load [3] (kg/day)	Present Watershed Load [4] (kg/day)	Present Atmospheric Deposition [5] (kg/day)	Present Benthic Flux (kg/day)	**Present Total Load [6]** (kg/day)	Observed TN Conc. [7] (mg/L)	Threshold TN Conc. (mg/L)
POPPONESSET BAY SYSTEM										
Mashpee River [a]	5.30	8.01	19.51	0.15	27.67	0.66	11.47	39.80	0.958-0.627	--
Shoestring Bay [a]	1.85	7.54	23.00	0.23	30.77	2.23	-11.85	21.15	0.690-0.520	--
Ockway Bay	0.24	0.76	2.39	0	3.15	1.09	1.78	6.02	0.677-0.536	--
Pinquicket Cove	0.11	0.19	0.58	0	0.76	0.29	-0.33	0.72	0.527	--
Popponesset Bay	0.18	1.19	5.57	0	6.76	4.01	-5.04	5.73	0.485-0.422	--
System Total	7.68	17.68	51.05	0.38	69.11	8.28	-3.97	73.42	--	0.380[8]

[1] assumes entire watershed is forested (i.e., no anthropogenic sources)
[2] composed of non-wastewater loads, e.g. fertilizer, runoff, present-day natural surfaces and atmospheric deposition to lakes
[3] existing wastewater treatment facility discharges to groundwater
[4] composed of combined present-day natural surfaces, fertilizer, runoff, and septic system loadings
[5] atmospheric deposition to embayment surface only
[6] composed of natural background, fertilizer, runoff, septic system atmospheric deposition and benthic flux loadings
[7] average of 1997 – 2003 data, ranges show the upper to lower regions (highest-lowest) of an sub-embayment. Individual yearly means and standard deviations in Table
[8] Threshold for sentinel site located at the upper portion of Popponesset Bay and Mouth of Shoestring Bay (PBh), infaunal "targets" for Shoestring and Ockway Bays in the range of 0.400 – 0.500 were used to "check" the validity of the sentinel threshold value.
[a] Loads to Shoestring Bay and Mashpee River include loads from rivers.

Table ES-2. Present Watershed Loads, Thresholds Loads, and the percent reductions necessary to achieve the Thresholds Loads for the Popponesset Bay embayment system, Towns of Mashpee and Barnstable, Massachusetts.

Embayment Systems and Sub-Embayments	Present Watershed Load (1) (kg/day)	Target Threshold Watershed Load (2) (kg/day)	Atmospheric Deposition (kg/day)	Benthic Flux (3) (kg/day)	TMDL (4) (kg/day)	Percent watershed load reductions needed to achieve threshold loads
Popponesset Bay System						
Mashpee River	27.67	13.95	0.66	9.47	24.08	-49.5%
Shoestring Bay	30.77	19.71	2.23	-8.73	13.21	-35.9%
Ockway Bay	3.15	0.76	1.09	1.11	2.96	-75.9%
Pinquickset Cove	0.76	0.76	0.29	-0.33	0.72	0.0%
Popponesset Bay	6.76	2.77	4.01	-4.91	1.87	-59.0%

(1) Composed of combined present-day natural surfaces, fertilizer, runoff, and septic system

(2) Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentration identified in Table ES-1.

(3) Projected future flux (present rates reduced approximately proportional to watershed load reductions).

(4) Sum of target threshold watershed load, atmospheric deposition load, and benthic flux load.

University of Massachusetts Dartmouth
The School for Marine Science and Technology

Massachusetts Department of Environmental Protection

Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Quashnet River, Hamblin Pond, and Jehu Pond, in the Waquoit Bay System of the Town of Mashpee, Massachusetts

Executive Summary

1. Background

This report presents the results generated from the implementation of the Massachusetts Estuaries Project's Linked Watershed-Embayment Approach to the Quashnet River, Hamblin Pond, and Jehu Pond sub-embayments to the larger Waquoit Bay System. These three sub-systems to Waquoit Bay are coastal embayments within the Town of Mashpee, Massachusetts. Analyses of the Quashnet River, Hamblin Pond, and Jehu Pond Systems was performed to assist the Town of Mashpee with up-coming nitrogen management decisions associated with the Town's current and future wastewater planning efforts, as well as wetland restoration, anadromous fish runs, shell fishery, open-space, and harbor maintenance programs. As part of the MEP approach, habitat assessments were conducted on the embayments based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. Nitrogen loading thresholds for use as goals for watershed nitrogen management are the major product of the MEP effort. In this way, the MEP offers a science-based management approach to support the Town of Mashpee resource planning and decision-making process. The primary products of this effort are: (1) a current quantitative assessment of the nutrient related health of the Quashnet River, Hamblin Pond, and Jehu Pond systems, (2) identification of all nitrogen sources (and their respective N loads) to embayment waters, (3) nitrogen threshold levels for maintaining Massachusetts Water Quality Standards within embayment waters, (4) analysis of watershed nitrogen loading reduction to achieve the N threshold concentrations in embayment waters, and (5) a functional calibrated and validated Linked Watershed-Embayment modeling tool that can be readily used for evaluation of nitrogen management alternatives (to be developed by the Towns) for the restoration of the Quashnet River, Hamblin Pond, and Jehu Pond systems.

Wastewater Planning: As increasing numbers of people occupy coastal watersheds, the associated coastal waters receive increasing pollutant loads. Coastal embayments throughout

the Commonwealth of Massachusetts (and along the U.S. eastern seaboard) are becoming nutrient enriched. The elevated nutrients levels are primarily related to the land use impacts associated with the increasing population within the coastal zone over the past half-century.

The regional effects of both nutrient loading and bacterial contamination span the spectrum from environmental to socio-economic impacts and have direct consequences to the culture, economy, and tax base of Massachusetts's coastal communities. The primary nutrient causing the increasing impairment of our coastal embayments is nitrogen, with its primary sources being associated with wastewater disposal, with various other widely distributed non-point sources (e.g. fertilizers, runoff, atmospheric deposition) playing a lesser role. Nitrogen related water quality decline represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their shallow nature and large shoreline area, are generally the first coastal systems to show the effect of nutrient pollution from terrestrial sources.

In particular, the Quashnet River, Hamblin Pond, and Jehu Pond systems within the Town of Mashpee are at risk of eutrophication (over enrichment) from enhanced nitrogen loads entering through groundwater and surface water from the increasingly developed watersheds. Eutrophication is a process that occurs naturally and gradually over a period of tens or hundreds of years. However, human-related (anthropogenic) sources of nitrogen may be introduced into ecosystems at an accelerated rate that cannot be easily absorbed, resulting in a phenomenon known as cultural eutrophication. In both marine and freshwater systems, cultural eutrophication results in degraded water quality, adverse impacts to ecosystems, and limits on the use of water resources.

The Town of Mashpee has recognized the severity of the problem of eutrophication and the need for watershed nutrient management and are currently developing Comprehensive Wastewater Management Plans, which they plan to rapidly implement. Both the Towns of Mashpee and Falmouth share the waters of the Waquoit Bay System and have nutrient management activities related to their tidal embayments. While the Town of Mashpee has focused primarily on the MEP effort in the Quashnet River, Hamblin Pond, and Jehu Pond systems, restoration of the Waquoit System will depend upon the efforts of both municipalities working in a coordinated fashion. These groups have recognized that a rigorous scientific approach yielding site-specific nitrogen loading targets was required for decision-making and alternatives analysis. At present, both municipalities are focused on nitrogen management to restore their embayments, with nitrogen thresholds being determined under the programmatic umbrella of the Massachusetts Estuaries Project, which is a partnership effort between all MEP collaborators and the Towns. The modeling tools developed as part of the MEP provide the quantitative information necessary for the Towns' nutrient management groups to predict the impacts on water quality from a variety of proposed management scenarios.

Nitrogen Loading Thresholds and Watershed Nitrogen Management: Realizing the need for scientifically defensible management tools has resulted in a focus on determining the aquatic system's assimilative capacity for nitrogen. The highest-level approach is to directly link the watershed nitrogen inputs with embayment hydrodynamics to produce water quality results that can be validated by water quality monitoring programs. This approach when linked to state-of-the-art habitat assessments yields accurate determination of the "allowable N concentration increase" or "threshold nitrogen concentration". These determined nitrogen concentrations are then directly relatable to the watershed nitrogen loading, which also accounts for the spatial distribution of the nitrogen sources, not just the total load. As such, changes in nitrogen load from differing parts of the embayment watershed can be evaluated relative to the degree to

which those load changes drive embayment water column nitrogen concentrations toward the "threshold" for the embayment system. To increase certainty, the "Linked" Model is independently calibrated and validated for each embayment.

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The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach, which links watershed inputs with embayment circulation and nitrogen characteristics.

The Linked Model builds on well-accepted basic watershed nitrogen loading approaches such as those used in the Buzzards Bay Project, the CCC models, and other relevant models. However, the Linked Model differs from other nitrogen management models in that it:

- requires site-specific measurements within each watershed and embayment;
- uses realistic "best-estimates" of nitrogen loads from each land-use (as opposed to loads with built-in "safety factors" like Title 5 design loads);
- spatially distributes the watershed nitrogen loading to the embayment;
- accounts for nitrogen attenuation during transport to the embayment;
- includes a 2D or 3D embayment circulation model depending on embayment structure;
- accounts for basin structure, tidal variations, and dispersion within the embayment;
- includes nitrogen regenerated within the embayment;
- is validated by both independent hydrodynamic, nitrogen concentration, and ecological data;
- is calibrated and validated with field data prior to generation of "what if" scenarios.

The Linked Model Approach's greatest assets are its ability to be clearly calibrated and validated, and its utility as a management tool for testing "what if" scenarios for evaluating watershed nitrogen management options.

For a comprehensive description of the Linked Model, please refer to the *Full Report: Nitrogen Modeling to Support Watershed Management: Comparison of Approaches and Sensitivity Analysis*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm. A more basic discussion of the Linked Model is also provided in Appendix F of the *Massachusetts Estuaries Project Embayment Restoration Guidance for Implementation Strategies*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm. The Linked Model suggests which

management solutions will adequately protect or restore embayment water quality by enabling towns to test specific management scenarios and weigh the resulting water quality impact against the cost of that approach. In addition to the management scenarios modeled for this report, the Linked Model can be used to evaluate additional management scenarios and may be updated to reflect future changes in land-use with an embayment watershed or changing embayment characteristics. In addition, since the Model uses a holistic approach (the entire watershed, embayment and tidal source waters), it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries. Unlike many approaches, the Linked Model accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics and accommodates the spatial distribution of these processes. For an overview of several management scenarios that may be employed to restore embayment water quality, see *Massachusetts Estuaries Project Embayment Restoration Guidance for Implementation Strategies*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm.

Application of MEP Approach: The Linked Model was applied to the Quashnet River, Hamblin Pond, and Jehu Pond embayment systems using site-specific data collected by the MEP and water quality data from the Mashpee Nutrient Monitoring Program, which continued to collect data through summer 2004, since it is the only source of nitrogen baseline data for the whole of the Waquoit Bay System (see Chapter 2). The Town of Mashpee is currently conducting planning for the watersheds of the eastern three sub-embayments and for the adjacent Popponesset Bay System. As part of this effort, the Town of Mashpee supported MEP data collection efforts and also supported the collection of the only nitrogen related water quality data available for these sub-embayments (and for the main Bay). Evaluation of upland nitrogen loading was conducted by the MEP, data was provided by the Town of Mashpee Planning Department and watershed boundaries delineated by USGS, as part of the MEP. This land-use data was used to determine watershed nitrogen loads within the Quashnet River, Hamblin Pond, and Jehu Pond sub-embayment systems to Waquoit Bay (current and build-out loads are summarized in Table IV-3). Water quality within each sub-embayment is the integration of nitrogen loads with the site-specific estuarine circulation. Therefore, water quality modeling of these tidally influenced estuaries included a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Once the hydrodynamics of the system was quantified, transport of nitrogen was evaluated from tidal current information developed by the numerical models.

A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents and water elevations was employed for the Quashnet River, Hamblin Pond, and Jehu Pond embayment systems. Once the hydrodynamic properties of the estuarine systems were computed, two-dimensional water quality model simulations were used to predict the dispersion of the nitrogen at current loading rates. Using standard dispersion relationships for estuarine systems of this type, the water quality model and the hydrodynamic model were then integrated in order to generate estimates regarding the spread of total nitrogen from the site-specific hydrodynamic properties. The distributions of nitrogen loads from watershed sources were determined from land-use analysis, while nitrogen entering Mashpee's coastal embayments was quantified by direct measurement of stream nutrient concentrations and freshwater flow in streams discharging directly to the embayment. These streams are predominantly groundwater fed. Boundary nutrient concentrations in Nantucket Sound source waters were taken from water quality monitoring data. Measurements of current salinity distributions throughout the estuarine waters of the Quashnet River, Hamblin Pond, and Jehu Pond embayment systems were used to calibrate the water quality model, with validation using measured nitrogen

concentrations (under existing loading conditions). The underlying hydrodynamic model was calibrated and validated independently using water elevations measured in time series throughout the embayment.

MEP Nitrogen Thresholds Analysis: The threshold nitrogen level for an embayment represents the tidally averaged water column concentration of nitrogen that will support the habitat quality being sought. The water column nitrogen level is ultimately controlled by the watershed nitrogen load and the nitrogen concentration in the inflowing tidal waters (boundary condition). The water column nitrogen concentration is modified by the extent of sediment regeneration. Threshold nitrogen levels for the embayment systems in this study were developed to restore or maintain SA waters or high habitat quality. High habitat quality was defined as supportive of eelgrass and infaunal communities. Dissolved oxygen and chlorophyll a were also considered in the assessment.

The tidally averaged total nitrogen thresholds derived in Section VIII-2 of this report were used to adjust the calibrated constituent transport model developed in Section V of this report. Watershed nitrogen loads were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold levels in each sentinel system within the embayment of interest. Water quality modeling results help to analyze whether a nutrient reduction approach will be effective in meeting a nutrient threshold for a specific embayment. However, the approach for any specific embayment discussed in this report serves as only one manner of achieving the selected threshold level for the sentinel sub-embayment within the estuarine system. This results, in part, from the differential response to a nitrogen load depending upon where it enters the estuarine system (e.g. near the inlet versus the headwaters). Therefore, the specific examples presented herein do not represent the only method for achieving nitrogen reductions to meet threshold levels. However, it is certain that a more targeted nitrogen reduction program that incorporates more localized wastewater treatment and use of natural attenuation processes will result in the most cost-effective plan for restoring the Quashnet River, Hamblin Pond, and Jehu Pond embayment systems.

The Massachusetts Estuaries Project's thresholds analysis, as presented in this technical report, provides the site-specific nitrogen reduction guidelines for nitrogen management of the Quashnet River, Hamblin Pond, and Jehu Pond embayment systems in the Town of Mashpee. Future water quality modeling scenarios should be run which incorporate the spectrum of strategies that result in nitrogen loading reduction to the embayment. The MEP analysis has initially focused upon nitrogen loads from on-site septic systems as a test of the potential for achieving the level of total nitrogen reduction for restoration of each embayment system. The concept was that since septic system nitrogen loads generally represent 72% of the controllable watershed load to Eastern Waquoit Bay (Quashnet River, Hamblin Pond, and Jehu Pond embayment systems) and are more manageable than other of the nitrogen sources, the ability to achieve needed reductions through this source is a good gauge of the feasibility for restoration of these systems.

2. Problem Assessment (Current Conditions)

Habitat assessments were conducted on each sub-embayment to East Waquoit Bay based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. The Quashnet River, Hamblin Pond, and Jehu Pond embayment systems showed variations in habitat quality, both between embayments and along the longitudinal axis of the systems such as Great River to Jehu Pond and Little River to Hamblin Pond. In general, embayments show

declining habitat quality, moving from the inlet to the inland-most tidal reach. This trend is seen in both the nitrogen levels (highest inland), eelgrass distribution, infaunal community stress indicators and community properties, as well as summer dissolved oxygen and chlorophyll a records. The following is a brief synopsis of the present habitat quality within each of the embayments. The underlying quantitative data is presented on nitrogen (Section VI.1.3), oxygen and chlorophyll *a* (Section VII.2), eelgrass (Section VII.3), and benthic infauna (Section VII.4).

Combining the dissolved oxygen and chlorophyll a data yield a clear pattern of nutrient related habitat quality. A further analysis incorporating eelgrass and infaunal indicators is included in Section VII. At present, the Quashnet River Estuary is showing poor oxygen status (based upon depletions, daily excursions, mooring in lower basin) and large phytoplankton blooms. While this system appears to be stressed throughout, there is a clear gradient from hypereutrophic in the upper regions to eutrophic in the lower basin. Jehu Pond is also showing nitrogen enriched conditions, with periodic hypoxia/anoxia in the basin and high phytoplankton biomass. Hamblin Pond is showing the best nutrient related habitat quality, based both upon its moderately good oxygen conditions and moderate phytoplankton biomass. Based upon the dissolved oxygen and chlorophyll data the nutrient related habitat quality of the three estuarine sub-embayments to eastern Waquoit Bay can be classified is as follows:

- Quashnet River estuary – Significantly Impaired
- Jehu Pond – Moderately/Significantly Impaired
- Hamblin Pond – Moderately Impaired

At present, eelgrass is not present within the Quashnet River Estuary, nor was there evidence of eelgrass beds in 1951. This is consistent with observations in the 1960's of nutrient enriched conditions and macroalgae within this sub-embayment (Curley et al. 1971). In contrast, Hamblin Pond/Little River and Jehu Pond/Great River were almost completely colonized by eelgrass in the period 1951-1987 (Figures VII-7 and VII-8). The data suggest that during the 1980's eelgrass in these tributary embayments to Waquoit Bay began to significantly decline in coverage. The decline continued and by 2001 only 5%-10% of the beds remained (Table VII-4). More recent observations indicate that the residual beds are still declining in area, with only marginal areas remaining. In addition, to the on-going DEP mapping, the more recent bed loss (since 2001) has been confirmed by the multiple MEP staff conducting sampling and the mooring studies. It appears that as these systems became nutrient enriched, that they could no longer support eelgrass beds. The proximate cause of loss is most likely related to nutrient related shifts in habitat quality, most significantly the high chlorophyll a (turbidity/shading) and low dissolved oxygen levels. However, it is likely that if nitrogen loading were to decrease, eelgrass could be restored in these basins to the 1951 pattern. This is supported by the fact that small areas still remain and that the decline from "full" coverage has been recent.

It is significant that eelgrass was not detected in the Quashnet River Estuary in the 1951 data. The upper reaches of this estuary are highly altered, but the lower basin with direct communication to the Bay also did not support beds. Part of the reason, as suggested above, may be related to higher historical nitrogen loading to this estuary, but other causes such as tidal restriction cannot be evaluated at this time. Overall the mapping data indicate that nitrogen management of the Hamblin Pond and Jehu Pond estuaries should target eelgrass restoration. Based upon the 1951-1987 coverage data, it appears that on the order of 200 acres of eelgrass

might be potentially recoverable in these estuarine sub-embayments, if nitrogen management alternatives were implemented (Table VII-4).

Based on analysis of infauna in each of the three sub-embayments to Eastern Waquoit Bay, clearly the Quashnet River Estuary is significantly impaired with only a single species being found (e.g. diversity = 0). The severely degraded nature of this habitat is underscored by the virtual absence of an infaunal community with only 18, 4, and 0 individuals being found at the three sites, compared to 100's to 1000's being found at healthy sites. The Jehu Pond and Hamblin Pond systems showed infaunal community habitats ranging from healthy to significantly impaired. There appears to be a gradient in habitat quality within the Jehu Pond/Great River Estuary. The basin of Jehu Pond supported a low number of species (4-6) and total individuals <150 at two of three stations and low diversity at all stations (<1.8). However, the Great River showed markedly better habitat, with 9-10 species and >1000 individuals per sample at each station, and slightly higher diversity. Hamblin Pond/Little River showed a similar pattern, although with much better habitat quality. Only the mid basin of Hamblin Pond was significantly impaired with all of the other stations showing 10-19 species and 500-3200 individuals per sample. Diversity was also high, generally $\geq$2.4. Most likely deposition within the mid basin of Hamblin Pond and subsequent organic matter loading effects are responsible for the observations at this station. However, the other areas of this system appear to support healthy benthic animal habitat (Lower Hamblin Pond and Little River) or habitat that is only moderately impaired (Upper Hamblin Pond).

3. Conclusions of the Analysis

The threshold nitrogen level for an embayment represents the upper limit of water-column concentration of nitrogen (tidally averaged) that will support the habitat quality being sought. The watercolumn nitrogen level is ultimately controlled by the integration of the watershed nitrogen load, the nitrogen concentration in the inflowing tidal waters (boundary condition) and dilution and flushing via tidal flows. The water column nitrogen concentration is modified by the extent of sediment regeneration and by direct atmospheric deposition.

Threshold nitrogen levels for each of the sub-embayment systems in this study were developed to restore or maintain SA waters or high habitat quality. In these systems, high habitat quality was defined as supportive of eelgrass and diverse benthic animal communities. Dissolved oxygen and chlorophyll *a* were also considered in the assessment.

Watershed nitrogen loads (Tables ES-1 and ES-2) for the Town of Mashpee Quashnet River, Hamblin Pond, and Jehu Pond embayment systems was comprised primarily of wastewater nitrogen. Land-use and wastewater analysis found that overall 72% of the controllable watershed nitrogen load to an embayment was from wastewater associated with on-site septic systems.

A major finding of the MEP is clearly that a single total nitrogen threshold can not be applied to Massachusetts' estuaries, based upon the results of the Popponesset Bay System and the Pleasant Bay and Nantucket Sound embayments associated with the Town of Chatham. This is almost certainly going to be true for the other embayments within the MEP area, as well.

The approach for determining nitrogen loading rates, which will maintain acceptable habitat quality throughout and embayment system, is to first identify a sentinel location within the embayment and second, to determine the nitrogen concentration within the water column

which will restore that location to the desired habitat quality. The sentinel location is selected such that its restoration will necessarily produce the high quality habitat throughout the embayment system, to meet historical levels and water quality standards. The sentinel locations and associated threshold nitrogen levels for the Quashnet River, Hamblin Pond, and Jehu Pond embayment systems were determined as follows:

- The sentinel system within the Quashnet River Estuary was set within the upper/mid basin (region above the bridge). The target nitrogen concentration to restore infaunal habitat in the Quashnet River is based upon the high quality infaunal sites in lower Hamblin Pond and in Little River (Stations 176 and 170, Figure VII-9). The tidally averaged nitrogen levels at these sites are 0.498 and 0.524 mg N L^{-1}, respectively. These values are consistent with the infaunal guidance levels within the Popponesset Bay sub-embayments of 0.5 to 0.4 mg N L^{-1} (0.5 mg N L^{-1} being the upper threshold value). Based upon these data a conservative estimate for the infaunal threshold for the Quashnet River Estuary is 0.50 mg N L^{-1}, with 0.52 likely to represent a slight stress, but still high quality habitat. The value stems from (1) analysis of nitrogen levels within the vestigial eelgrass bed in adjacent Waquoit Bay, near the inlet (measured TN of 0.395 mg N L^{-1}, tidally corrected <0.38 mg N L^{-1}), and (2) a similar analysis in West Falmouth Harbor.

- Within the Hamblin Pond/Little River and Jehu Pond/Great River Estuaries the sentinel locations were placed within the pond basins. The target nitrogen threshold focuses on eelgrass restoration of these systems. Based upon the modeling and ecological indicators, it appears that Jehu Pond could support eelgrass at a nitrogen threshold of 0.446 mg N L^{-1}. This is above the 0.38 mg N L^{-1} threshold likely for the main bay (and utilized for Stage Harbor and Popponesset Bay), but lower than the 0.527-0.552 found in the Bassing Harbor System. This level for Jehu Pond is also consistent with the pattern and timing of eelgrass loss throughout the Waquoit Bay System. Although Hamblin Pond is similar to Jehu Pond in gross structure, it has very different loading and attenuation characteristics. The result is that the structure of the system produces much lower nitrogen levels so a threshold of 0.38 mg N L-1 was selected for both systems to allow for uncertainties.

- Based upon sequential reductions in watershed nitrogen loading in the analysis described in the Section VIII-3, it will not be possible to achieve the target nitrogen levels for the Quashnet River, Hamblin Pond/Little River or Jehu Pond/Great River Estuary without lowering the nitrogen level within the main basin of Waquoit Bay. At present the flooding waters from Waquoit Bay are sufficiently nitrogen enriched that even modest nitrogen loads from the watersheds to these tributary estuaries result in nitrogen levels in excess of the nitrogen targets. In fact, the flood waters from the main basin currently exceed the 0.38 mg N L^{-1} target concentration.

The tidally averaged total nitrogen thresholds derived in Section VIII-2 were used to adjust the calibrated constituent transport model developed in Section VI. Watershed nitrogen loads were lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold level at the sentinel region for the Quashnet River, Hamblin Pond/Little River and Jehu Pond/Great River Estuaries. It is important to note that load reductions can be produced by reduction of any or all sources or by increasing the natural attenuation of nitrogen within the freshwater systems to the embayment.

- The only realistic mechanism for reaching 0.38 mg N L^{-1} within Jehu Pond requires nitrogen management relative to the Waquoit Bay basin in concert with nitrogen reductions within this sub-watershed. As such, the approach taken for determining the Threshold Load to Jehu Pond was to set the boundary condition in the main basin of Waquoit Bay at 0.35 mg N L^{-1}, a level unquestionably supportive of eelgrass. The second step was to reduce the watershed nitrogen load to Jehu Pond by about two-thirds of present day loading. Under these very conservative conditions, the nitrogen level attained in Jehu Pond is 0.446 mg N L^{-1}. The conclusion is that the nitrogen target restorative of eelgrass within this estuary is 0.446 mg N L^{-1}.

- Upon review of various modeling scenarios employed to determine threshold loading for Jehu Pond, it appears that the 0.38 mg N L-1 target is applicable to Hamblin Pond. Hamblin Pond watershed nitrogen management can achieve this nitrogen target when Jehu Pond nitrogen levels are reduced to 0.446 mg N L^{-1} and the Waquoit Bay main basin is lowered to 0.35 mg N L^{-1}. Therefore, it appears that nitrogen management to restore eelgrass in Jehu Pond and Hamblin Pond, and to lower nitrogen levels within the Waquoit Bay main basin, should be considered as part of an integrated nitrogen management plan.

- It appears that achieving the nitrogen target at the sentinel stations will be restorative of eelgrass habitat with the Hamblin Pond/Little River and Jehu Pond/Great River systems and restorative of infaunal habitat throughout Quashnet River.

It is important to note that the analysis of future nitrogen loading to the Quashnet River, Hamblin Pond/Little River and Jehu Pond/Great River Estuarine systems focuses upon additional shifts in land-use from forest/grasslands to residential and commercial development. However, the MEP analysis indicates that significant increases in nitrogen loading can occur under present land-uses, due to shifts in occupancy, shifts from seasonal to year-round useage and increasing use of fertilizers (presently less than half of the parcels use lawn fertilizers). Therefore, watershed-estuarine nitrogen management must include management approaches to prevent increased nitrogen loading from both shifts in land-uses (new sources) and from loading increases of current land-uses. The overarching conclusion of the MEP analysis of the Quashnet River, Hamblin Pond/Little River and Jehu Pond/Great River Estuarine Systems is that restoration will necessitate a reduction in the present (2002) nitrogen inputs and management options to negate additional future nitrogen inputs.

Table ES-1. Existing total and sub-embayment nitrogen loads to the estuarine waters of the Hamblin Pond /Jehu Pond and Quashnet River systems observed nitrogen concentrations, and sentinel system threshold nitrogen concentrations. Loads to estuarine waters of the systems include both upper watershed regions contributing to the major surface water inputs (Red Brook and Moonakiss River).

Sub-embayments	Natural Background Watershed Load [1] (kg/day)	Present Non-Septic System Land Use Load [2] (kg/day)	Present Septic System Load (kg/day)	Present WWTF Load [3] (kg/day)	Present Total Watershed Load [4] (kg/day)	Direct Atmospheric Deposition [5] (kg/day)	Present Net Benthic Flux (kg/day)	**Present Total Load [6]** (kg/day)	Observed TN Conc. [7] (mg/L)	Threshold TN Conc. (mg/L)
HAMBLIN POND/ JEHU POND SYSTEM										
Upper Hamlin Pond [a]	0.48	0.86	4.56	0.00	5.42	0.06	-4.98	0.50	0.65	--
Hamblin Pond	0.13	0.37	3.47	0.00	3.84	1.53	-3.48	1.89	0.54	**0.380**[8]
Little River	0.02	0.15	0.96	0.00	1.11	0.16	3.53	4.80		--
Lower Great River	0.07	0.47	2.48	0.00	2.95	0.75	10.06	13.76	0.57	--
Upper Great River	0.22	0.27	0.41	0.00	0.68	0.55	9.55	10.78	0.61	--
Jehu Pond	0.12	0.77	2.84	0.00	3.61	0.67	10.43	14.71	0.59	**0.446**[8]--
System Total [a]	**1.04**	**2.89**	**14.72**	**0.00**	**17.61**	**3.72**	**25.11**	**46.44**	**--**	**--**
QUASHNET SYSTEM										
Upper Quashnet [a]	4.29	10.34	14.39	0.43	25.16	0.33	10.05	35.54	0.83-0.77	**0.500**[8]
Lower Quashnet	0.02	0.22	0.57	0.00	0.79	0.25	4.78	5.82	0.55	--
System Total [a]	**4.31**	**10.56**	**14.96**	**0.43**	**25.95**	**0.58**	**14.83**	**41.36**	**--**	**--**

[1] assumes entire watershed is forested (i.e., no anthropogenic sources)
[2] composed of non-wastewater loads, e.g. fertilizer and runoff and natural surfaces and atmospheric deposition to lakes
[3] existing wastewater treatment facility discharges to groundwater
[4] composed of combined natural background, fertilizer, runoff, and septic system loadings
[5] atmospheric deposition to embayment surface only
[6] composed of natural background, fertilizer, runoff, septic system atmospheric deposition and benthic flux loadings
[7] average of 2001 – 2003 data, ranges show the upper to lower regions (highest-lowest) of an sub-embayment. Individual yearly means and standard deviations in Table VI-6.
[8] Threshold nitrogen level for sentinel sites located at Jehiu Pond, and the lower basin of the Quashnet River.
[a] Nitrogen load to this sub-embayment includes inputs from surface water sources (e.g., rivers).

Table ES-2 Present Watershed Loads, Threshold Loads, and the percent reductions necessary to achieve the Target NitrogenThreshold level within the Hamblin Pond /Jehu Pond and Quashnet River estuaries (Town of Mashpee, Massachusetts).

Sub-embayments	Direct Atmospheric Deposition (kg/day)	Present Watershed Load [1] (kg/day)	Target Threshold Watershed Load [2] **Scen A** (kg/day)	Target Threshold Watershed Load [2] **Scen B** (kg/day)	Net Benthic Flux [3] **Scen A** (kg/day)	Net Benthic Flux [3] **Scen B** (kg/day)	TMDL [4] **Scen A** (kg/day)	TMDL [4] **Scen B** (kg/day)	Percent watershed reductions to achieve threshold load levels **Scen A**	Percent watershed reductions to achieve threshold load levels **Scen B**
HAMBLIN POND/ JEHU POND SYSTEM										
Upper Hamlin Pond [a]	0.06	5.42	0.92	2.06	-3.17	-3.63	-2.19	-1.51	-83.0%	-62.0%
Hamblin Pond	1.53	3.84	0.47	1.34	-2.23	-2.54	-0.23	0.33	-87.8%	-65.1%
Little River	0.16	1.11	0.19	0.43	2.45	2.73	2.80	3.32	-82.9%	-61.3%
Lower Great River	0.75	2.95	0.6	0.6	7.12	7.12	8.47	8.47	-79.7%	-79.7%
Upper Great River	0.55	0.68	0.32	0.32	6.75	6.75	7.62	7.62	-52.9%	-52.9%
Jehu Pond	0.67	3.61	0.96	0.96	7.64	7.64	9.27	9.27	-73.4%	-73.4%
System Total [a]	**3.72**	**17.61**	**3.46**	**5.71**	**12.94**	**18.07**	**25.74**	**27.5**	**-80.4%**	**-67.6%**
QUASHNET SYSTEM										
Upper Quashnet [a]	0.33	25.16	10.77	15.51	5.56	7.04	16.66	47.71	-57.2%	-38.4%
Lower Quashnet	0.25	0.79	0.22	0.41	2.99	3.58	3.46	4.78	-72.2%	-48.1%
System Total [a]	**0.58**	**25.95**	**10.99**	**15.92**	**8.55**	**10.62**	**20.12**	**52.49**	**-57.6%**	**-38.7%**

(1) Composed of combined natural background, fertilizer, runoff, and septic system loadings.
(2) Target threshold watershed load is the load from the watershed needed to meet the nitrogen threshold concentration within the estuary identified in Table ES-1.
(3) Projected future flux (present rates reduced approximately proportional to watershed load reductions).
(4) Sum of target threshold watershed load, atmospheric deposition load, and benthic flux load.

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