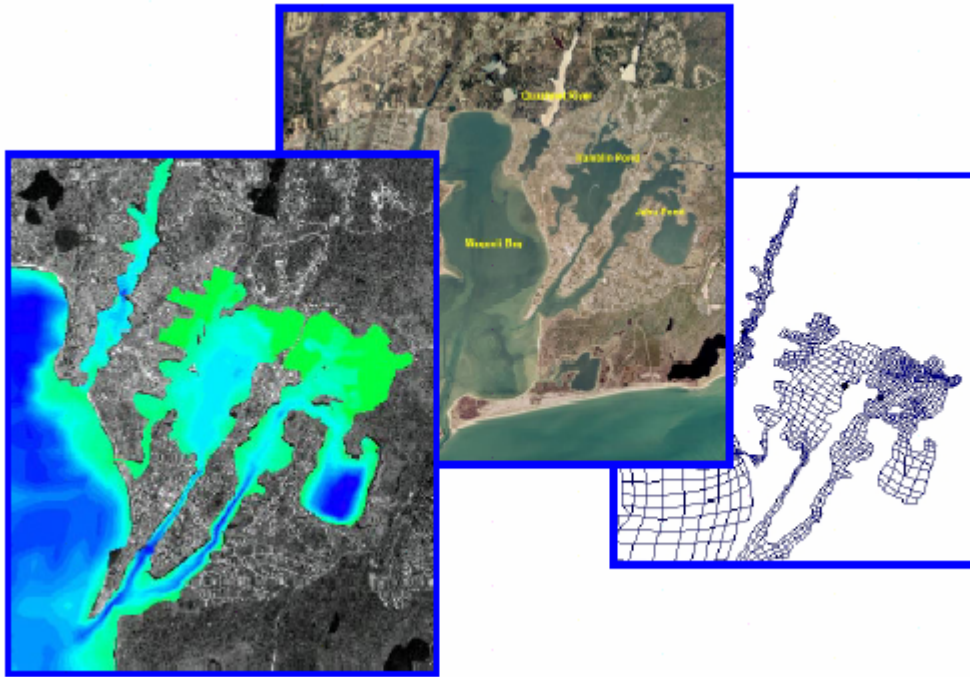


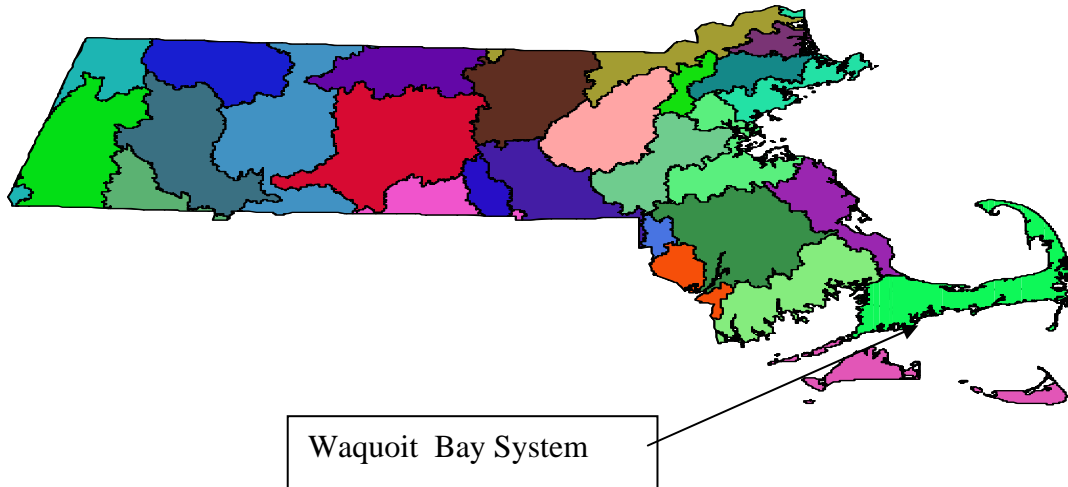
**FINAL**  
**Quashnet River, Hamblin Pond, Little River,**  
**Jehu Pond, and Great River**  
**in the Waquoit Bay System**  
**Total Maximum Daily Loads**  
**For Total Nitrogen**  
**(Report # 96-TMDL-5**  
**Control #218.0)**



**COMMONWEALTH OF MASSACHUSETTS**  
**EXECUTIVE OFFICE OF ENVIRONMENTAL AFFAIRS**  
STEPHEN R. PRITCHARD, SECRETARY  
**MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION**  
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**BUREAU OF RESOURCE PROTECTION**  
GLENN HAAS, ACTING ASSISTANT COMMISSIONER

January 31, 2006

**Popponesset Bay  
Total Maximum Daily Loads  
For Total Nitrogen**



**Key Feature:** Total Nitrogen TMDL for Popponesset Bay  
**Location:** EPA Region 1  
**Land Type:** New England Coastal  
**303d Listing:**

Great River	MA96-60_2002	0.16 sq mi	Nutrients
Hamblin Pond	MA96-58_2002	0.19 sq mi	Nutrients & Pathogens
Jehu Pond	MA96-59_2002	0.09 sq mi	Nutrients
Little River	MA96-61_2002	0.02 sq mi	Nutrients & Pathogens
Quashnet River	MA96-20_2002	0.1 sq mi	Nutrients & Organic Enrichment/Low DO & Pathogens

**Data Sources:** University of Massachusetts – Dartmouth/School for Marine Science and Technology; US Geological Survey; Applied Coastal Research and Engineering, Inc.; Cape Cod Commission, Town of Mashpee, Town of Falmouth

**Data Mechanism:** Massachusetts Surface Water Quality Standards, Ambient Data, and Linked Watershed Model

**Monitoring Plan:** Towns of Mashpee and Falmouth monitoring program (possible assistance from SMAST)

**Control Measures:** Sewering, Storm Water Management, Attenuation by Impoundments and Wetlands, Fertilizer Use By-laws

## **EXECUTIVE SUMMARY**

### **Problem Statement**

Excessive nitrogen (N) originating primarily from on-site wastewater disposal (both conventional septic systems and innovative/alternative systems) has led to significant decreases in the environmental quality of coastal rivers, ponds, and harbors in many communities in southeastern Massachusetts. In the Towns of Mashpee and Falmouth the problems in coastal waters include:

- Loss of eelgrass beds, which are critical habitats for macroinvertebrates and fish
- Undesirable increases in macro algae, which are much less beneficial than eelgrass
- Periodic extreme decreases in dissolved oxygen concentrations that threaten aquatic life
- Reductions in the diversity of benthic animal populations
- Periodic algae blooms

With proper management of nitrogen inputs these trends can be reversed. Without proper management more severe problems might develop, including:

- Periodic fish kills
- Unpleasant odors and scum
- Benthic communities reduced to the most stress-tolerant species, or in the worst cases, near loss of the benthic animal communities

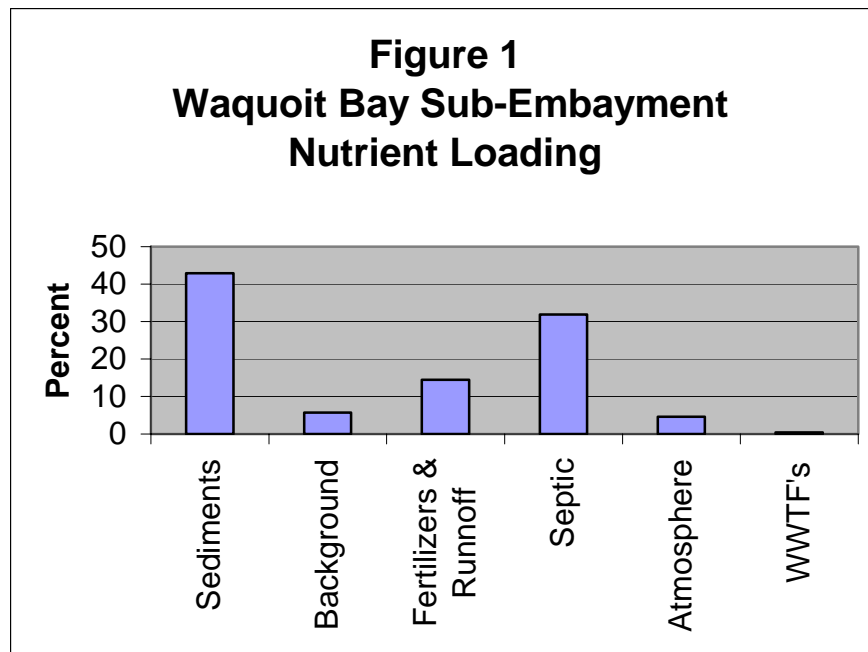
Coastal communities, including Mashpee and Falmouth, rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as for commercial fin fishing and shellfishing. Failure to reduce and control N loadings will result in complete replacement of eelgrass by macro-algae, a higher frequency of extreme decreases in dissolved oxygen concentrations and fish kills, widespread occurrence of unpleasant odors and visible scum, and a complete loss of benthic macroinvertebrates throughout most of the embayments. As a result of these environmental impacts, commercial and recreational uses of Waquoit Bay's coastal waters will be greatly reduced, and could cease altogether.

### **Sources of nitrogen**

Nitrogen enters the waters of coastal embayments from the following sources:

- The watershed
  - On-site subsurface wastewater disposal systems
  - Natural background
  - Runoff
  - Fertilizers
  - Wastewater treatment facilities
- Atmospheric deposition
- Nutrient-rich bottom sediments in the embayments

A large portion of the present N load originates from individual subsurface wastewater disposal (septic) systems, primarily serving individual residences, as seen in the following figure.



### Target Threshold Nitrogen Concentrations and Loadings

The N loadings (the quantity of nitrogen) to these three Waquoit Bay sub-embayments range from 0.98 kg/day in Hamblin Pond, to 39.83 kg/day in Upper Quashnet River. The resultant concentrations of N in these three sub-embayments range from 0.460 mg/L (milligrams of nitrogen per liter) in Hamblin Pond to 0.892 mg/L in the Upper Quashnet River.

In order to restore and protect these three Waquoit Bay sub-embayments, N loadings, and subsequently the concentrations of N in the water, must be reduced to levels below the thresholds that cause the observed environmental impacts. This concentration will be referred to as the target threshold concentration. It is the goal of the TMDL to reach this target threshold concentration, as it has been determined for each sub-embayment. The Massachusetts Estuaries Project (MEP) has determined that for these three Waquoit Bay sub-embayments, target threshold N concentrations in the range from 0.38 to 0.50 mg/L are protective of water quality standards. The mechanism for achieving these target threshold N concentrations is to reduce the N loadings to the sub-embayments. Based on the MEP work and their resulting Technical Report the Department has determined that the Total Maximum Daily Loads (TMDL) of N that will meet the target threshold concentrations range from 2-27 kg/day. The purpose of this document is to present TMDLs for each sub-embayment and to provide guidance to the Towns on possible ways to reduce the N loadings to implement the proposed TMDLs.

### Implementation

The primary goal of implementation will be lowering the concentrations of N by greatly reducing the loadings from on-site subsurface wastewater disposal systems through a variety of centralized or decentralized methods such as sewerage and treatment with nitrogen removal technology, advanced treatment of septage, upgrade/repairs of failed on-site systems, and/or installation of N-reducing on-site systems.

These strategies, plus ways to reduce N loadings from storm water runoff and fertilizers, are explained in detail in the “MEP Embayment Restoration Guidance for Implementation Strategies”, that is available on the MassDEP website at (<http://www.mass.gov/dep/water/resources/restore.htm>). The appropriateness of any of the alternatives will depend on local conditions, and will have to be determined on a case-by-case basis, using an adaptive management approach. Finally, growth within the communities of Mashpee, Falmouth, and Sandwich (part of the upper watershed only) which would exacerbate the problems associated with N loadings, should be guided by considerations of water quality-associated impacts.

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## Introduction

Section 303(d) of the Federal Clean Water Act requires each state (1) to identify waters for which effluent limitations normally required are not stringent enough to attain water quality standards and (2) to establish Total Maximum Daily Loads (TMDLs) for such waters for the pollutants of concern. The TMDL allocation establishes the maximum loadings (of pollutants of concern), from all contributing sources, that a water body may receive and still meet and maintain its water quality standards and designated uses, including compliance with numeric and narrative standards. The TMDL development process may be described in four steps, as follows:

1. Determination and documentation of whether or not a water body is presently meeting its water quality standards and designated uses.
2. Assessment of present water quality conditions in the water body, including estimation of present loadings of pollutants of concern from both point sources (discernable, confined, and concrete sources such as pipes) and non-point sources (diffuse sources that carry pollutants to surface waters through runoff or groundwater).
3. Determination of the loading capacity of the water body. EPA regulations define the loading capacity as the greatest amount of loading that a water body can receive without violating water quality standards. If the water body is not presently meeting its designated uses, then the loading capacity will represent a reduction relative to present loadings.
4. Specification of load allocations, based on the loading capacity determination, for non-point sources and point sources, that will ensure that the water body will not violate water quality standards.

After public comment and final approval by the EPA, the TMDL will serve as a guide for future implementation activities. The MassDEP will work with the Towns to develop specific implementation strategies to reduce N loadings, and will assist in developing a monitoring plan for assessing the success of the nutrient reduction strategies.

In the Waquoit Bay System, the pollutant of concern for this TMDL (based on observations of eutrophication), is the nutrient nitrogen. Nitrogen is the limiting nutrient in coastal and marine waters, which means that as its concentration is increased, so is the amount of plant matter. This leads to nuisance populations of macro-algae and increased concentrations of phytoplankton and epiphyton which impair eelgrass beds and imperil the healthy ecology of the affected water bodies.

The TMDLs for total N for the three eastern coastal sub-embayments within the Waquoit Bay System are based primarily on data collected, compiled, and analyzed by University of Massachusetts Dartmouth's School of Marine Science and Technology (SMAST), the Cape Cod Commission, the Towns of Mashpee and Falmouth and others, as part of the Massachusetts Estuaries Project (MEP). The data was collected over a study period from 2001 to 2003. This study period will be referred to as the "Present Conditions" in the TMDL since it is the most recent data available. The accompanying MEP Technical Report presents the results of the analyses of these three coastal sub-embayments using the MEP Linked Watershed-Embayment Nitrogen Management Model (Linked Model). The analyses were performed to assist the Towns with decisions on current and future wastewater planning, wetland restoration, anadromous fish runs, shellfisheries, open-space, and harbor maintenance programs. A critical element of this approach is the assessments of water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure that were conducted on each of the three sub-embayments studied. These assessments served as the basis for generating N loading thresholds for use as goals for watershed N management. The

TMDLs are based on the site-specific thresholds generated for each sub-embayment. Thus, the MEP offers a science-based management approach to support the wastewater management planning and decision-making process in the Towns of Mashpee and Falmouth.

## Description of Water Bodies and Priority Ranking

The Waquoit Bay System in Mashpee and Falmouth Massachusetts, at the southwestern edge of Cape Cod, faces Nantucket Sound to the south, and consists of a number of sub-embayments of varying size and hydraulic complexity, characterized by limited rates of flushing, shallow depths and heavily developed watersheds (see Figure 2 on following page). The three sub-embayments studied constitute important components of the Towns’ natural and cultural resources. The nature of enclosed sub-embayments in populous regions brings two opposing elements to bear: 1) as protected marine shoreline they are popular regions for boating, recreation, and land development and 2) as enclosed bodies of water, they may not be readily flushed of the pollutants that they receive due to the proximity and density of development near and along their shores. In particular, the sub-embayments within the Waquoit Bay System are at risk of further eutrophication from high nutrient loads in the groundwater and runoff from their watersheds. Because of excessive nutrients, these three sub-embayments are already listed as waters requiring TMDLs (Category 5) in the MA 2002 Integrated List of Waters, as summarized in Table 1A. These three sub-embayments are broken down into five waterbody segments in this List and will result in 5 TMDLs.

**Table 1A. Waquoit Bay Waterbody Segments in Category 5 of the Massachusetts 2002 Integrated List<sup>1</sup>**

NAME	WATERBODY SEGMENT	DESCRIPTION	SIZE	Pollutant Listed
<b>Waquoit Bay System</b>				
Great River	MA96-60_2002	From inlet of Abigails Brook to Waquoit Bay (excluding Jehu Pond), Mashpee	0.16 sq mi	-Nutrients
Hamblin Pond	MA96-58_2002	From inlet of Red Brook to outlet of Little River and inlet/outlet of Waquoit Bay west of Meadow Neck Road, Falmouth/Mashpee	0.19 sq mi	-Nutrients -Pathogens
Jehu Pond	MA96-59_2002	Mashpee	0.09sq mi	-Nutrients
Little River	MA96-61_2002	From outlet of Hamblin Pond to the Great River, Mashpee	0.02 sq mi	-Nutrients -Pathogens
Quashnet River	MA96-20_2002	Just south of Route 28 to mouth at Waquoit Bay, Falmouth. Also known as Moonakis River.	0.1 sq mi	-Nutrients -Organic enrichment /Low DO -Pathogens

<sup>1</sup> These segments are also classified as Category 5 on the Draft 2004 Integrated List.

A complete description of all three sub-embayments is presented in Chapters I and IV of the MEP Technical Report from which the majority of the following information is drawn. TMDLs were prepared for all 5 waterbody segments within the 3 sub-embayments listed below.

- Waquoit Bay System sub-embayments in this system:
  - Hamblin Pond/Little River
  - Jehu Pond/Great River
  - Quashnet River





**Figure 2 Overview of the 3 Eastern Sub-embayments to Waquoit Bay**

The sub-embayments addressed by this document are determined to be high priorities based on 3 significant factors: (1) the initiative that these Towns have taken to assess the conditions of the entire Waquoit embayment system, (2) the commitment made by these Towns to restoring and preserving the sub-embayments, and (3) the extent of eutrophication in the sub-embayments. In particular, these sub-embayments are at risk of further degradation from increased N loads entering through groundwater and surface water from their increasingly developed watersheds. In both marine and freshwater systems, an excess of nutrients results in degraded water

quality, adverse impacts to ecosystems, and limits on the use of water resources. The general conditions related to the major indicators of habitat impairment, due to excess nutrient loadings, are tabulated in Table 1B. Observations are summarized in the Problem Assessment section below, and detailed in Chapter VII, Assessment of Embayment Nutrient Related Ecological Health, of the MEP Technical Report.

**Table 1B. General summary of conditions related to the major indicators of habitat impairment observed in the three Waquoit Bay System sub-embayments.**

Waquoit Bay System Sub-embayments	Eel Grass Loss <sup>1</sup>	Dissolved Oxygen Depletion	Chlorophyll <i>a</i> <sup>2</sup>	Macroalgae	Benthic Fauna <sup>3</sup>
Great River	89%	<b>MI</b>	no data	no data	<b>MI</b>
Hamblin Pond	95%	<b>MI</b>	<b>MI</b>	no data	<b>MI</b>
Jehu Pond	89%	<b>SI</b>	<b>MI/SI</b>	no data	<b>SI</b>
Little River	95%	<b>MI</b>	no data	no data	<b>GF</b>
Quashnet River	NS	<b>SI</b>	<b>SI/SD</b>	<b>SD</b>	<b>SD</b>

<sup>1</sup>Based on comparison of present conditions to 1951 Survey data.

<sup>2</sup> Algal blooms are consistent with chlorophyll *a* levels above 20 ug/L

<sup>3</sup> Based on observations of the type of species, number of species, and number of individuals

**GF** – Good to Fair – little or no change from normal conditions \*

**MI** – Moderately Impaired – slight to reasonable change from normal conditions \*

**SI** – Significantly Impaired- considerably and appreciably changed from normal conditions \*

**SD** – Severe Degraded – critically or harshly changed from normal conditions \*

**NS** - Non-supportive habitat, no eelgrass was present in 1951 Survey data.

\* - these terms are more fully described in MEP report “Site-Specific Nitrogen Thresholds for Southeastern Massachusetts Embayments: Critical Indicators”

December 22, 2003 (<http://www.mass.gov/dep/water/resources/esttmdls.htm>)

## Problem Assessment

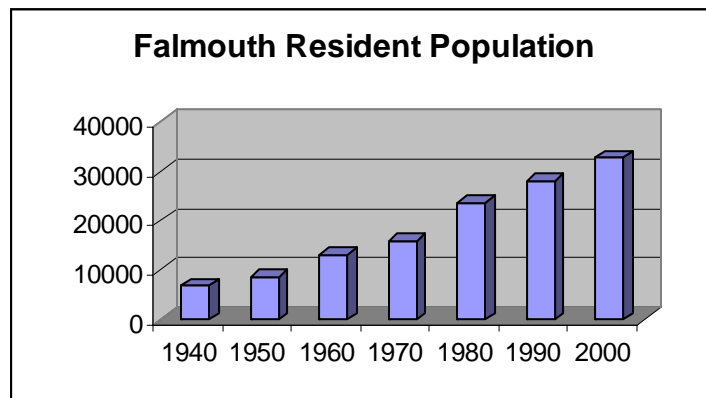
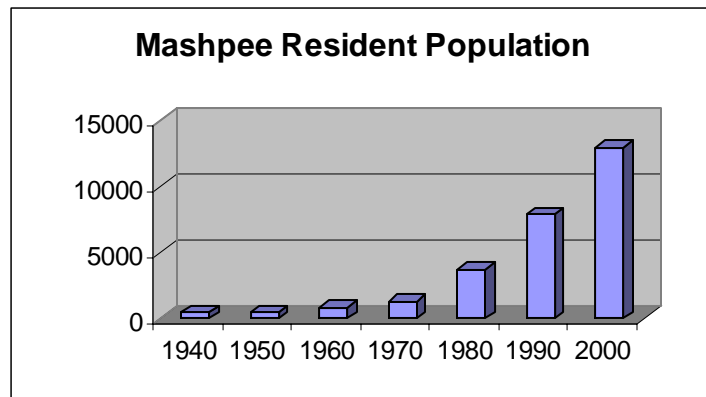
The watersheds of Waquoit Bay’s embayments have all had rapid and extensive development of single-family homes and the conversion of seasonal into full time residences. This is reflected in a substantial transformation of land from forest to suburban use between the years 1951 to 2000. Water quality problems associated with this development result primarily from on-site wastewater treatment systems, and to a lesser extent, from runoff, including fertilizers, from these developed areas.

On-site subsurface wastewater disposal system effluents discharge to the ground, enter the groundwater system and eventually enter the surface water bodies. In the sandy soils of Cape Cod, effluent that has entered the groundwater travel towards the coastal waters at an average rate of one foot per day. The nutrient load to the groundwater system is directly related to the number of subsurface wastewater disposal systems, which in turn are related to the population. The population of Mashpee and Falmouth, as with all of Cape Cod, has increased markedly since 1950. In addition, summertime residents and visitors swell the population of the entire Cape by about 300% according to the Cape Cod Commission.

(<http://www.capecodcommission.org/data/trends98.htm#population>).

The increase in year round residents is illustrated in the following figure. Figure 3 is based on actual U.S. Census Bureau data.

Figure 3



Prior to the 1950's there were few homes and many of those were seasonal. During these times water quality was not a problem and eel grass beds were plentiful. Dramatic declines in water quality, and the quality of the estuarine habitats, throughout Cape Cod, have paralleled its population growth since these times. The problems in these particular sub-embayments studied generally include periodic decreases of dissolved oxygen, decreased diversity of benthic animals, and periodic algal blooms. Eelgrass beds, which are critical habitats for macroinvertebrates and fish, have greatly diminished from these waters. All the sub-embayments which historically supported eelgrass (as evidenced by the 1951 survey) have almost all shown a nearly 90% or greater reduction in area

Coastal communities, including Mashpee and Falmouth, rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as commercial fin fishing and shellfishing. The continued degradation of these coastal sub-embayments, as described above, will significantly reduce the recreational and commercial value and use of these important environmental resources.

Habitat and water quality assessments were conducted on each sub-embayment based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. The three sub-embayments in this study display a range of habitat quality. In general, the habitat quality of the sub-embayments studied is highest near the tidal inlet on Waquoit Bay and poorest in the inland-most tidal reaches. This is indicated by gradients of the various indicators. Nitrogen concentrations are highest inland and lowest near the mouths. Eelgrass has been

dramatically reduced from the original 1951 survey. The dissolved oxygen records for the tidally influenced lower Quashnet River and the upper region of Hamblin Pond indicate that these sub-embayments currently maintain a high and moderate level of oxygen stress, respectively. Jehu Pond showed a high level of oxygen depletion, to a level, which will impair habitat quality. Dissolved oxygen levels periodically approached anoxia. Based upon all of the chlorophyll and oxygen data it appears that the Quashnet River sub-embayment is showing oxygen stress throughout its reach and it is likely that the level of depletion is higher in the upper and mid reaches than in the lower basin, consistent with the distribution of phytoplankton biomass. Jehu and Hamblin Ponds support moderate to high chlorophyll levels, respectively. The Quashnet River is a severely degraded habitat relative to supporting benthic infaunal communities. The Hamblin Pond and Jehu Pond sub-embayments showed infaunal community habitats ranging from healthy to significantly impaired, respectively.

## **Pollutant of Concern, Sources, and Controllability**

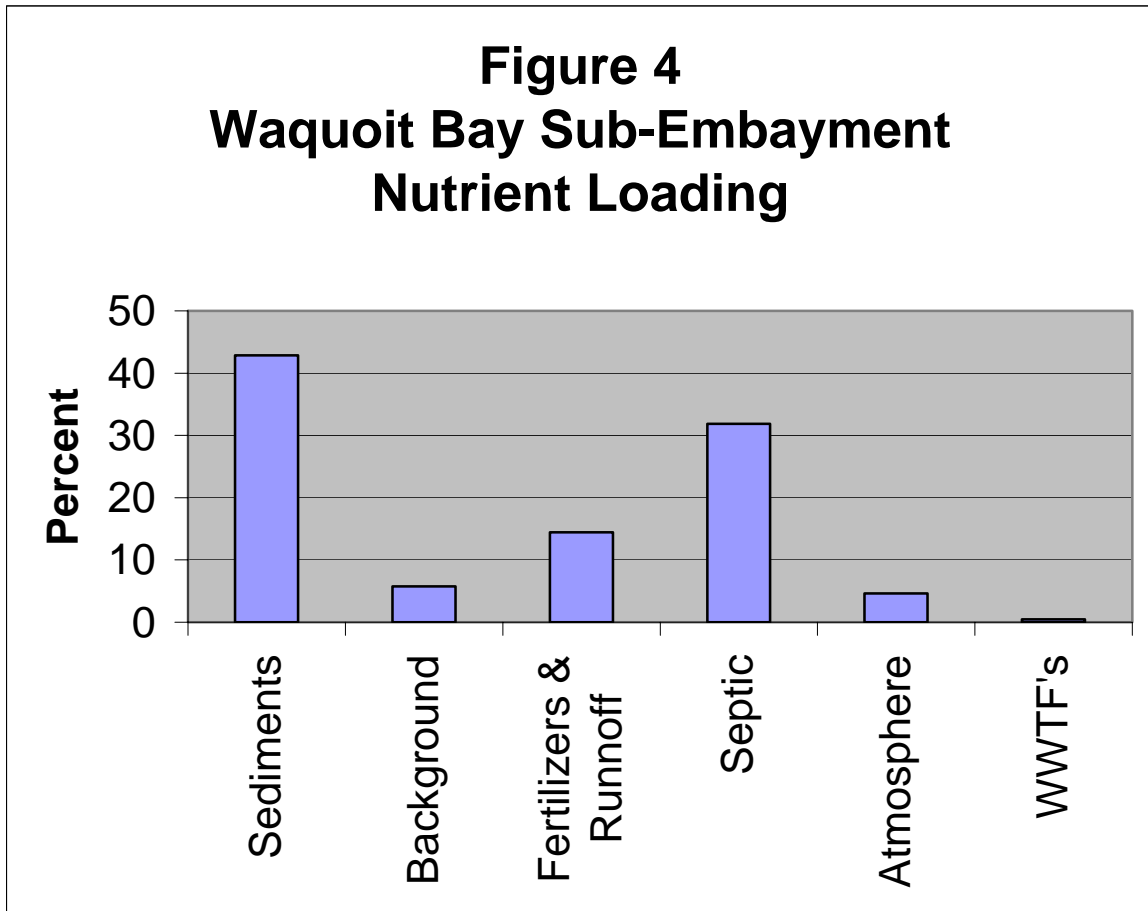
In the coastal embayments of the Towns of Mashpee and Falmouth, as in most marine and coastal waters, the limiting nutrient is nitrogen. Nitrogen concentrations beyond those expected naturally contribute to undesirable conditions, including the severe impacts described above, through the promotion of excessive growth of plants and algae, including nuisance vegetation.

Each of the embayments covered in this TMDL has had extensive data collected and analyzed through the Massachusetts Estuaries Program (MEP) and with the cooperation and assistance from the Town of Mashpee, the Town of Falmouth, the USGS, and the Cape Cod Commission. Data collection included both water quality and hydrodynamics as described in Chapters I, IV, V, and VII of the MEP Technical Report.

These investigations revealed that loadings of nutrients, especially N, are much larger than they would be under natural conditions, and as a result the water quality has deteriorated. A principal indicator of decline in water quality is the disappearance of eelgrass from a large percentage of its natural habitat in these sub-embayments. This is a result of nutrient loads causing excessive growth of algae in the water (phytoplankton) and algae growing on eelgrass (epiphyton), both of which result in the loss of eelgrass through the reduction of available light levels.

As is illustrated by Figure 4, most of the N affecting these three eastern sub-embayments to Waquoit Bay originates from the sediments and on-site subsurface wastewater disposal systems (septic systems), with considerably less N originating from natural background sources, runoff, fertilizers, waste water treatment facilities, and atmospheric deposition. Although this figure shows that overall the sediments are a large N source, examination of the sections of individual sub-embayments indicates that some of them have sediments that provide a significant sink of N (Table 3). Under certain environmental conditions sediments can denitrify, thus freeing up capacity in the sediments to absorb more nitrogen. Where the sediments result in N loading it should be emphasized that this is a result of N loading from other sources. As the N loading from other sources decreases, the sediment N loading will decrease.

## Percent contribution of various sources of nitrogen in Waquoit Bay's three eastern sub-embayments



The level of “controllability” of each source, however, varies widely:

Atmospheric nitrogen cannot be adequately controlled locally – it is only through region and nation-wide air pollution control initiatives that reductions are feasible;

Sediment nitrogen control by such measures as dredging is not feasible on a large scale. However, the concentrations of N in sediments, and thus the loadings from the sediments, will decline over time if sources in the watershed are removed, or reduced to the target levels discussed later in this document. Increased dissolved oxygen will help keep nitrogen from fluxing;

Fertilizer – related nitrogen loadings can be reduced through bylaws and public education;

Stormwater sources of N can be controlled by best management practices (BMPs), bylaws and stormwater infrastructure improvements;

Septic system sources of nitrogen are the largest controllable sources. These can be controlled by a variety of

case-specific methods including: sewerage and treatment at centralized or decentralized locations, upgrading/repairing failed systems, transporting and treating septage at treatment facilities with N removal technology either in or out of the watershed, or installing nitrogen-reducing on-site wastewater treatment systems.

Natural Background is the background load as if the entire watershed was still forested and contains no anthropogenic sources. It cannot be controlled locally.

WWTFs effluent nitrogen can be reduced by advanced treatment processes that include denitrification.

Cost/benefit analyses will have to be conducted on all of the possible N loading reduction methodologies in order to select the optimal control strategies, priorities, and schedules.

## **Description of the Applicable Water Quality Standards**

Water quality standards of particular interest to the issues of cultural eutrophication are dissolved oxygen, nutrients, aesthetics, excess plant biomass, and nuisance vegetation. The Massachusetts water quality standards (314 CMR 4.0) contain numeric criteria for dissolved oxygen, but have only narrative standards that relate to the other variables, as described below:

314 CMR 4.05(5)(a) states “Aesthetics – All surface waters shall be free from pollutants in concentrations that settle to form objectionable deposits; float as debris, scum, or other matter to form nuisances, produce objectionable odor, color, taste, or turbidity, or produce undesirable or nuisance species of aquatic life.”

314 CMR 4.05(5)(c) states, “Nutrients – Shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication”.

314 CMR 4.05(b) 1:

(a) Class SA

1. Dissolved Oxygen -

- a. Shall not be less than 6.0 mg/l unless background conditions are lower;
- b. natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 75% of saturation due to a discharge; and
- c. site-specific criteria may apply where background conditions are lower than specified levels or to the bottom stratified layer where the Department determines that designated uses are not impaired.

(b) Class SB

1. Dissolved Oxygen -

- a. Shall not be less than 5.0 mg/L unless background conditions are lower;
- b. natural seasonal and daily variations above this level shall be maintained; levels shall not be lowered below 60% of saturation due to a discharge; and
- c. site-specific criteria may apply where back-ground conditions are lower than specified levels or to the bottom stratified layer where the Department determines that designated uses are not impaired.

Thus, the assessment of eutrophication is based on site-specific information within a general framework that emphasizes impairment of uses and preservation of a balanced indigenous flora and fauna. This approach is

recommended by the US Environmental Protection Agency in their draft Nutrient Criteria Technical Guidance Manual for Estuarine and Coastal Marine Waters (EPA-822-B-01-003, Oct 2001). The Guidance Manual notes that lakes, reservoirs, streams, and rivers may be subdivided by classes, allowing reference conditions for each class and facilitating cost-effective criteria development for nutrient management. However, individual estuarine and coastal marine waters have unique characteristics, and development of individual water body criteria is typically required.

It is this framework; coupled with an extensive outreach effort that MassDEP is employing to develop nutrient TMDLs for coastal waters, with the technical support of SMAST.

## **Methodology - Linking Water Quality and Pollutant Sources**

Extensive data collection and analyses have been described in detail within the MEP Technical Report. Those data were used by SMAST to assess the loading capacity of each sub-embayment. Physical (Chapter V), chemical and biological (Chapters IV, VII, and VIII) data were collected and evaluated. The primary water quality objective was represented by conditions that:

- 1) Restore the natural distribution of eelgrass because it provides valuable habitat for shellfish and finfish
- 2) Prevent algal blooms
- 3) Protect benthic communities from impairment or loss
- 4) Maintain dissolved oxygen concentrations that are protective of the estuarine communities.

The details of the data collection, modeling and evaluation are presented and discussed in Chapters IV, V, VI, VII and VIII of the MEP Technical Report. The main aspects of the data evaluation and modeling approach are summarized below, taken from pages 4 through 7 of that report.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach. It fully links watershed inputs with embayment circulation and N characteristics, and is characterized as follows:

- requires site specific measurements within the watershed and each sub-embayment;
- uses realistic “best-estimates” of N loads from each land-use (as opposed to loads with built-in “safety factors” like Title 5 design loads);
- spatially distributes the watershed N loading to the embayment;
- accounts for N 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 N regenerated within the embayment;
- is validated by both independent hydrodynamic, N concentration, and ecological data;
- is calibrated and validated with field data prior to generation of “what if” scenarios.

The Linked Model has been applied previously to watershed N management in 15 embayments throughout Southeastern Massachusetts. In these applications it became clear that the model can be calibrated and validated, and has use as a management tool for evaluating watershed N management options.

The Linked Model, when properly calibrated and validated for a given embayment, becomes a N management planning tool as described in the model overview below. The model can assess solutions for the protection or restoration of nutrient-related water quality and allows testing of management scenarios to support cost/benefit evaluations. In addition, once a model is fully functional it can be refined for changes in land-use or embayment characteristics at minimal cost. In addition, since the Linked Model uses a holistic approach that incorporates 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.

The Linked Model provides a quantitative approach for determining an embayments: (1) N sensitivity, (2) N threshold loading levels (TMDL) and (3) response to changes in loading rate. The approach is fully field validated and unlike many approaches, accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics (Figure I-2 of the MEP Technical Report). This methodology integrates a variety of field data and models, specifically:

- Monitoring - multi-year embayment nutrient sampling
  
- Hydrodynamics -
  - embayment bathymetry (depth contours throughout the embayment)
  - site specific tidal record (timing and height of tides)
  - water velocity records (in complex systems only)
  - hydrodynamic model
  
- Watershed Nitrogen Loading
  - watershed delineation
  - stream flow (Q) and N load
  - land-use analysis (GIS)
  - watershed N model
  
- Embayment TMDL - Synthesis
  - linked Watershed-Embayment Nitrogen Model
  - salinity surveys (for linked model validation)
  - rate of N recycling within embayment
  - dissolved oxygen record
  - Macrophyte survey
  - Infaunal survey (in complex systems)

### ***Application of the Linked Watershed-Embayment Model***

The approach developed by the MEP for applying the linked model to specific sub-embayments, for the purpose of developing target N loading rates, includes:

- 1) selecting one or two sub-embayments within the embayment system, located close to the inland-most reach or reaches, which typically has the poorest water quality within the system. These are called “sentinel” sub-embayments;



- 2) using site-specific information and a minimum of 3 years of sub-embayment-specific data to select target/threshold N concentrations for each sub-embayment. This is done by refining the draft threshold N concentrations that were developed as the initial step of the MEP process. The target concentrations that were selected generally occur in higher quality waters near the mouth of the embayment system;
- 3) running the calibrated water quality model using different watershed N loading rates, to determine the loading rate which will achieve the target N concentration within the sentinel sub-embayment. Differences between the modeled N load required to achieve the target N concentration, and the present watershed N load, represent N management goals for restoration and protection of the embayment system as a whole.

Previous sampling and data analyses, and the modeling activities described above, resulted in four major outputs that were critical to the development of the TMDLs. Two outputs are related to N **concentration**:

- the present N concentrations in the sub-embayments
- site-specific target (threshold) concentrations

and, two outputs are related to N **loadings**:

- the present N loads to the sub-embayments
- load reductions necessary to meet the site specific target N concentrations

A brief overview of each of the outputs follows:

#### Nitrogen concentrations in the sub-embayments

##### a) Observed “present” conditions:

Table 2 presents the average concentrations of N measured in the sub-embayments from 2001 through 2003. Concentrations of N are the highest in the Quashnet River (0.892 mg/L). Nitrogen in the other sub-embayments ranges in concentration from 0.376 to 0.774 mg/L, resulting in overall ecological habitat quality ranging from good/fair to severely degraded. The individual yearly means and standard deviations of the averages are presented in Table A-1 of Appendix A.

##### b) Modeled site-specific target threshold nitrogen concentrations:

A major component of TMDL development is the determination of the maximum concentrations of N (based on field data) that can occur without causing unacceptable impacts to the aquatic environment. Prior to conducting the analytical and modeling activities described above, SMAST selected appropriate nutrient-related environmental indicators and tested the qualitative and quantitative relationship between those indicators and N concentrations. The Linked Model was then used to determine site-specific threshold N concentrations by using the specific physical, chemical and biological characteristics of each sub-embayment.

**Table 2. Observed present nitrogen concentrations and target threshold nitrogen concentrations derived for the Waquoit Bay Sub-embayments**

Embayment System And Sub-embayments	Sub-embayment Observed Nitrogen Concentrations <sup>1</sup> (mg/L)	Sub-embayment Threshold Nitrogen Concentrations (mg/L)
<b>Waquoit Bay</b>		
Great River	0.606	0.446
Hamblin Pond	0.539	0.38
Jehu Pond	0.590	0.446
Little River	0.569	0.38
Quashnet River	0.503-0.830 <sup>2</sup>	0.50

<sup>1</sup> calculated as the average of the separate yearly means of 2001-2003 data. Individual yearly means and standard deviations of the average are presented in Table A-1 Appendix A

<sup>2</sup> listed as a range since it was sampled as four separate segments (see Table A-1 Appendix A)

As listed in Table 2, the site-specific target (threshold) N concentrations vary. Quashnet River has a threshold nitrogen concentration of 0.50 mg/L. Jehu Pond and Great River have a threshold nitrogen concentration of 0.446 mg/L, Hamblin Pond and Little River have a threshold nitrogen concentration of 0.38 mg/L.

The findings of the analytical and modeling investigations for these three sub-embayment systems are discussed and explained below:

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

Threshold N 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.

The overall N loads (Tables ES-1 and ES-2 of the MEP Technical Report) for the Waquoit Bay System three eastern sub-embayments have a large septic system N component. Land-use and wastewater analysis found that generally 68% of the controllable N load to embayment was from septic system effluent.

The threshold N levels for these Waquoit Bay sub-embayments were determined as follows:

The approach for determining nitrogen loading rates, which will maintain acceptable habitat quality throughout the 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. Since each sub-embayment has different characteristics (nutrient loading, nutrient attenuation, tidal flushing, impaired water quality values, etc.) the determination of the acceptable nitrogen concentration must be done on an individual sub-embayment basis.

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 170 and 176, Figure VII-9 of the MEP Technical Report). The tidally averaged nitrogen levels at these sites are 0.498 and 0.524 mg/L N respectively. These values are consistent with the infaunal guidance levels within the Popponesset Bay sub-embayments of 0.5 to 0.4 mg/L N (0.5 mg/L N 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/L N, with 0.52 mg/L N 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/L N, tidally corrected <0.38 mg/L), 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/L N. This is above the 0.38 mg/L threshold likely for the main bay (and utilized for Stage Harbor and Popponesset Bay), but lower than the 0.527-0.552 mg/L found in similar observed conditions such as 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/L 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 of the MEP Technical Report, 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/L target concentration.
- The tidally averaged total nitrogen thresholds derived in Section VIII-2 of the MEP Technical Report were used to adjust the calibrated constituent transport model developed in Section VI (MEP Technical Report). 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.
- The only realistic mechanism for reaching 0.38 mg/L N 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/L N, 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/L. The conclusion is that the nitrogen target restorative of eelgrass within this estuary is 0.446 mg/L.
- Upon review of various modeling scenarios employed to determine threshold loading for Jehu Pond, it appears that the 0.38 mg/L target is also applicable to Hamblin Pond. Hamblin Pond watershed N

management can achieve this N target when Jehu Pond nitrogen levels are reduced to 0.446 mg/L N and the Waquoit Bay main basin is lowered to 0.35 mg/L N. Therefore, it appears that nitrogen management to restore eelgrass in Jehu and Hamblin Ponds, and to lower N levels within the Waquoit Bay main basin, should be considered as part of an integrated nitrogen management plan.

- Achieving the nitrogen target at the sentinel stations will be restorative of eelgrass habitat within 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-use conditions, due to shifts in occupancy, shifts from seasonal to year-round usage 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 overriding 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 (2003) nitrogen inputs and management options to negate additional future nitrogen inputs.

#### Nitrogen loadings to the sub-embayments

##### a) Present loading rates:

In the Waquoit Bay System overall, the highest N loading from controllable sources is from on-site wastewater treatment systems, which is almost always the highest N loading source in each sub-embayment. On-site septic system loadings range from 0.41 kg/day to as high as 14.39 kg/day. Nitrogen loading from the nutrient-rich sediments (referred to as benthic flux) is significant in these sub-embayments. As discussed previously, however, the direct control of N from sediments is not considered feasible. However, the magnitude of the benthic contribution is related to the watershed load. Therefore, reducing the incoming load should reduce the benthic flux over time. The total N loading from all sources ranges from 0.98 kg/day in Upper Hamblin Pond to 39.83 kg/day in the Upper Quashnet River. A further breakdown of N loading, by source, is presented in Table 3. The data on which Table 3 is based can be found in Table ES-1 of the MEP Technical Report.

##### b) Nitrogen loads necessary for meeting the site-specific target nitrogen concentrations.

As previously indicated, the present N loadings to the three Waquoit Bay sub-embayments studied must be reduced in order to restore conditions and to avoid further nutrient-related adverse environmental impacts. The critical final step in the development of the TMDL is modeling and analysis to determine the loadings required to achieve the target N concentrations. Table 4 lists the present controllable watershed N loadings from the three eastern sub-embayments of the Waquoit Bay System. The last two columns indicate one scenario of the reduced sub-watershed loads and percentage reductions that could achieve the target concentrations in the sentinel systems (see following section). It is very important to note that load reductions can be produced through reduction of any or all sources of N, potentially increasing the natural attenuation of nitrogen within the freshwater systems to the embayments, and/or modifying the tidal flushing through inlet reconfiguration. The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the communities involved.

**Table 3. Nitrogen loadings to the Waquoit Bay sub-embayments from within the watersheds (natural background, land use-related runoff, and septic systems), from WWTFs, from the atmosphere, and from nutrient-rich sediments within the embayments.**

Waquoit System Sub-embayments	Natural Background <sup>1</sup> Watershed Load (kg/day)	Present Land Use Load <sup>2</sup> (kg/day)	Present Septic System Load (kg/day)	Present WWTF Load (kg/day)	Present Atmospheric Deposition (kg/day)	Present Benthic Flux <sup>3</sup> (kg/day)	Total nitrogen load from all sources (kg/day)
<b>HAMBLIN POND/ JEHU POND SYSTEM</b>							
Upper Great River	0.22	0.27	0.41	0.00	0.55	9.55	11.00
Lower Great River	0.07	0.47	2.48	0.00	0.75	10.06	13.83
Upper Hamblin Pond	0.48	0.86	4.56	0.00	0.06	-4.98	0.98
Hamblin Pond	0.13	0.37	3.47	0.00	1.53	-3.48	2.02
Jehu Pond	0.12	0.77	2.84	0.00	0.67	10.43	14.83
Little River	0.02	0.15	0.96	0.00	0.16	3.53	4.82
<b>QUASHNET SYSTEM</b>							
Upper Quashnet River	4.29	10.34	14.39	0.43	0.33	10.05	39.83
Lower Quashnet River	0.02	0.22	0.57	0.00	0.25	4.78	5.84

<sup>1</sup> assumes entire watershed is forested (i.e., no anthropogenic sources)

<sup>2</sup> composed of fertilizer, runoff, and atmospheric deposition to lakes

<sup>3</sup> nitrogen loading from (to) the sediments

The presentation of load reductions in Table 4 is to establish the general degree and spatial pattern of reduction that will be required for restoration of these N impaired embayments. It is also very important to note that each of the three sub-embayments will be re-evaluated and integrated into the assessment and modeling of the whole of the Waquoit Bay System once developed. The loadings presented in Table 4 represent one, but not the only, loading reduction scenario that can meet the TMDL goal. Other alternatives may also achieve the desired threshold concentration as well and can be explored using the MEP modeling approach. In the scenario presented, the percentage reductions in N loadings to meet threshold concentrations range from 38% in the Upper Quashnet River up to 80 % in the Lower Great River. Table VIII-2 of the MEP Technical Report (and rewritten as Appendix B of this document) summarizes the present loadings from on-site subsurface wastewater disposal systems and the reduced loads that would be necessary to achieve the threshold N concentrations in these Waquoit Bay sub-embayments, under the scenario modeled here. In this scenario only the on-site subsurface wastewater disposal system loads were reduced to the level of the target threshold watershed load. It should be emphasized once again that this is only one scenario that will meet the target N concentrations in the sentinel systems, which is the ultimate goal of the TMDL. There can be variations depending on the chosen sub-watershed and which controllable source is selected for reduction. Alternate scenarios will result in different amounts of nitrogen being reduced in different sub-watersheds. For example, taking out additional nitrogen upstream will impact how much nitrogen has to be taken out downstream. The towns should take any reasonable effort to reduce the controllable nitrogen sources.

**Table 4. Present Controllable Watershed nitrogen loading rates, reduced loading rates that will achieve target threshold nitrogen concentrations, and the percent reductions of the existing loads which will achieve the target threshold loadings in this scenario.**

Waquoit Bay System Sub-embayments	Present controllable watershed load <sup>1</sup> (kg/day)	Target Threshold Watershed Load <sup>2</sup> (kg/day)	Percent watershed load reductions needed to achieve threshold loads
Upper Great River	0.68	0.32	52.9
Lower Great River	2.95	0.6	79.7
Upper Hamblin Pond	5.42	2.06	62.0
Hamblin Pond	3.84	1.34	65.1
Jehu Pond	3.61	0.96	73.4
Little River	1.11	0.43	61.3
Upper Quashnet River	25.16	15.51	38.4
Lower Quashnet River	0.79	0.41	48.1

<sup>1</sup> Composed of combined fertilizer, runoff, WWTP effluent, and septic system loadings

<sup>2</sup> Target threshold watershed load is the combined load from the sub-watersheds using one scenario that will meet the embayment threshold N concentrations identified in Table 2 above.

### **Total Maximum Daily Loads**

As described in EPA guidance, a total maximum daily load (TMDL) identifies the loading capacity of a water body for a particular pollutant. EPA regulations define loading capacity as the greatest amount of loading that a water body can receive without violating water quality standards. The TMDLs are established to protect and/or restore the estuarine ecosystem, including eelgrass, the leading indicator of ecological health, thus meeting water quality goals for aquatic life support. Because there are no “numerical” water quality standards for N, the TMDLs for the three Waquoit Bay sub-embayments studied are aimed at determining the loads that would correspond to sub-embayment-specific N concentrations determined to be protective of the water quality and ecosystems.

The effort includes detailed analyses and mathematical modeling of land use, nutrient loads, water quality indicators, and hydrodynamic variables (including residence time), for each sub-embayment. The results of the mathematical model are correlated with estimates of impacts on water quality, including negative impacts on eelgrass (the primary indicator), as well as dissolved oxygen, chlorophyll, and benthic infauna.

The TMDL can be defined by the equation:

$$\text{TMDL} = \text{BG} + \text{WLAs} + \text{LAs} + \text{MOS}$$

Where

TMDL = loading capacity of receiving water

BG = natural background

WLAs = portion allotted to point sources

LAs = portion allotted to (cultural) non-point sources

MOS = margin of safety

## Background Loading

Natural background N loading estimates are presented in Table 3 above. Background loading was calculated on the assumption that the entire watershed is forested, with no anthropogenic sources of N.

## Wasteload Allocations

Wasteload allocations identify the portion of the loading capacity allocated to existing and future point sources of wastewater. EPA interprets 40 CFR 130.2(h) to require that allocations for NPDES regulated discharges of storm water be included in the waste load component of the TMDL. On Cape Cod the vast majority of storm water percolates into the ground and aquifer and proceeds into the embayment systems through groundwater migration. The Linked Model accounts for storm water loadings and groundwater loading in one aggregate allocation as a non-point source – combining the assessments of waste water and storm water (including storm water that infiltrates into the soil and direct discharge pipes into water bodies) for the purpose of developing control strategies. Although the vast majority of storm water percolates into the ground, there are a few storm water pipes that discharge directly to water bodies that are subject to the requirements of the Phase II Storm Water NPDES Program. Therefore, any storm water discharges subject to the requirements of a storm water Phase II NPDES permit must be treated as a waste load allocation. Since the majority of the nitrogen loading comes from septic systems, fertilizer and storm water that infiltrates into the groundwater, the allocation of nitrogen for any storm water pipes that discharge directly to any of the embayments is insignificant as compared to the overall groundwater load. Based on land use, the Linked Model accounts for loading for storm water, but does not differentiate storm water into a load and waste load allocation. Nonetheless, based on the fact that there are few storm water discharge pipes within NPDES Phase II communities that discharge directly to embayments or waters that are connected to the embayments, the waste load allocation for these sources is considered to be less than 0.33% (57.83 kg/year) as compared to the overall nitrogen load (17577 kg/year) to the embayments. Looking at individual sub-embayments this load ranged from 0.10-2.92% compared to the individual nitrogen load to each sub-embayment (Appendix C). This is based on the percent of impervious surface within 200 feet of the waterbodies and the relative load from this area compared to the overall load (Table IV-5 of the MEP Technical Report). Although most stormwater infiltrates into the ground on Cape Cod, some impervious areas within approximately 200 of the shoreline may discharge stormwater via pipes directly to the waterbody. For the purposes of waste load allocation it was assumed that all impervious surfaces within 200ft of the shoreline discharge directly to the waterbody. This load is obviously negligible when compared to other sources.

There are two wastewater treatment facilities that discharge to groundwater in the three Waquoit Bay sub-embayments studied, but they are not considered point sources under EPA definition. Both of these facilities are in the Quashnet River sub-watershed. Both of these facilities are required to both nitrify and denitrify as part of their NPDES discharge permit. They both discharge less than 10 mg/L N to the groundwater.

EPA policy also requires that stormwater regulated under the NPDES program be identified and included as a wasteload allocation. As discussed, for the purpose of this TMDL, stormwater loadings are not differentiated into point and non-point sources, because most storm water discharges directly to the ground. EPA and MassDEP authorized the Towns of Mashpee, Falmouth, and Sandwich for coverage under the NPDES Phase II General Permit for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems (MS4s) in 2003. The watershed of the three Waquoit Bay sub-embayments studied that is in Mashpee and Sandwich are located in an area subject to the requirements of the permit, as EPA has mapped these entire areas of the watershed as regulated areas. EPA did not designate the entire watershed area in Falmouth as a regulated urbanized area. While communities need to comply with the Phase II permit only in the mapped Urbanized Areas, the Town of Falmouth has decided to extend all the stormwater permit requirements throughout the entire town, including the three Waquoit Bay sub-embayments watershed area.

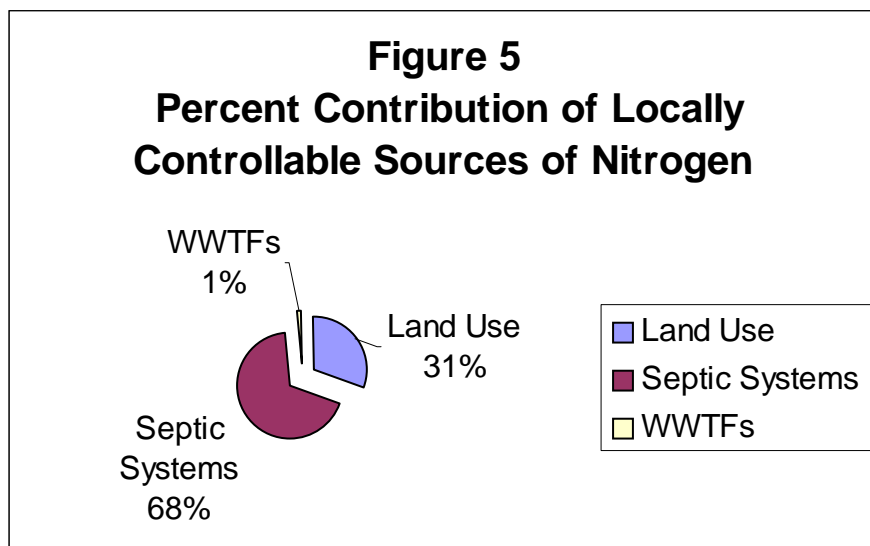
The Phase II general permit requires the permittee to determine whether the approved TMDL is for a pollutant likely to be found in storm water discharges from the MS4. The MS4 is required to implement the storm water waste load allocation, BMP recommendations or other performance requirements of a TMDL and assess whether the waste load allocation is being met through implementation of existing stormwater control measures or if additional control measures are necessary.

### Load Allocations

Load allocations identify the portion of loading capacity allocated to existing and future nonpoint sources. In the case of the Waquoit Bay System sub-embayments studied, the nonpoint source loadings are primarily from on-site subsurface wastewater disposal systems. Additional N sources include: natural background, stormwater runoff (including N from fertilizers), the two WWTFs groundwater discharges, atmospheric deposition, and nutrient-rich sediments.

Generally, stormwater that is subject to the EPA Phase II Program would be considered a part of the wasteload allocation, rather than the load allocation. As presented in Chapter IV, V, and VI, of the MEP Technical Report, on Cape Cod the vast majority of stormwater percolates into the aquifer and enters the embayment system through groundwater. Given this, the TMDL accounts for stormwater loadings and groundwater loadings in one aggregate allocation as a non-point source, thus combining the assessments of wastewater and storm water for the purpose of developing control strategies. Ultimately, when the Phase II Program is implemented in Mashpee and Falmouth, new studies, and possibly further modeling, will identify what portion of the stormwater load may be controllable through the application of Best Management Practices (BMPs).

The two WWTFs currently discharge about 0.43 kg/day of nitrogen into the groundwater. This represents less than 1% of the nitrogen load into the Waquoit Bay System sub-embayments studied (rounded off to 1% in Figure 5 below). This small percentage of N load is due to the fact that the amount of wastewater effluent discharged by these facilities is small and also that the groundwater discharge permits for these facilities has such a low nitrogen limit that the facilities must use treatment technology which will denitrify the effluent prior to discharge. If the towns shifted loads from on-site systems that do not denitrify (septic systems do not normally denitrify) to these wastewater treatment facilities, it would lead to overall decline in N loadings to the sub-embayments.



The sediment loading rates incorporated into the TMDL are lower than the existing sediment flux rates listed in Table 3 above because projected reductions of N loadings from the watershed will result in reductions of nutrient concentrations in the sediments, and therefore, over time, reductions in loadings from the sediments



will occur. Benthic N flux is a function of N loading and particulate organic nitrogen (PON). Projected benthic fluxes are based upon projected PON concentrations and watershed N loads, and are calculated by multiplying the present N flux by the ratio of projected PON to present PON, using the following formulae:

$$\text{Projected N flux} = (\text{present N flux}) (\text{PON projected} / \text{PON present})$$

When:

$$\text{PON projected} = (R_{\text{load}}) (D_{\text{PON}}) + \text{PON}_{\text{present offshore}}$$

$$\text{When } R_{\text{load}} = (\text{projected N load}) / (\text{Present N load})$$

And  $D_{\text{PON}}$  is the PON concentration above background determined by:

$$D_{\text{PON}} = (\text{PON}_{\text{present embayment}} - \text{PON}_{\text{present offshore}})$$

The benthic flux modeled for the three eastern sub-embayments of the Waquoit Bay System is reduced from existing conditions based on the load reduction and the observed PON concentrations within each sub-embayment relative to Waquoit Bay (boundary condition). The benthic flux input to each sub-embayment was reduced (toward zero) based on the reduction of N in the watershed load.

The loadings from atmospheric sources incorporated into the TMDL, however, are the same rates presently occurring, because, as discussed above, local control of atmospheric loadings is not considered feasible.

Locally controllable sources of N within the watersheds are categorized as on-site subsurface wastewater disposal system wastes, land use (which includes stormwater runoff and fertilizers), and waste water treatment facilities. Figure 5 above emphasizes the fact that the overwhelming majority of locally controllable N comes from on-site subsurface wastewater disposal systems.

## **Margin of Safety**

Statutes and regulations require that a TMDL include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality [CWA para 303 (d)(20)(C), 40C.G.R. para 130.7(1)]. The EPA's 1991 TMDL Guidance explains that the MOS may be implicit, i.e., incorporated into the TMDL through conservative assumptions in the analysis, or explicit, i.e., expressed in the TMDL as loadings set aside for the MOS. The MOS for the Waquoit Bay System TMDL is implicit, and the conservative assumptions in the analyses that account for the MOS are described below.

### 1. Use of conservative data in the linked model

The watershed N model provides conservative estimates of N loads to the embayments. Nitrogen transfer through direct groundwater discharge to estuarine waters is based upon studies indicating negligible aquifer attenuation and dilution, i.e. 100% of load enters embayment. This is a conservative estimate of loading because studies have also shown that in some areas less than 100% of the load enters the estuary. Nitrogen from the upper watershed regions, which travel through ponds or wetlands, almost always enter the embayment via stream flow, are directly measured (over 12-16 months) to determine attenuation. In these cases the land-use model has shown a slightly higher predicted N load than the measured discharges in the streams/rivers, which have been assessed to date. Therefore, the watershed model as applied to the surface water watershed areas again presents a conservative estimate of N loads because the actual measured N in streams was lower than the modeled concentrations.

The hydrodynamic and water quality models have been assessed directly. In the many instances where the hydrodynamic model predictions of volumetric exchange (flushing) have also been directly measured by field measurements of instantaneous discharge, the agreement between modeled and observed values has been  $\geq 95\%$ . Field measurement of instantaneous discharge was performed using acoustic doppler current profilers (ADCP) at key locations within each embayment (with regards to the water quality model, it was possible to conduct a quantitative assessment of the model results as fitted to a baseline dataset - a least squares fit of the modeled versus observed data showed an  $R^2 > 0.95$ , indicating that the model accounted for 95% of the variation in the field data). Since the water quality model incorporates all of the outputs from the other models, this excellent fit indicates a high degree of certainty in the final result. The high level of accuracy of the model provides a high degree of confidence in the output, therefore, less of a margin of safety is required.

In the case of N attenuation by freshwater ponds, attenuation was derived from measured site-specific N concentrations, pond delineations and pond bathymetry. These measured attenuation factors were higher than that used in the land-use model. This site-specific data supports a pond attenuation in the 50-60% range as a conservative estimate for the watershed to the three eastern embayments to the Waquoit Bay System.

Similarly, the water column N validation dataset was also conservative. The model is validated to measured water column N. However, the model predicts average summer N concentrations. The very high or low measurements are marked as outliers. The effect is to make the N threshold more accurate and scientifically defensible. If a single measurement 2 times higher than the next highest data point in the series raises the average 0.05 mg/L nitrogen, this would allow for a higher “acceptable” load to the embayment. Marking the very high outlier is a way of preventing a single and rare bloom event from changing the N threshold for a system. This effectively strengthens the data set so that a higher margin of safety is not required.

Finally, the reductions in benthic regeneration of N are most likely underestimates, i.e. conservative. The reduction is based solely on a reduced deposition of PON, due to lower primary production rates under the reduced N loading in these systems. As the N loading decreases and organic inputs are reduced, it is likely that rates of coupled remineralization-nitrification, denitrification and sediment oxidation will increase.

Benthic regeneration of N is dependant upon the amount of PON deposited to the sediments and the percentage that is regenerated to the water column versus being denitrified or buried. The regeneration rate projected under reduced N loading conditions was based upon two assumptions:(1) PON in the embayment in excess of that of inflowing tidal water (boundary condition) results from production supported by watershed N inputs and (2) Presently enhanced production will decrease in proportion to the reduction in the sum of watershed N inputs and direct atmospheric N input. The latter condition would result in equal embayment versus boundary condition production and PON levels if watershed N loading and direct atmospheric deposition could be reduced to zero (an impossibility of course). This proportional reduction assumes that the proportion of remineralized N will be the same as under present conditions, which is almost certainly an underestimate. As a result, future N regeneration rates are overestimated which adds to the margin of safety.

## 2. Conservative threshold sites/nitrogen concentrations

Conservatism was used in the selection of the threshold sites and N concentrations. Sites were chosen that had stable eelgrass or benthic animal (infaunal) communities, and not those just starting to show impairment, which would have slightly higher N concentrations. Meeting the target thresholds in the sentinel sub-embayments will result in reductions of N concentrations in the rest of the systems.

## 3 Conservative approach

The target loads were based on tidal averaged N concentrations on the outgoing tide, which is the worst case

because that is when the N concentrations are the highest. The N concentrations will be lower on the flood tides, therefore this approach is conservative.

In addition to the margin of safety within the context of setting the N threshold levels, described above, a programmatic margin of safety also derives from continued monitoring of these sub-embayments to support adaptive management. This continuous monitoring effort provides the ongoing data to evaluate the improvements that occur over the multi-year implementation of the N management plan. This will allow refinements to the plan to ensure that the desired level of restoration is achieved.

### Seasonal Variation

Nutrient loads to the sub-embayments are based on annual loads for two reasons. Since the TMDLs for the waterbody segments are based on the most critical time period, i.e. the summer growing season, the TMDLs are protective for all seasons. The daily loads can be converted to annual loads by multiplying by 365 (the number of days in a year). Nutrient loads to the sub-embayments are based on annual loads for two reasons. The first is that primary production in coastal waters can peak in both the late winter-early spring and in the late summer-early fall periods. Second, as a practical matter, the types of controls necessary to control the N load, the nutrient of primary concern, by their very nature do not lend themselves to intra-annual manipulation since the majority of the N is from non-point sources. Thus, the annual loads make sense, since it is difficult to control non-point sources of nitrogen on a seasonal basis and that nitrogen sources can take considerable time to migrate to impacted waters.

### TMDL Values for Waquoit Bay Sub-Embaysments

As outlined above, the total maximum daily loadings of N that would provide for the restoration and protection of each sub-embayment were calculated by considering all sources of N grouped by natural background, point sources, and non-point sources. A more meaningful way of presenting the loadings data, from an implementation perspective, is presented in Table 5. In this table the N loadings from the atmosphere and

**Table 5. The Total Maximum Daily Loads (TMDL) for the Waquoit Bay System eastern sub-embayments, represented as the sum of the calculated target thresholds loads (from controllable watershed sources), atmospheric deposition, and sediment sources (benthic flux).**

<b>Waterbody Segment from Category 5 of the 2002 Integrated List</b>	<b>Target Watershed Threshold Load <sup>1</sup> (kg/day)</b>	<b>Atmospheric Deposition (kg/day)</b>	<b>Benthic Flux <sup>2</sup> (kg/day)</b>	<b>TMDL <sup>3</sup> (kg/day)</b>
<b>Great River/Jehu Pond</b>	1.88	1.97	21.51	<b>25</b>
<b>Little River /Hamblin Pond</b>	3.83	1.75	-3.44	<b>2</b>
<b>Quashnet River</b>	15.92	0.58	10.62	<b>27</b>

<sup>1</sup> Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentrations identified in Table 2.

<sup>2</sup> Projected sediment N loadings obtained by reducing the present loading rates (Table 3) proportional to proposed watershed load reductions and factoring in the existing and projected future concentrations of PON.

<sup>3</sup> Sum of target threshold watershed load, atmospheric deposition load, and benthic flux load.

nutrient-rich sediments are listed separately from the target watershed threshold loads, which are composed of natural background N along with locally controllable N from the WWTFs, on-site subsurface wastewater

disposal systems, stormwater runoff, and fertilizers. In the case of the Waquoit Bay sub-embayments that were studied, the TMDLs were calculated by projecting reductions in locally controllable on-site subsurface wastewater disposal system, stormwater runoff, and fertilizer sources. Once again the goal of this TMDL is to achieve the identified N threshold concentration in the identified sentinel system. The target load identified in this table represents one alternative loading scenario to achieve that goal but other scenarios may be possible and approvable as well.

## Implementation Plans

The critical element of this TMDL process is achieving the sub-embayment specific N concentrations presented in Table 2 above, that are necessary for the restoration and protection of water quality and eelgrass habitat within the three Waquoit Bay sub-embayments studied. In order to achieve those target concentrations, N loading rates must be reduced throughout the Waquoit Bay System. Table 5, above, lists target watershed threshold loads for each sub-embayment studied. If those threshold loads are achieved, the three sub-embayments studied will be protected.

As previously noted, this loading reduction scenario is not the only way to achieve the target N concentrations. The Towns are free to explore other loading reduction scenarios through additional modeling as part of the Comprehensive Wastewater Management Plan (CWMP). It must be demonstrated, however, that any alternative implementation strategies will be protective of the overall Waquoit Bay System, and that none of the sub-embayments will be negatively impacted. To this end, additional linked model runs can be performed by the MEP at a nominal cost to assist the planning efforts of the Towns in achieving target N loads that will result in the desired threshold concentrations.

The CWMP should include a schedule of the selected strategies and estimated timelines for achieving those targets. However, the MassDEP realizes that an adaptive management approach may be used to observe implementation results over time and allow for adjustments based on those results.

Because the vast majority of controllable N load is from individual on-site subsurface wastewater disposal systems for private residences, the CWMP should assess the most cost-effective options for achieving the target N watershed loads, including but not limited to, sewerage and treatment for N control of sewage and septage at either centralized or de-centralized locations, and denitrifying systems for all private residences.

The Towns, however, are urged to meet the target threshold N concentrations by reducing N loadings from any and all sources, through whatever means are available and practical, including reductions in stormwater runoff and/or fertilizer use within the watershed through the establishment of local by-laws and/or the implementation of stormwater BMPs, in addition to reductions in on-site subsurface wastewater disposal system loadings.

Although it is not explained in detail previously in this TMDL, it should be noted here that parts of the Town of Sandwich are in the watershed of these three Waquoit Bay sub-embayments. A portion of the upper watershed is located in Sandwich. Thus the development of any implementation plan should keep in mind that a third town needs to be included in coordinating efforts to maximize the reduction in N loading.

DEP's MEP Implementation Guidance report (<http://www.mass.gov/dep/water/resources/restore.htm>) provides N loading reduction strategies that are available to the Towns of Mashpee, Falmouth and Sandwich, and that could be incorporated into the implementation plans. The following topics related to N reduction are discussed in the Guidance:

- Wastewater Treatment
  - On-Site Treatment and Disposal Systems
  - Cluster Systems with Enhanced Treatment
  - Community Treatment Plants

- Municipal Treatment Plants and Sewers
- Tidal Flushing
  - Channel Dredging
  - Inlet Alteration
  - Culvert Design and Improvements
- Stormwater Control and Treatment \*
  - Source Control and Pollution Prevention
  - Stormwater Treatment
- Attenuation via Wetlands and Ponds
- Water Conservation and Water Reuse
- Management Districts
- Land Use Planning and Controls
  - Smart Growth
  - Open Space Acquisition
  - Zoning and Related Tools
- Nutrient Trading

\* The Towns of Mashpee, Falmouth and Sandwich are three of 237 communities in Massachusetts covered by the Phase II stormwater program requirements.

### **Monitoring Plan for TMDL Developed Under the Phased Approach**

The Department recommends that the Towns of Mashpee and Falmouth develop a detailed monitoring plan consistent with the Comprehensive Wastewater Management Planning process and as part of the detailed plan for the TMDL implementation process. The monitoring plan must be designed to determine if water quality improvements occur as a result of implementing this TMDL. This monitoring plan should be developed and conducted in phases according to the identification of N reduction options as part of the adaptive management approach to achieving water quality standards. The Department recognizes the long-term nature of the time horizon for full implementation of the TMDL; however, reasonable milestones in the shorter term are necessary.

Growth should be guided by a consideration of water quality-associated impacts.

### **Reasonable Assurances**

DEP possesses the statutory and regulatory authority, under the water quality standards and/or the State Clean Water Act (CWA), to implement and enforce the provisions of the TMDL, including requirements for N loading reductions from on-site subsurface wastewater disposal systems. However, because most non-point source controls are voluntary, reasonable assurance is based on the commitment of the locality involved. Both Mashpee and Falmouth have demonstrated this commitment through the comprehensive wastewater planning that they initiated well before the generation of the TMDL. The Towns expect to use the information in this TMDL to generate support from their citizens to take the necessary steps to remedy existing problems related to N loading from on-site subsurface wastewater disposal systems, stormwater, and runoff (including fertilizers), and to prevent any future degradation of these valuable resources. Moreover, reasonable assurances that the TMDL will be implemented include enforcement of regulations, availability of financial incentives and local, state and federal programs for pollution control. Storm water NPDES permit coverage will address discharges from municipally owned storm water drainage systems. Enforcement of regulations controlling non-point discharges include local implementation of the Commonwealth's Wetlands Protection Act and Rivers Protection Act, Title 5 regulations for on-site subsurface wastewater disposal systems, and other local regulations such as the Town of Rehoboth's stable regulations. Financial incentives include federal funds available under Sections 319, 604 and 104(b) programs of the CWA, which are provided as part of the Performance Partnership Agreement between MA MassDEP and EPA. Other potential funds and assistance are

available through Massachusetts' Department of Agriculture's Enhancement Program and the United States Department of Agriculture's Natural Resources Conservation Services. Additional financial incentives include income tax credits for Title 5 upgrades and low interest loans for Title 5 on-site subsurface wastewater disposal system upgrades available through municipalities participating in this portion of the state revolving fund program.

## Appendix A

Table A – 1: Summarizes the nitrogen concentrations for Waquoit Bay sub-embayments (from Chapter VI of the accompanying MEP Technical Report)

Table VI-1. Measured and modeled Nitrogen concentrations for the Waquoit Bay system, at stations shown in Figure VI-2, and used in the model calibration plots. All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means.										
Sub-Embayment	monitoring station	2001 mean	2002 mean	2003 mean	data mean	s.d. all data	N	model min	model average	model max
Jehu Pond - JHP	WB 1	0.701	0.581	0.576	0.590	0.065	11	0.577	0.595	0.614
Upper Great River - GRu	WB 2	0.763	0.611	0.558	0.606	0.110	12	0.454	0.557	0.614
Great/Little River - GRI	WB 3	0.774	0.576	0.505	0.569	0.122	12	0.395	0.453	0.570
Hamblin Pond – Hpu	WB 4	-	0.585	0.460	0.539	0.086	11	0.498	0.529	0.551
FW Red Brook - RBfw	WB 5	0.662	0.645	-	0.647	0.026	7	-	-	-
Hamblin Pond Drain-HPcut	WB 10	-	0.551	0.570	0.559	0.066	10	0.477	0.512	0.612
Seapuit River	WB 11	0.484	0.501	0.504	0.500	0.049	12	-	-	-
Upper Waquoit Bay - WBu	WB 12	0.576	0.482	0.447	0.478	0.078	12	-	-	-
Lower Waquoit Bay - WBl	WB 13	0.497	0.392	0.376	0.395	0.072	12	-	-	-
FW Quashnet River-QRfw	WB 6	0.734	0.493	0.471	0.503	0.105	25	-	-	-
Upper Quashnet River-QRu	WB 7	1.587	0.674	0.892	0.830	0.444	10	0.736	0.787	0.842
Mid Quashnet River - QRm	WB 8	0.667	0.830	0.668	0.771	0.279	11	0.683	0.773	0.839
Lower Quashnet River-QRI	WB 9	-	0.560	0.525	0.546	0.091	10	0.465	0.560	0.690

## Appendix B

Table B –1 Summarizes the present on-site subsurface wastewater disposal system loads, and the loading reductions that would be necessary to achieve the TMDL by reducing on-site subsurface wastewater disposal system loads, ignoring all other sources.

Comparison of sub-embayment watershed *septic loads* (attenuated) used for modeling of **Present Conditions** and loading to the Jehu Pond, Hamblin Pond, and Quashnet River Estuaries within the Waquoit Bay System. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

	Present Septic Load (kg/day)	Septic Load (kg/day)	%change
Hamblin Pond	3.47	0.87	-75
Upper Hamblin Pond	1.32	0.33	-75
Little River	0.96	0.24	-75
Lower Great River	2.48	0.00	-100
Upper Great River	0.41	0.00	-100
Jehu Pond	2.84	0.00	-100
Red Brook	3.24	0.81	-75
Upper Quashnet River	0.57	0.19	-67
Lower Quashnet River	1.80	0.59	-67
Moonakis River	16.64	4.16	-67



## Appendix C

The Three Eastern Coastal Sub-Embaysments within the Waquoit Bay System estimated wasteload allocation (WLA) from runoff of all impervious areas within 200 feet of waterbodies.

Subwatershed Name	Impervious subwatershed buffer areas <sup>1</sup>		Total subwatershed Impervious areas		Total Impervious subwatershed load	Total subwatershed load	Impervious subwatershed buffer area WLA	
	Acres	%	Acres	%	Kg/year	Kg/year	Kg/year <sup>2</sup>	% <sup>3</sup>
Quashnet River	4.9	5.5	1177.9	16.9	2419	9795	10.06	0.10
Hamblin Pond	5.4	6.8	108.6	9.2	252	3956	12.53	0.32
Little River	4.3	4.3	8.3	16.5	26	461	13.47	2.92
Great River	8.4	8.2	33.8	6.0	106	1802	26.34	1.46
Jehu Pond	4.2	9.6	23.6	13.2	72	1563	12.81	0.82
TOTAL	27.2	8.3	1352.2	15.0	2875	17577	57.83	0.33

<sup>1</sup>The entire impervious area within a 200 foot buffer zone around all waterbodies as calculated from GIS. Due to the soils and geology of Cape Cod it is unlikely that runoff would be channeled as a point source directly to a waterbody from areas more than 200 feet away. Some impervious areas within approximately 200 feet of the shoreline may discharge stormwater via pipes directly to the waterbody. For the purposes of the wasteload allocation (WLA) it was assumed that all impervious surfaces within 200feet of the shoreline discharge directly to the waterbody.

<sup>2</sup>The impervious subwatershed buffer area (acres) divided by total subwatershed impervious area (acres) then multiplied by total impervious subwatershed load (kg/year).

<sup>3</sup>The impervious subwatershed buffer area WLA (kg/year) divided by the total subwatershed load (kg/year) then multiplied by 100.