DRAFT
Madaket and Long Pond Estuarine System Total Maximum Daily Loads For Total Nitrogen
(Report # 97-TMDL-5 Control # 283.0)

COMMONWEALTH OF MASSACHUSETTS
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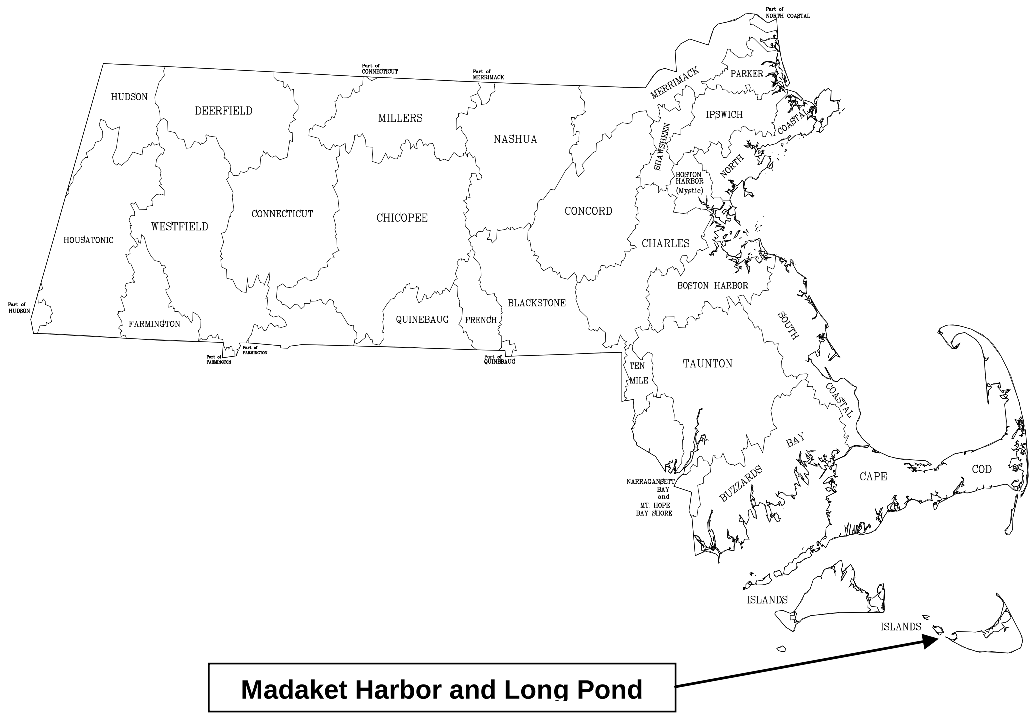


Key Feature: Total Nitrogen TMDLs for Madaket Harbor and Long Pond Estuarine System

Location: EPA Region 1

Land Type: New England Coastal

303d Listing: The water body segments impaired and on the Category 5 list include Hither Creek, Long Pond and Madaket Harbor.

Data Sources: University of Massachusetts – Dartmouth/School for Marine Science and Technology; US Geological Survey; Applied Coastal Research and Engineering, Inc.; Town of Nantucket

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

Monitoring Plan: Town of Nantucket monitoring program (technical assistance from SMAST)

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

Executive Summary

Problem Statement

Excessive nitrogen (N) originating from a range of sources has added to the impairment of the environmental quality of the Madaket Harbor and Long Pond Estuarine System. Excessive N is indicated by:

- Undesirable increases in macro algae
- 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 N 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 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 could result in an overabundance of 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 the Madaket Harbor and Long Pond Estuarine System will be greatly reduced.

Sources of Nitrogen

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

- The watershed
    - Natural background
    - Septic Systems
    - Runoff
    - Fertilizers
    - Wastewater treatment facilities
- Atmospheric deposition
- Nutrient-rich bottom sediments in the embayments

Figure ES-A and Figure ES-B illustrate the percent contribution of all the sources of N and the controllable N sources to the estuary system, respectfully. Values are based on Table IV-2 and Figure IV-6 from the Massachusetts Estuaries Project (MEP) Technical Report. As evident, most of the present *controllable* load to this system comes from septic systems.

Figure ES-A: Percent Contributions of All Nitrogen Sources to the Madaket Harbor and Long Pond Estuarine System

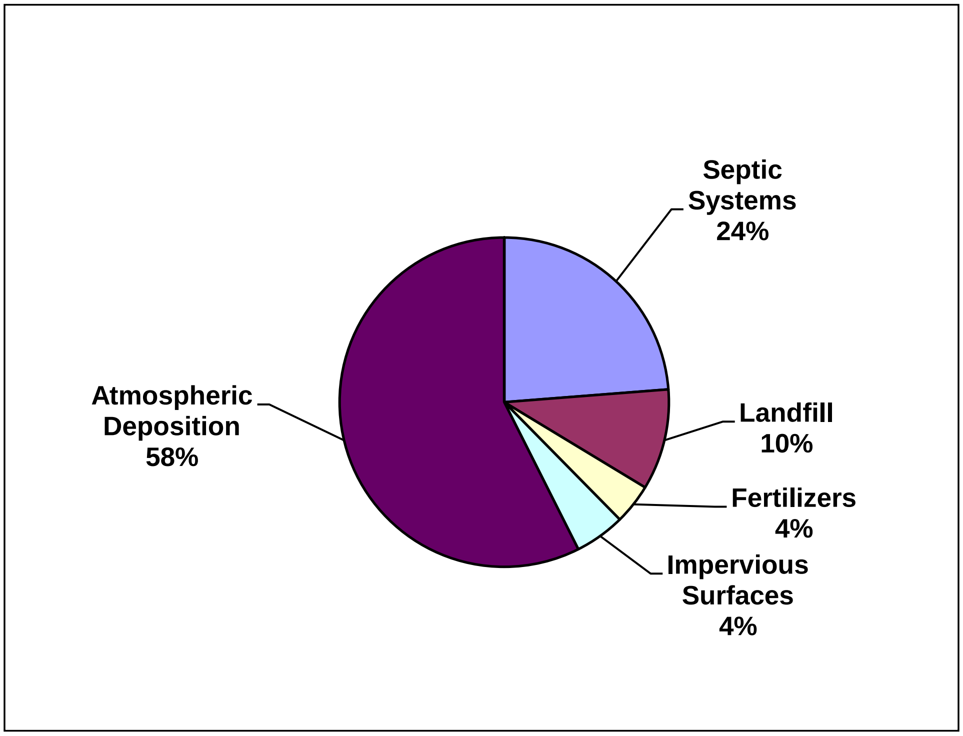
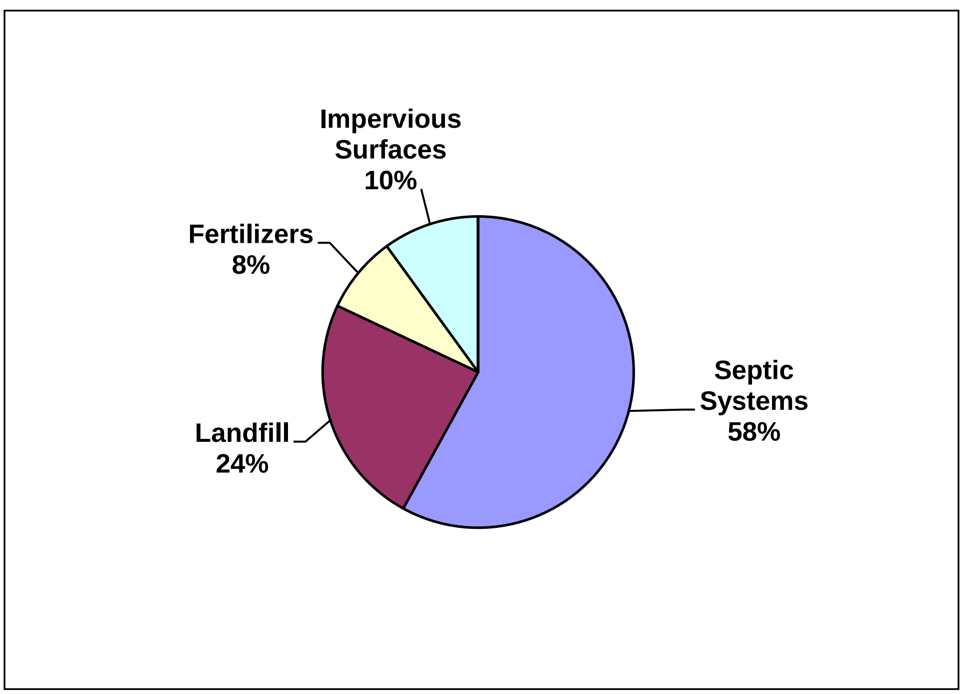


Figure ES-B: Percent Contributions of Controllable Nitrogen Sources to the Madaket Harbor and Long Pond Estuarine System



Target Threshold N Concentrations and Loadings

The N loadings (the quantity of N) to this system ranged from 9.27 kg/day in Madaket Harbor to 4.58 kg/day in Hither Creek, and 5.14 kg/day in Long Pond with total loads for the Madaket Harbor and Long Pond Estuarine System of 21.41 kg N/day (as reported in Table IV-2 of the MEP Technical Report). The resultant concentrations of N ranged from 0.336-0.422 mg/L in Madaket Harbor, 0.581-0.780 mg/L in Hither Creek and 0.894 – 1.058 mg/L in Long Pond (range of average annual means collected from 13 stations during 2002-2004 as reported in Table VI-1 of the MEP Technical Report, and included in Appendix A of this report).

In order to restore and protect this estuarine system, N loadings, and subsequently the concentrations of N in the water, must be reduced to levels below those that cause the observed environmental impacts. This N concentration will be referred to as the *target threshold N concentration*. The Massachusetts Estuaries Project (MEP) has determined that by achieving a N concentration of 0.45 mg/L near sentinel station M11 in Hither Creek, water and habitat quality will be restored in these systems. The mechanism for achieving the target threshold N concentrations is to reduce the N loadings to the watershed of the harbor estuarine system. Based on the MEP sampling and modeling analyses and their Technical Report, the MEP study has determined that the Total Maximum Daily Loads (TMDL) of N that will meet the target threshold N concentration of 0.45 mg/L range from 1.67 kg/day in the Hither Creek subwatershed to 27.218 kg/day in the Madaket Harbor subwatershed. To meet these TMDLs this report recommends a reduction of 100% of the septic load for the Hither Creek subwatershed and assumes that the landfill load will be eliminated by completing the ongoing mining and capping project being conducted by the town. This document presents the TMDLs for these water body systems and provides guidance to the watershed community of Nantucket on possible ways to reduce the N loadings to within the recommended TMDL and protect the waters of these embayment systems.

Implementation

The primary goal of TMDL implementation will be lowering the concentrations of N by reducing the loadings from on-site subsurface wastewater disposal systems by 100% in the Hither Creek subwatershed. However, there is a variety of loading reduction scenarios that could achieve the target threshold N concentrations. Local officials can explore other loading reduction scenarios through additional modeling as part of their Comprehensive Wastewater Management Plan (CWMP). In addition, the Town of Nantucket is currently involved in an implementation process to reduce the landfill contribution to the nitrogen load of Long Pond. It is expected that the landfill nitrogen loads will likely be eliminated after completion of this project and these TMDLs are calculated based on that assumption. Implementing best management practices (BMPs) to reduce N loadings from fertilizers and runoff where possible will also help to lower the total N load to these systems. Methods for reducing N loadings from these sources are explained in detail in the "MEP Embayment Restoration Guidance for Implementation Strategies" that is available on the MassDEP website http://www.mass.gov/dep/water/resources/coastalr.htm#guidance. 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.

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Introduction

Section 303(d) of the Federal Clean Water Act requires each state to identify waters that are not meeting water quality standards and 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 watershed town of Nantucket 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 Madaket Harbor and Long Pond Estuarine System the pollutant of concern for these TMDLs (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 impairs the healthy ecology of the affected water bodies.

The TMDLs for total N for the Madaket Harbor and Long Pond Estuarine System are based primarily on data collected, compiled and analyzed by University of Massachusetts Dartmouth's School of Marine Science and Technology (SMAST) Coastal Systems Program and the Town of Nantucket Marine Department as part of the Massachusetts Estuaries Project (MEP). The data were collected over a study period from 2001 through 2007. This study period will be referred to as the "present conditions" in the TMDL report since it contains the most recent data available. The accompanying MEP Technical Report can be found at http://www.oceanscience.net/estuaries/reports.htm. The MEP Technical Report presents the results of the analyses of the coastal embayment systems using the MEP Linked Watershed-Embayment N Management Model (Linked Model). The analyses were performed to assist the watershed community 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 assessment of water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements and benthic community structure that was conducted on this embayment. These assessments served as the basis for generating a N loading threshold for use as a goal for watershed N management. The TMDLs are based on the site specific N threshold generated for this estuarine system. Thus, the MEP offers a science-based management approach to support the wastewater management planning and decision-making process in the watershed community of Nantucket.

Description of Water Bodies and Priority Ranking

The Madaket Harbor and Long Pond Estuarine System is located entirely within the Town of Nantucket making Nantucket the sole municipal steward of this system (see Figures 1 and 2).

The estuarine system is located at the western end of Nantucket Island. Madaket Harbor is an open-water, well flushed shallow basin with its western boundary generally open to Nantucket Sound and the Atlantic Ocean. A dynamic network of sand shoals along the harbor boundary may restrict circulation somewhat. The southern boundary of the Harbor is defined by a long sand spit that periodically is breached to the Atlantic Ocean and the northern shore is defined by Eel Point.

The only surface water tributary to Madaket Harbor is Hither Creek, which is connected to brackish Long Pond via Madaket Ditch. Hither Creek is an artificially deepened basin that opens into Madaket Harbor, Madaket Ditch is a shallow, narrow ditch and inland Long Pond is brackish and shallow. This tributary component obtains freshwater inflow primarily via groundwater contributions due to the highly permeable nature of the watershed soils. Compared to the harbor, circulation and flushing are limited, especially within Long Pond. Long Pond was divided into a northern, middle and lower section in the MEP study.

This estuarine system constitutes an important component of the area’s natural and cultural resources. The nature of enclosed 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 Madaket Harbor and Long Pond Estuarine system are at risk of further eutrophication from high nutrient loads in the groundwater and runoff from their watersheds. Hither Creek and Long Pond are already listed as impaired for nutrients and requiring a TMDL (Category 5) in the MA 2008 Integrated List of Waters, as summarized in Table 1. Madaket Harbor and Long Pond are listed as impaired for pathogens and are included in Table 1 for completeness. Further discussion of pathogens is beyond the scope of this TMDL.

Table 1. Nantucket MEP Study Waterbodies in Category 5 of the MA 2008 Integrated List (MassDEP 2008)

Name	Water Body Segment	Description	Size	Pollutant Listed
Hither Creek (9764000)	MA97-28_2008	From the outlet of Madaket Ditch to Madaket Harbor at an imaginary line drawn easterly from Jackson Point to Little Neck, Nantucket	0.07 sq mi	-Nutrients -Organic enrichment/Low DO
Long Pond (97050)	MA97-29_2008	South of Madaket Road, including White Goose Cove, Nantucket	0.12 sq mi	-Nutrients -Organic enrichment/Low DO -Pathogens -Turbidity
Madaket Harbor (97910)	MA97-27_2008	Waters encompassed within imaginary lines from Eel Point to the northern tip of Esther Island, from the southern tip of Esther Island southeasterly to the opposite shore and from Jackson Point easterly to Little Neck, Nantucket	1.4 sq mi	-Pathogens

Complete descriptions of these embayment systems are presented in Chapters I and IV of the MEP Technical Report. A majority of the information presented here is drawn from this report. Chapters VI and VII of the MEP Technical Report provide assessment data that show that the Madaket Harbor and Long Pond Estuarine System is impaired because of nutrients, low dissolved oxygen levels, elevated chlorophyll *a* levels, and benthic fauna habitat. Table 2 identifies the segments previously listed in Category 5 of the Integrated List of Waters by MassDEP and the segments that were observed to be impaired through the MEP analysis.

The embayments addressed by this document have been determined to be "high priority" based on three significant factors: (1) the initiative that the Town of Nantucket has taken to assess the conditions of the entire embayment system; (2) the commitment made by the town to restore the Madaket Harbor and Long Pond; and (3) the extent of impairment in the Madaket Harbor and Long Pond Estuarine System. 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. 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 2: Comparison of Impaired Parameters for the Nantucket Segments

Name	DEP Listed Impaired Parameter	SMAST Listed Impaired Parameter
Madaket Harbor	- Pathogens	-Nutrients
Hither Creek	-Nutrients -Organic enrichment/Low DO	-Nutrients -DO level -Chlorophyll -Benthic fauna
Long Pond	-Nutrients -Organic enrichment/Low DO -Pathogens -Turbidity	-Nutrients -DO level -Chlorophyll -Benthic fauna

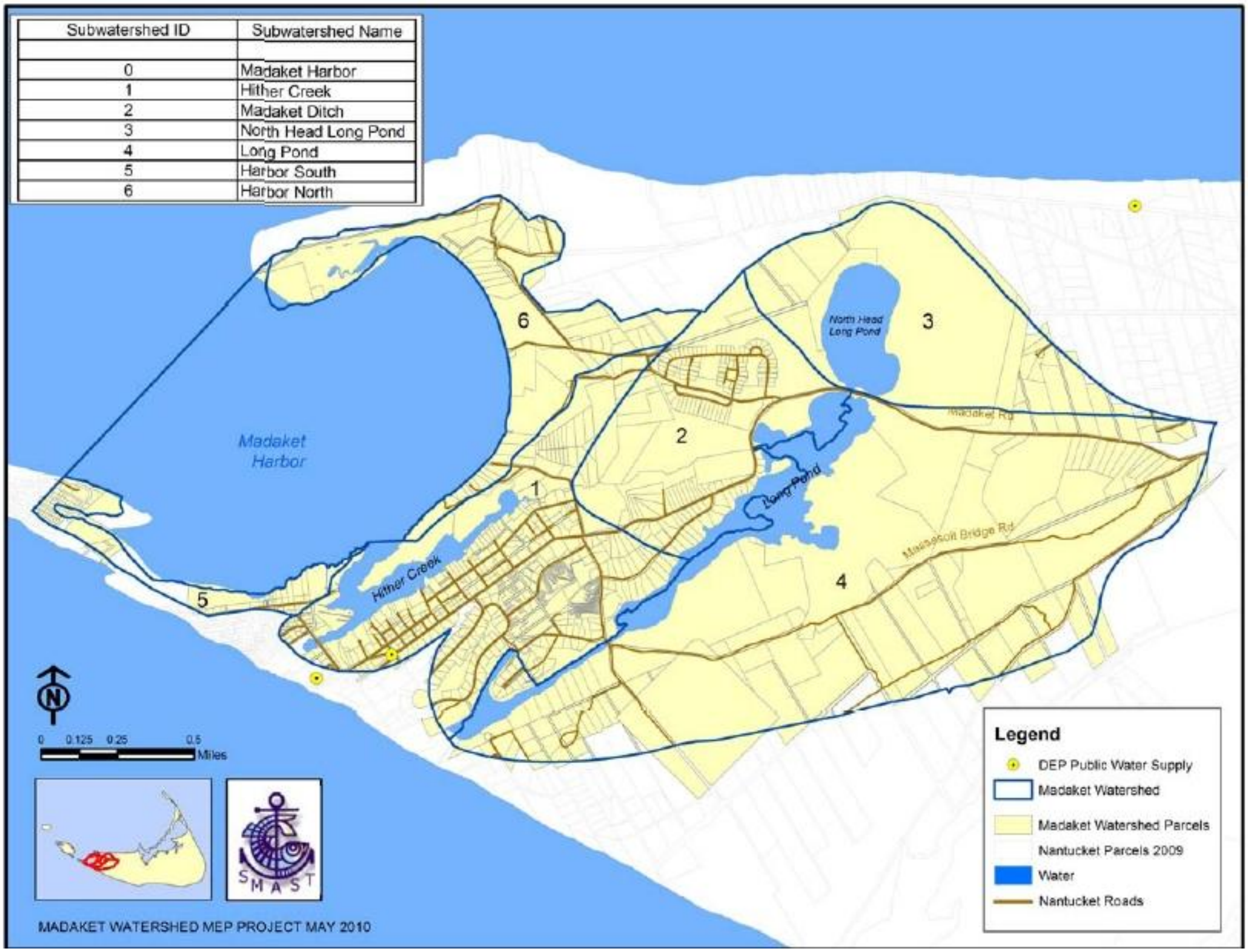


Figure 1: Watershed Delineations for the Madaket Harbor and Long Pond Estuarine System

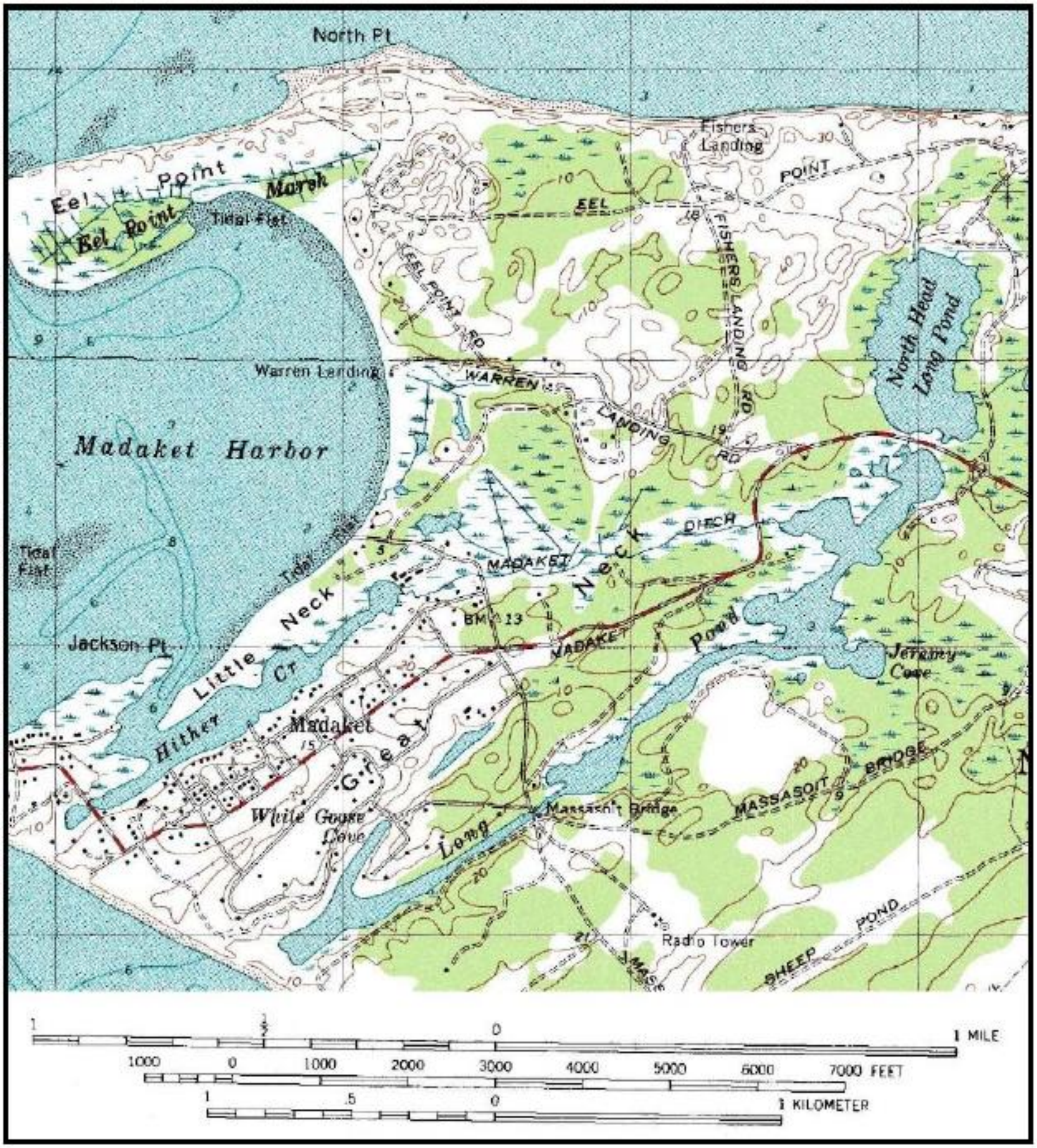


Figure 2: Map of the Madaket Harbor and Long Pond Estuarine System
(from United States Geological Survey topographic maps).

Problem Assessment

Water quality problems associated with development within the watershed result primarily from septic systems and from runoff, including fertilizers.

The water quality problems affecting nutrient-enriched embayments generally include periodic decreases of dissolved oxygen, decreased diversity and quantity of benthic animals and periodic algae blooms. In the most severe cases habitat degradation could lead to periodic fish kills, unpleasant odors and scums and near loss of the benthic community and/or presence of only the most stress-tolerant species of benthic animals.

Coastal communities, including Nantucket, 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 shell fishing. The continued degradation of this coastal embayment, as described above, will significantly reduce the recreational and commercial value and use of these important environmental resources.

Figure 3 shows how the population of Nantucket has more than doubled from less than 4,000 people in 1930 to over 9,500 people in 2000. Increases in N loading to estuaries are directly related to increasing development and population in the watershed. The Town of Nantucket has been among the fastest growing towns in the Commonwealth over the past two decades. This increase in population contributes to a decrease in undeveloped land and an increase in septic systems, runoff from impervious surfaces and fertilizer use. Although the Nantucket downtown area is serviced by a centralized wastewater treatment facility, all the residences in the Madaket Harbor and Long Pond watershed are serviced by septic systems. The greatest level of development and residential load is situated in the nearshore regions of the system. These unsewered areas contribute significantly to the system through transport in direct groundwater discharges to estuarine waters and through surface water flows from Long Pond to Madaket Ditch and Hither Creek.

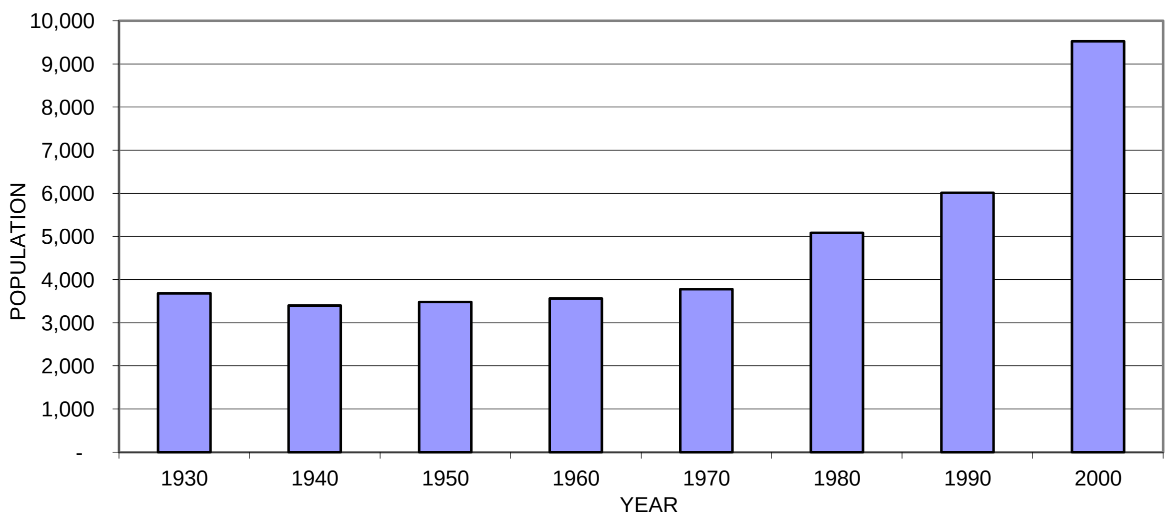


Figure 3: Resident Population for Nantucket

Habitat and water quality assessments were conducted on this estuarine system based upon water quality monitoring data, changes in eelgrass distribution, time-series water column oxygen measurements and benthic community structure. The MEP evaluation of habitat quality supported by each area considers its natural structure and its ability to support eelgrass beds and the types of infaunal communities that they support (Table 3). At present, Madaket Harbor and particularly Hither Creek and Long Pond appear to have reached their nitrogen loading thresholds. This is demonstrated by the existing low habitat and water quality of Hither Creek (loss of eelgrass) and Long Pond. Although large portions of Madaket Harbor still support eelgrass, the slight decline of eelgrass in certain areas suggests a degree of impairment. Consistent with a system at its nitrogen threshold for eelgrass habitat, most of the Harbor is currently supporting productive benthic animal communities, oxygen is not depleted, chlorophyll *a* levels are low and macroalgae is sparse. In contrast Hither Creek is nitrogen enriched with a tidally averaged TN concentration of 0.51 mg N/l compared to 0.33 mg N/l seen in Madaket Harbor. This results in high chlorophyll *a*, periodic hypoxia, and complete loss of eelgrass, dense macroalgae and impaired benthic communities. Long Pond is also nitrogen enriched, however due to the influence of natural wetland systems the level of impairment is moderate as demonstrated by high chlorophyll *a* levels and periodic blooms, and somewhat altered benthic community structure. There is no evidence that eelgrass habitat existed previously in the Long Pond basins so absence does not indicate impairment of this habitat.

Table 3: General Summary of Conditions Related to the Major Indicators of Habitat Impairment Observed in the Madaket Harbor and Long Pond Estuarine System

Health Indicator	Madaket Harbor Estuarine System				
	Madaket Harbor	Hither Creek	Long Pond		
			Mid	Lower	North Head
Dissolved Oxygen	H	SI	MI/SI	MI	H
Chlorophyll	H	MI/SI	SI	MI/SI	H/MI
Macroalgae	H	SI	-	-	-
Eelgrass	H	SI	--	--	--
Infaunal Animals	H	SI	MI	MI	H/MI
Overall	**H**	**SI**	**MI**	**MI**	**H/MI**

H - Healthy Habitat Conditions*
MI – Moderately Impaired*
SI – Significantly Impaired- considerably and appreciably changed from normal conditions*
* - 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/nitroest.pdf
\- drift algae sparse or absent
-- no evidence this basin is supportive of eelgrass

Pollutant of Concern, Sources, and Controllability

In the coastal embayments of the Town of Nantucket, as in most marine and coastal waters, the limiting nutrient is N. 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.

The embayments addressed in this TMDL report have had extensive data collected and analyzed through the Massachusetts Estuaries Program (MEP) and with the cooperation and assistance from the Town of Nantucket, 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.

Figure 4a illustrates all of the sources of N to the Madaket Harbor and Long Pond Estuarine System and Figure 4b shows just the controllable sources. As evident, most of the controllable N affecting these systems originates from on-site subsurface wastewater disposal systems (septic systems). The level of "controllability" of each source, however, varies widely:

Atmospheric deposition– Although helpful, local controls are not adequate – it is only through region- and nation-wide air pollution control initiatives that significant reductions are feasible, however the N from these sources might be subjected to enhanced natural attenuation as it moves towards the estuary.

Fertilizer –Fertilizer and related N loadings can be reduced through best management practices (BMPs), bylaws and public education.

Impervious surfaces and storm-water runoff sources of N can be controlled by BMPs, bylaws and storm-water infrastructure improvements and public education;

Septic system sources of N can be controlled by a variety of case-specific methods including: sewering and treatment at centralized or decentralized locations, transporting and treating septage at treatment facilities with N removal technology either in or out of the watershed, or installing N-reducing on-site wastewater treatment systems.

Landfill – the Town of Nantucket operates a landfill adjacent to the north eastern shore of Long Pond. Nitrogen loads from the landfill are currently being reduced by a 5 year program to mine the accumulated deposits and line and cap remaining materials. Nitrogen loads from the landfill site will be reduced by activities completed during the present 5 year phase, and will likely be eliminated if the landfill is capped in the future.

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

Figure 4a: Percent Contribution of Nitrogen Sources to the Madaket Harbor and Long Pond Estuarine System

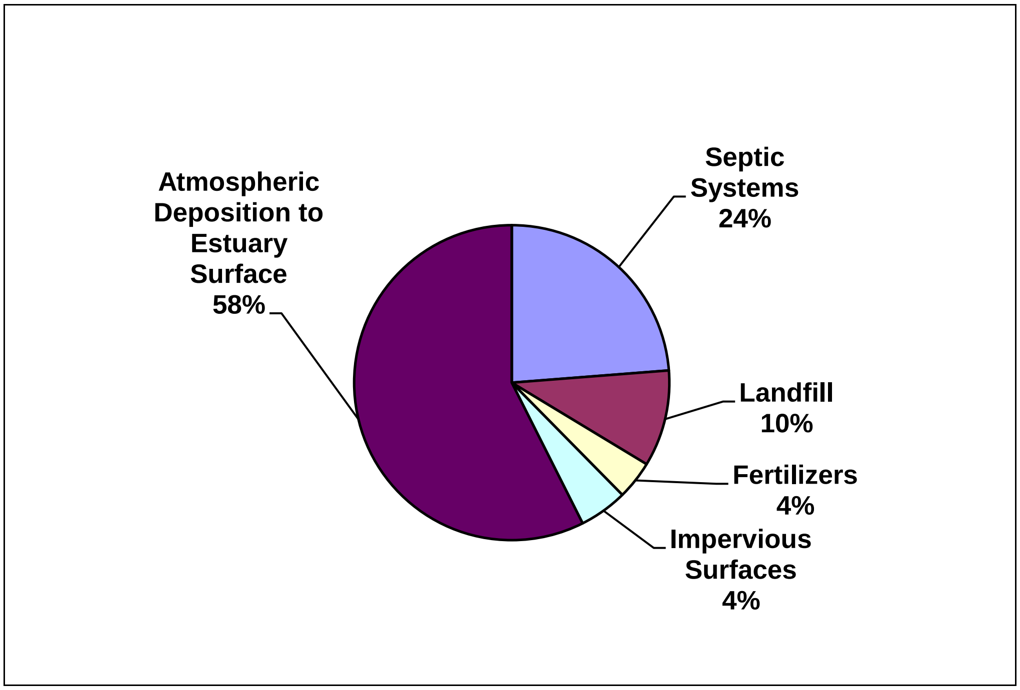
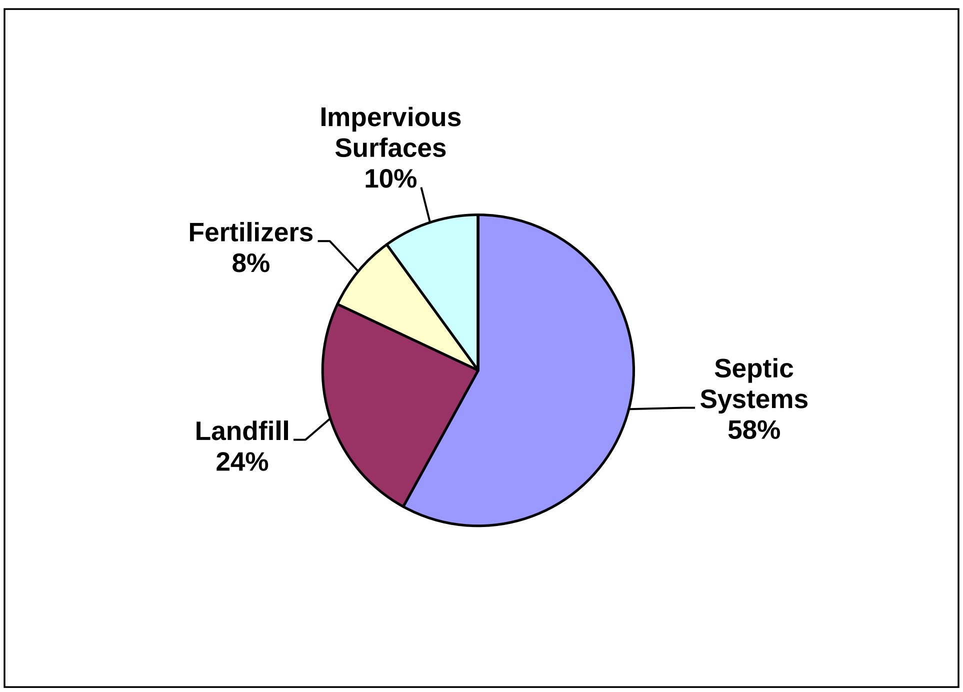


Figure 4b: Percent Contributions of Controllable Nitrogen Sources to the Madaket Harbor and Long Pond Estuarine System



Description of the Applicable Water Quality Standards

The water quality classifications of the saltwater portions of Madaket Harbor and Long Pond Estuarine System are SA (all surface waters subject to the rise and fall of the tide), and the freshwater portions of the system are classified as B. Water quality standards of particular interest to the issues of cultural eutrophication are dissolved oxygen, nutrients, aesthetics, and 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 or combinations 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 - Unless naturally occurring, all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses and shall not exceed the site specific criteria developed in a TMDL or as otherwise established…"

314 CMR 4.05(b) 1:

Class SA:
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.

Class B:
Dissolved Oxygen -
a. Shall not be less than 6.0 mg/L in cold water fisheries and not less than 5.0 mg/L in warm water fisheries;
b. Where natural background conditions are lower, DO shall not be less than natural background conditions. Natural seasonal and daily variations that are necessary to protect existing and designated uses shall be maintained.

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 tend to have unique characteristics and development of individual water body criteria is typically required.

Methodology - Linking Water Quality and Pollutant Sources

Extensive data collection and analyses have been described in detail in the MEP Technical Report. Those data were used by SMAST to assess the loading capacity of each 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 harmful or excessive algal blooms;
3) Restore and preserve benthic communities;

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.

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 over 30 embayments thus far 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. Also, 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 embayment's (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. 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 embayments for the purpose of developing target N loading rates includes:

1) Selecting one or two stations within the embayment system located close to the inland-most reach or reaches which typically have the poorest water quality within the system. These are called "sentinel" stations;

2) Using site-specific information and a minimum of three years of sub-embayment-specific data to select target threshold N concentrations for each sub-embayment. This is done by refining the draft target threshold N concentrations that were developed as the initial step of the MEP process. The target threshold N 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 that will achieve the target threshold N concentration at the sentinel station. Differences between the modeled N load required to achieve the target threshold 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 TMDL. Two outputs are related to **N concentration:**

a) The present N concentrations in the sub-embayments
b) Site-specific target threshold N concentrations

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

a) The present N loads to the sub-embayments
b) Load reductions necessary to meet the site specific target N concentrations

In summary: if the water quality standards are met by reducing the N concentration (and thus the N load) at the sentinel station(s), then the water quality goals will be met throughout the entire system.

A brief overview of each of the outputs follows:

<u>Nitrogen concentrations in the embayment</u>

a) Observed "present" conditions:

Table 4 presents the average concentrations of N measured in this estuarine system from three years of data collection by the Nantucket Marine Department and SMAST (2002, 2003 and 2004). The overall means and standard deviations of the averages are presented in Appendix A (taken from Table VI-1 of the MEP Technical Report). Water quality sampling stations are shown in Figure 5. The sentinel station, M11 is labeled in bold italics.

Table 4: Present Nitrogen Concentrations and Sentinel Station Target Threshold Nitrogen Concentrations for the Madaket Harbor and Long Pond Estuarine System

Sub-embayment	Range of Observed Nitrogen Concentration [1] (mg/L)	Target Threshold Nitrogen Concentration (mg/L)
Madaket Harbor	0.336-0.422	
Hither Creek	0.581-0.780	0.45[2]
Long Pond	0.894-1.058	0.80[3]

[1] Average total N concentrations from present loading based on an average of the annual N means from 2002 - 2004.
[2] Target threshold N concentration at Hither Creek sentinel station M11
[3] Secondary target threshold N concentration for Long Pond (pond average of stations LOP01, LOP02, LOP03, LOP04)

Figure 5: Water Quality Sampling Stations in the Madaket Harbor and Long Pond Estuarine System

b) Modeled site-specific target threshold N 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 target threshold N concentrations by using the specific physical, chemical and biological characteristics of each harbor embayment system.

The target threshold N concentration for an embayment represents the average water column concentration of N that will support the habitat quality and dissolved oxygen concentrations 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), 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.
Target threshold N concentrations in this study were developed to restore or maintain SA waters or high habitat quality. In this system, high habitat quality was defined as stable fringing eelgrass beds in Hither Creek and overall diverse benthic animal communities and dissolved oxygen levels that would support Class SA waters.

The target threshold nitrogen concentrations for the sub-embayments listed in Table 4 were determined as follows:

The approach for determining nitrogen loading rates, which will maintain acceptable habitat quality throughout an 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 the restoration of that one site will necessarily bring the other regions of the system to acceptable habitat quality levels. Once the sentinel site and its target threshold nitrogen concentration are determined, the MEP study modeled nitrogen loads until the targeted nitrogen concentration was achieved.

The determination of the critical nitrogen threshold for maintaining high habitat with the Madaket Harbor and Long Pong Estuarine System is based on the nutrient and oxygen levels, temporal trends in eelgrass distribution and benthic community indicators. Overall the main, open water basin of Madaket Harbor is supporting high quality eelgrass habitat and productive benthic animal communities. However, the enclosed basin of Hither Creek is nitrogen enriched, demonstrated by high chlorophyll, periodic episodes of low oxygen, complete loss of eelgrass habitat, areas of dense drift algae and impaired benthic animal habitat. Long Pond is also nitrogen enriched beyond its assimilative capacity, but given the natural and organic matter enrichment of wetland influenced tidal basins such as brackish Long Pond the level of impairment is only moderate, demonstrated by high chlorophyll levels and a somewhat impaired benthic community. There is no evidence that eelgrass habitat ever existed previously in Long Pond, so this absence does not indicate impairment. Therefore, the threshold analysis focused on the goal of restoring eelgrass habitat for Hither Creek. Restoration of eelgrass to pre- 1951 coverage is now unlikely due to the enhanced depth of this sub-basin therefore restoration of the fringing eelgrass beds that existed in 1951 and 1995 is the management target. Nitrogen management to restore eelgrass habitat within Hither Creek will also result in restoration of the impaired benthic habitat, as nitrogen enrichment will be significantly reduced to the overall estuary. The most appropriate sentinel station for this system was determined to be located at the northern-most extent of the 1951 eelgrass coverage in Hither Creek which coincides with the baseline Nantucket water quality monitoring station M11.

To achieve the restoration target of restoring the fringing eelgrass bends in Hither Creek requires lowering the level of nitrogen enrichment. In shallow systems like Hither Creek, eelgrass beds are sustainable at higher TN levels than in deeper waters. For example, the observed loss of eelgrass in Hither Creek is similar to that in shallow Farm Pond on Martha’s Vineyard where declining eelgrass was observed at a tidally averaged TN of

0.51 mg/L. Other similar examples include Bournes Pond where eelgrass can still be found (although stressed) at the mouth of a tributary at a tidally averaged TN concentration of 0.481 mg/L, while the more stable beds in Israel's Cove had a tidally average TN of 0.429 mg/L. Therefore to restore eelgrass habitat in Hither Creek the nitrogen concentration at the sentinel location needs to be between 0.48 and 0.43 mg/L TN. A threshold concentration of 0.45 mg/l TN was determined to be appropriate for the Hither Creek sentinel station to restore eelgrass and infaunal habitat with this basin. This target threshold concentration is consistent with high quality shallow water habitat in Bournes Pond and is similar to eelgrass observed within the Parker's River at a tidally averaged TN level of 0.45 mg/L TN. This represents a relatively high target threshold nitrogen concentration as a result of the shallow depth of the area of potential eelgrass habitat.

The benthic habitats in the brackish Long Pond system are naturally nitrogen enriched so a moderate reduction in nitrogen levels was determined to be sufficient to restore benthic habitat here. In tidal wetlands nitrogen levels between 1 and 2 mg/L TN are associated with unimpaired habitat. This is consistent with the only slight impairment of the North Head of Long Pond at TN levels of 0.894 mg/L and the moderately impaired benthic habitat in Long Pond at a basin averaged TN of 0.939 mg/L. Therefore, a secondary target nitrogen threshold concentration of 0.8 mg/L TN (pond-wide average) was determined to be supportive of benthic animal habitat in this system. Watershed nitrogen management to achieve this "check" nitrogen level will ensure restoration of infaunal habitats within the down-gradient reach as well. The secondary criteria should be met when the target threshold is met at the sentinel station. Based on this, eelgrass is the primary nitrogen management goal for Hither Creek and improved infaunal habitat quality the management target for Long Pond.

The findings of the analytical and modeling investigations for theses embayment systems are discussed and explained below.

Nitrogen loadings to the embayment

a) Present Loading rates:

In the Madaket Harbor and Long Pond Estuarine System overall, the highest N loading from ***controllable*** sources is from on-site wastewater treatment systems. The MEP Technical Report calculates that septic systems account for 58% of the controllable N load to Madaket Harbor and Long Pond. Other sources include the landfill (24%), fertilizers (8%), and runoff from impervious surfaces (10%). The MEP study determined that sediments did not contribute nitrogen to this system. Atmospheric nitrogen deposition to the estuary and watershed surface area was found to be significant (58% of the total load) however this source is considered uncontrollable. (See Figures 4a and 4b.)

A subwatershed breakdown of N loading, by source, is presented in Table 5. The data on which Table 5 is based can be found in Table ES-1 and Table IV-2 of the MEP Technical Report.

As previously indicated, the present N loadings to these embayment systems must be reduced in order to restore the impaired 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 that will achieve the target threshold N concentrations.

Table 5: Present Nitrogen Loadings to the Madaket Harbor and Long Pond Estuarine System

Sub-embayment	Present Land Use Load[1] (kg N/day)	Present Septic System Load (kg N/day)	Present Watershed Load[2] (kg N/day)	Present Atmospheric Deposition[3] (kg N/day)	Present Benthic Flux[4] (kg N/day)	Total Nitrogen Load from All Sources[5] (kg N/day)
Madaket Harbor	0.279	0.384	0.663	8.603	17.952	27.218
Hither Creek	1.134	2.907	4.041	0.534	0	4.575
Madaket Ditch	0.923	1.510	2.433	--	0.061	2.494
Long Pond	2.888	0.342	3.230	0.975	3.283	7.488
North Head Long Pond	0.167	0.071	0.238	0.693	0.995	1.926
System Total	5.392	5.214	10.605	10.805	22.291	43.701

[1] Includes fertilizers, runoff, landfill and atmospheric deposition to lakes and natural surfaces
[2] Includes fertilizer, runoff, landfill, atmospheric deposition to lakes and natural surfaces and wastewater inputs
[3] Atmospheric deposition to the estuarine surface only
[4] Nitrogen loading from sediments, negative fluxes have been set to zero
[5] Composed of fertilizer, runoff, landfill, wastewater, atmospheric deposition and benthic nitrogen input

b) Nitrogen loads necessary for meeting the site-specific target threshold N concentrations:

Table 6 lists the present watershed N loadings from the Madaket Harbor and Long Pond Estuarine System and the percent watershed load reductions necessary to achieve the target threshold N concentration at the sentinel stations.

It is very important to note that load reductions can be produced through a variety of strategies: reduction of any or all sources of N; increasing the natural attenuation of N within the freshwater systems; and/or modifying the tidal flushing through inlet reconfiguration (where appropriate). This scenario establishes the general degree and spatial pattern of reduction that will be required for restoration of the N impaired portions of this system. The Town of Nantucket should take any reasonable actions to reduce the controllable N sources.

Table 6: Present Watershed Nitrogen Loading Rates, Calculated Loading Rates that are Necessary to Achieve Target Threshold Nitrogen Concentrations, and the Percent Reductions of the Existing Loads Necessary to Achieve the Target Threshold Loadings

Sub-embayment System	Present Total Watershed Load [1] (kg/day)	Target Threshold Watershed Load[2] (kg/day)	Percent Watershed Load Reductions Needed to Achieve Target
Madaket Harbor	0.663	0.663	0%
Hither Creek	4.041	1.134	71.9%
Madaket Ditch	2.433	2.433	0%
North Head Long Pond	0.238	0.238	0%
Long Pond	3.230	1.101	65.9%
Total for Madaket Harbor/ Long Pond Estuarine System	10.605	5.570	47.5%

[1] Composed of septic, fertilizer, landfill and runoff loadings.
[2] Target threshold watershed load is the N load from the watershed (including natural background) needed to meet the target threshold N concentrations identified in Table 4, above.
Taken from Tables ES-2 and VIII-3 in the MEP Technical Report

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 Madaket Harbor and Long Pond estuarine system are aimed at establishing the loads that would correspond to specific N concentrations determined to be protective of the water quality and ecosystems.

The development of a TMDL requires detailed analyses and mathematical modeling of land use, nutrient loads, water quality indicators, and hydrodynamic variables (including residence time) for each waterbody system. 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 *a* and benthic infauna.

The TMDL can be defined by the equation:

$$TMDL = BG + WLAs + LAs + MOS$$

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 is included in the loading estimates, but is not quantified or presented separately. It is a component of the target watershed threshold.

Waste Load Allocations

Waste load allocations identify the portion of the loading capacity allocated to existing and future point sources of wastewater. In the Madaket Harbor and Long Pond estuary system there are no NPDES regulated point source discharges in the watershed. EPA interprets 40 CFR 130.2(h) to require that allocations for NPDES regulated discharges of storm water also be included in the waste load component of the TMDL. It should be noted that no part of the Town of Nantucket is designated as an urbanized area by EPA and thus is not required to obtain coverage under the NPDES Phase II General Permit for Storm-water Discharges from Small Municipal Separate Storm Sewer Systems (MS4s) in 2003. Subsequently, in the Madaket Harbor and Long Pond watershed there are no Phase II NPDES permitted stormwater discharges. However, there are a few storm water pipes that discharge directly to water bodies and MassDEP has determined that these must also be treated as part of a waste load allocation.

In the Madaket/Long Pond watershed, as in much of Cape Cod and the Islands, 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 and groundwater loadings 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. Based on land use, the Linked Model accounts for loading from storm-water, but does not differentiate storm-water into a load and waste load allocation.

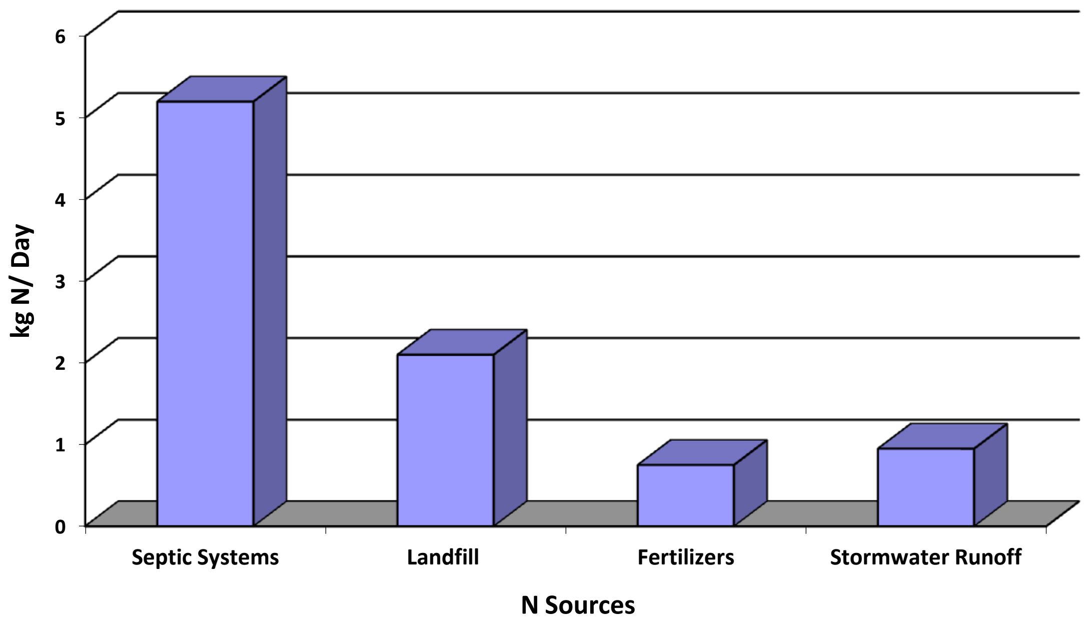
Since the majority of the nitrogen loading comes from septic systems, and to a lesser extent fertilizer, the landfill and storm-water runoff that infiltrates into the groundwater, the allocation of nitrogen for any storm-water pipes that discharge directly to any of the embayments is expected to be insignificant as compared to the overall groundwater load. This is based on determining the percent of impervious surface within 200 feet of the waterbody and calculating the potential relative load from this area via storm drains compared to the overall load. (For the purposes of waste load allocation it was assumed that all impervious surfaces within 200ft of the shoreline discharge directly to the waterbody.) MassDEP has calculated the potential waste load allocation for this 200 foot buffer zone previously in nitrogen TMDLs for eleven embayments on Cape Cod. Percent contribution of N into these waterbodies when all impervious surface within 200 feet of the shoreline is considered ranged from 0.2% - 1.1% (mean = 0.53%). Without exception, this calculated load was negligible when compared to other sources. Because the land use and soils in Nantucket surrounding Madaket Harbor and Long Pond is typical of Cape Cod and the Islands and similar to other embayments where this calculation was performed it is assumed that the load from stormwater runoff from impervious surfaces within 200 feet of the Madaket Harbor and Long Pond system is also negligible.

Load Allocations

Load allocations identify the portion of loading capacity allocated to existing and future nonpoint sources. In the case of the Madaket Harbor and Long Pond estuary system the locally controllable nonpoint source loadings are from on-site subsurface wastewater disposal systems (septic systems) and other land uses (which include storm-water runoff, except from impervious cover within 200 feet of the waterbody which is defined above as part of the waste load, the landfill and fertilizers). Figure 4b (above) and Figure 6 (below) illustrate that septic systems are the most significant portion of the controllable N load (5.2 kg N/day), with landfill contribution a distant second (2.1 kg N/day). Fertilizers and runoff combined contribute 1.7 kg N/day (from

Table IV-2 in the MEP Technical Report). In addition, there are nonpoint sources of N from sediments, natural background and atmospheric deposition that are not feasibly controllable.

Figure 6: Madaket Harbor and Long Pond Estuarine System Locally Controllable N Sources



Generally, storm-water that is subject to the EPA Phase II Program is considered a part of the waste load allocation, rather than the load allocation (see waste load allocation discussion). As discussed above and presented in Chapter IV, V, and VI, of the MEP Technical Report, on Cape Cod and the Islands the vast majority of storm-water percolates into the aquifer and enters the embayment system through groundwater, thus defining the stormwater in pervious areas to be a component of the nonpoint source load allocation. Therefore, the TMDL accounts for storm-water 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. As the Phase II Program is implemented in Nantucket, new studies, and possibly further modeling, will identify what portion of the storm-water load may be controllable through implementation of Best Management Practices (BMPs).

The sediment loading rates incorporated into the TMDL are lower than the existing benthic input listed in Table 5 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 N (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:

Projected N flux = (present N flux) (PON projected / PON present)

When: $PON\ projected = (R_{load})\ (D_{PON}) + PON_{present\ offshore}$

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

And: D_{PON} is the PON concentration above background determined by:
$D_{PON} = (PON_{present\ embayment} - PON_{present\ offshore})$

The benthic flux modeled for the Madaket Harbor and Long Pond estuary system is reduced from existing conditions based on the load reduction and the observed PON concentrations within each sub-embayment relative to Nantucket Sound (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.

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©, 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 Madaket Harbor and Long Pond TMDLs are 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 embayment. 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 travels through ponds or wetlands, almost always enters the embayment via stream flow, and is 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 that 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 >95%. Field measurement of instantaneous discharge was performed using acoustic doppler current profilers (ADCP) at key locations within the 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.

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 two times higher than the next highest data point in the series raises the average 0.05 mg N/L, 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 predicted 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 dependent 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 sentinel station/target threshold nitrogen concentration:

Conservatism was used in the selection of the sentinel stations and target threshold N concentrations. The 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 concentration. Meeting the target threshold N concentrations at the sentinel stations will result in reductions of N concentrations in the rest of the system.

3. Conservative approach:

The target loads were based on tidally averaged N concentrations on the outgoing tide, which is the worst case condition because that is when the N concentrations are the highest. The N concentrations will be lower on the flood tides and therefore this approach is conservative.

In addition to the margin of safety within the context of setting the N threshold levels as described above, a programmatic margin of safety also derives from continued monitoring of these 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

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 embayment 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 N on a seasonal basis and N sources can take considerable time to migrate to impacted waters.

TMDL Values for the Madaket Harbor and Long Pond Estuarine System

As outlined above, the total maximum daily loadings of N that would provide for the restoration and protection of the 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 7.

In this table the N loadings from the atmosphere are listed separately from the target watershed threshold loads which are composed of natural background N along with locally controllable N from the on-site subsurface wastewater disposal systems, the landfill, storm-water runoff and fertilizer sources. In the case of the Madaket Harbor and Long Pond system the TMDLs were calculated by projecting reductions in locally controllable septic systems in the Hither Creek subwatershed as well as removing the landfill load from the Long Pond subwatershed. Once again the goals of these TMDLs are to achieve the identified target threshold N concentration at the identified sentinel stations. The target loads identified in this table represents one alternative-loading scenario to achieve that goal but other scenarios may be possible and approvable as well.

Table 7: The Total Maximum Daily Loads (TMDL) for the Madaket Harbor and Long Pond Estuarine System, Represented as the Sum of the Calculated Target Threshold Loads, Atmospheric Deposition and Sediment Load

Sub-embayment System	Target Threshold Watershed Load[1] (kg N/day)	Atmospheric Deposition (kg N/day)	Nitrogen Load from Sediments[2] (kg N/day)	TMDL[3] (kg N/day)
Madaket Harbor	0.663	8.603	17.952	27.218
Hither Creek	1.134	0.534	0	1.668
Madaket Ditch	2.433	-	0.061	2.494
North Head Long Pond	0.238	0.693	0.995	1.926
Long Pond	1.101	0.975	2.273	4.349
Total for Systems	5.570	10.805	21.281	37.656

[1] Target threshold watershed load (including natural background) is the load from the watershed needed to meet the embayment target threshold nitrogen concentration identified in Table 4.
[2] Projected sediment N loadings obtained by reducing the present benthic flux loading rates (Table 5) proportional to proposed watershed load reductions and factoring in the existing and projected future concentrations of PON. (Negative fluxes set to zero.)
[3] Sum of target threshold watershed load, sediment load and atmospheric deposition load.

Implementation Plans

The critical element of this TMDL process is achieving the sentinel station specific target threshold N concentrations presented in Table 4 above that are necessary for the restoration and protection of water quality and eelgrass habitat within the Madaket Harbor and Long Pond estuarine system. In order to achieve these target threshold N concentrations, N loading rates must be reduced throughout the harbor embayment system.

It should be noted that the Town of Nantucket is currently involved in a five year implementation process to reduce the landfill contribution to the nitrogen load of Long Pond by mining and removing some material and lining/capping the remaining material. It is expected that the landfill nitrogen loads will likely be eliminated after completion of this project. Based on a modeled future scenario of removing the landfill N load from the system, the MEP study predicts that removal of the landfill load will result in a 20% reduction in total watershed N load. This reduction is not sufficient to reach the target threshold nitrogen concentration of 0.45 mg/l at the sentinel station. Additional load reductions are required to meet the 0.45 mg/l target threshold nitrogen concentration. However, as previously noted, there is a variety of loading reduction scenarios that could achieve the target threshold N concentrations. Local officials can explore other loading reduction scenarios through additional modeling as part of their Comprehensive Wastewater Management Plan (CWMP). It must be demonstrated however, that any alternative implementation strategies will be protective of the entire embayment system. To this end, additional linked model runs can be performed by the MEP at a nominal cost to assist the planning efforts of the town in achieving target N loads that will result in the desired target threshold N concentration.

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 septic 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, sewering and treatment for N control of sewage and septage at either centralized or de-centralized locations and denitrifying systems for all private residences.

Nantucket is 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 storm-water runoff and/or fertilizer use within the watershed through the establishment of local by-laws and/or the implementation of storm-water BMPs in addition to reductions in on-site subsurface wastewater disposal system loadings.

Based on land-use and the fact that the watersheds of these systems are located completely within the Town of Nantucket it follows that nitrogen management necessary for the restoration of the Madaket Harbor and Long Pond Estuarine System may be formulated and implemented entirely through the Town of Nantucket's actions.

MassDEP's MEP Implementation Guidance report:
http://www.mass.gov/dep/water/resources/coastalr.htm#guidance provides N loading reduction strategies that are available to Nantucket and 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
- Storm-water Control and Treatment *
    - Source Control and Pollution Prevention
    - Storm-water 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

*Nantucket is not one of the 237 communities in Massachusetts covered by the Phase II storm-water program requirements.

Monitoring Plan

MassDEP is of the opinion that there are two forms of monitoring that are useful to determine progress towards achieving compliance with the TMDL. MassDEP's position is that implementation will be conducted through an iterative process where adjustments maybe needed in the future. The two forms of monitoring include 1) tracking implementation progress as approved in the Nantucket CWMP plan and 2) monitoring water quality and habitat conditions in the estuaries, including but not limited to, the sentinel stations identified in the MEP Technical Report.

The CWMP will evaluate various options to achieve the goals set out in the TMDL report and the MEP Technical Report. It will also make a final recommendation based on existing or additional modeling runs, set out required activities, and identify a schedule to achieve the most cost effective solution that will result in compliance with the TMDL. Once approved by the Department, tracking progress on the agreed upon plan will, in effect, also be tracking progress towards water quality improvements in conformance with the TMDL.

Relative to water quality MassDEP believes that an ambient monitoring program much reduced from the data collection activities needed to properly assess conditions and to populate the model, will be important to determine actual compliance with water quality standards. Although the TMDL values are not fixed, the target threshold N concentrations at the sentinel stations are fixed. Through discussions amongst the MEP it is generally agreed that existing monitoring programs which were designed to thoroughly assess conditions and populate water quality models can be substantially reduced for compliance monitoring purposes. Although more specific details need to be developed on a case-by-case basis MassDEP believes that about half the current effort (using the same data collection procedures) would be sufficient to monitor compliance over time and to observe trends in water quality changes. In addition, the benthic habitat and communities would require periodic monitoring on a frequency of about every 3-5 years. Finally, in addition to the above, existing monitoring conducted by MassDEP for eelgrass should continue into the future to observe any changes that may occur to eelgrass populations as a result of restoration efforts.

The MEP will continue working with the watershed communities to develop and refine monitoring plans that remain consistent with the goals of the TMDL. It must be recognized however that development and implementation of a monitoring plan will take some time, but it is more important at this point to focus efforts on reducing existing watershed loads to achieve water quality goals.

Reasonable Assurances

MassDEP 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 through its many permitting programs 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. Nantucket has demonstrated this commitment through the comprehensive wastewater planning that they initiated well before the generation of the TMDL. The town expects 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, storm-water, 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 MassDEP and EPA. Other potential funds and assistance are available through the 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.

As the town implements these TMDLs the loading values (kg/day of N) will be used by MassDEP for guidance for permitting activities and should be used by the community as a management tool.

Appendix A: Summary of the Nitrogen Concentrations for Madaket Harbor/Long Pond Estuarine System.
(From the MEP Technical Report, Linked Watershed-embayment Model to Determine Critical Nitrogen Loading Threshold for the Madaket Harbor and Long Pond Estuarine System, Town of Nantucket, MA, March, 2011)

Table VI-1. Town of Madaket water quality monitoring data, and modeled Nitrogen concentrations for the Madaket Harbor System used in the model calibration plots of Figure VI-2. 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	2002 mean	2003 mean	2004 mean	mean	s.d. all data	N	model min	model max	model average
Madaket Bay	M1	0.402	0.333	0.272	0.336	0.098	25	0.3053	0.3197	0.3107
Madaket Bay	M2	0.427	0.413	0.349	0.395	0.083	27	0.3165	0.324	0.3205
Madaket Bay	M3	0.501	0.387	0.347	0.415	0.090	27	0.3186	0.3411	0.328
Hither Creek	M4	0.644	0.647	0.422	0.581	0.193	35	0.3986	0.5423	0.4639
Hither Creek	M5	0.883	0.691	0.684	0.780	0.178	19	0.4946	0.6945	0.613
Madaket Bay	M6	0.419	0.317	0.315	0.347	0.067	10	0.3095	0.3279	0.3161
Madaket Bay	M10	0.527	0.431	0.312	0.422	0.127	16	0.3192	0.3424	0.3266
Hither Creek	M11	0.690	0.636	0.441	0.620	0.215	24	0.4587	0.5732	0.5107
Long Pond	LOPO1	1.243	0.746	1.185	1.058	0.404	18	0.9997	1.1027	1.0394
Long Pond	LOPO2	1.157	0.860	0.895	0.971	0.369	18	0.9336	1.0513	0.9827
Long Pond	LOPO3	--	1.001	0.848	0.924	0.234	10	0.818	0.956	0.8821
Long Pond	LOPO4	0.939	0.889	0.821	0.894	0.278	25	0.7542	0.9319	0.8515
North Head Long Pond	LOPO5	1.029	0.929	0.781	0.954	0.271	26	0.8674	0.9345	0.8937

Appendix B: Madaket Harbor/ Long Pond Estuarine System Five Total Nitrogen TMDLs

Sub-embayment	Segment ID	Description	TMDL (kg N/day)
Madaket Harbor	MA97-27_2008	Waters encompassed within imaginary lines from Eel Point to the northern tip of Esther Island, from the southern tip of Esther Island southeasterly to the opposite shore and from Jackson Point easterly to Little Neck, Nantucket. Listed on the 2008 CWA §303(d) list for pathogens.	27.22
Hither Creek	MA97-28_2008	From the outlet of Madaket Ditch to Madaket Harbor at an imaginary line drawn easterly from Jackson Point to Little Neck, Nantucket. Listed on the 2008 CWA §303(d) list for nutrients, organic enrichment/low DO.	1.67
Madaket Ditch	--	Determined to be impaired for nutrients during the development of this TMDL.	2.49
North Head Long Pond	--	Determined to be impaired for nutrients during the development of this TMDL.	1.93
Long Pond	MA97-29_2008	South of Madaket Road, including White Goose Cove, Nantucket. Listed on the 2008 CWA §303(d) list for nutrients, organic enrichment/low DO, pathogens, turbidity.	4.35
Total for System			37.66