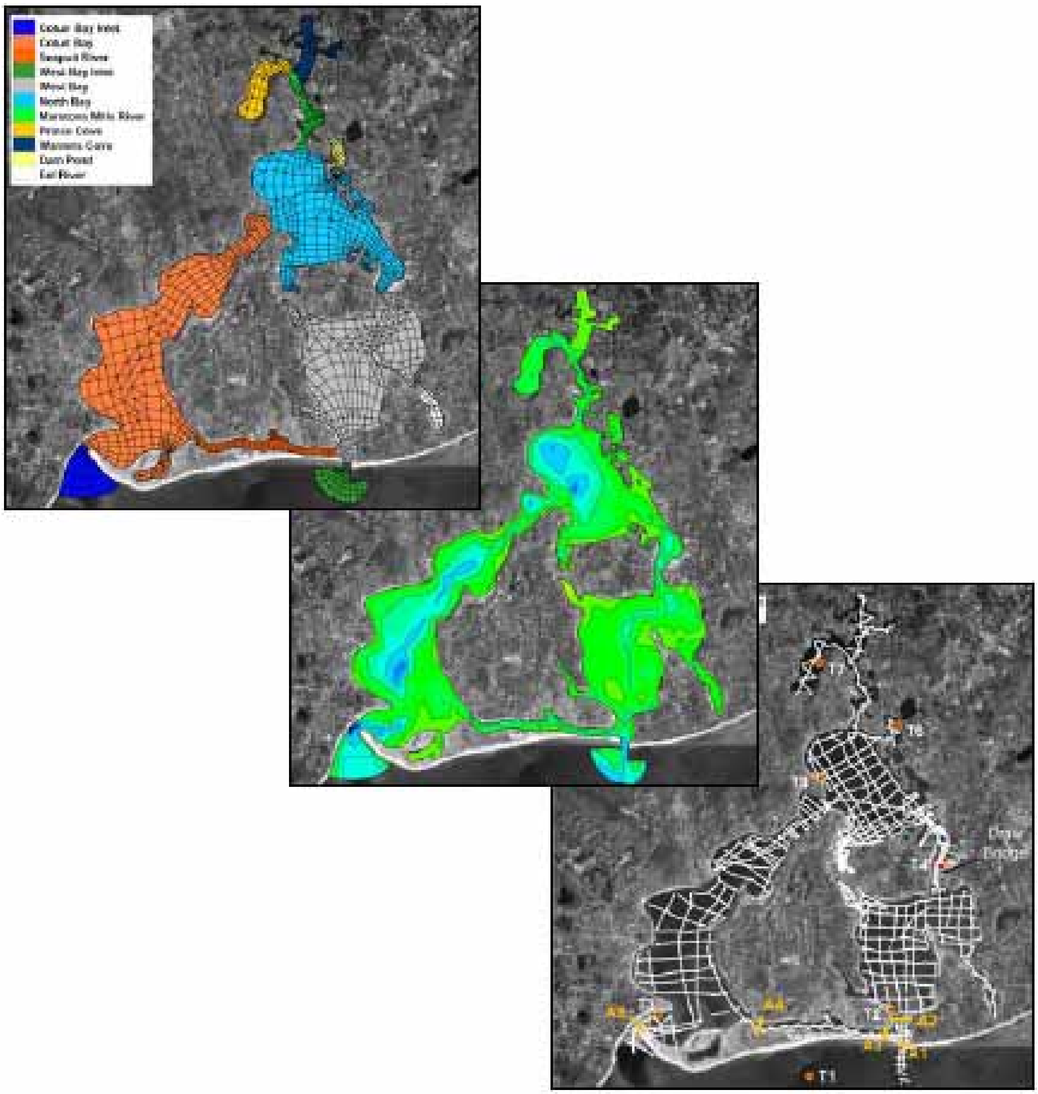
# FINAL
# Three Bays System
# Total Maximum Daily Loads For Total Nitrogen
**(Report # 96-TMDL-10 Control #242.0)**



**COMMONWEALTH OF MASSACHUSETTS**
**EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS**
IAN A. BOWLES, SECRETARY
**MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION**
LAURIE BURT, COMMISSIONER
**BUREAU OF RESOURCE PROTECTION**
ARLEEN O'DONNELL, ASSISTANT COMMISSIONER
**DIVISION OF WATERESHED MANAGEMENT**
GLENN HAAS, DIRECTOR

September 7, 2007

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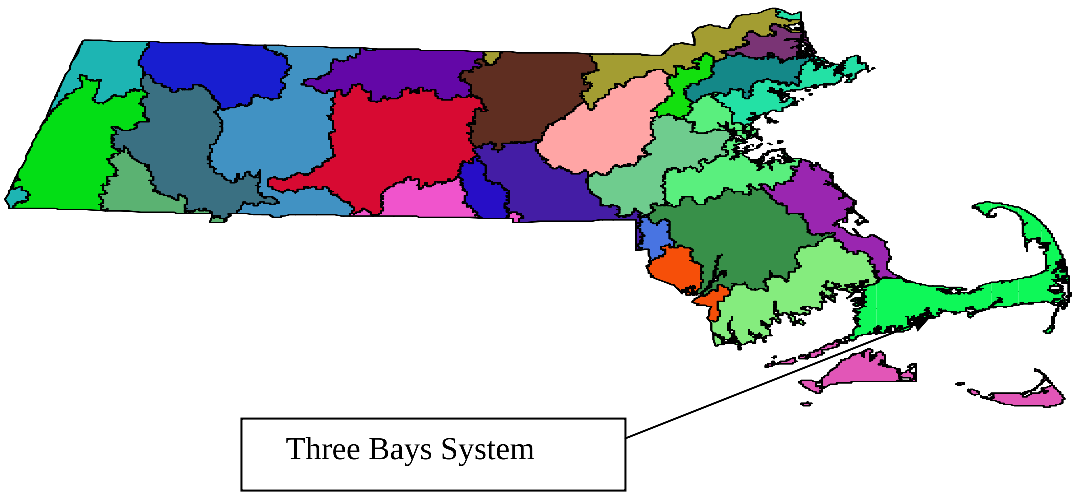



**Key Feature:** Total Nitrogen TMDL for Three Bays System
**Location:** EPA Region 1
**Land Type:** New England Coastal
**303d Listing:** The waterbody segments impaired and on the Category 5 list includes Cotuit Bay, North Bay, Prince Cove, Seapuit River, and West Bay.
**Data Sources:** University of Massachusetts – Dartmouth/School for Marine Science and Technology; US Geological Survey; Applied Coastal Research and Engineering, Inc.; Cape Cod Commission, Town of Barnstable, Town of Sandwich, and Town of Mashpee.
**Data Mechanism:** Massachusetts Surface Water Quality Standards, Ambient Data, and Linked Watershed Model
**Monitoring Plan:** Town of Barnstable 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 coastal waters of Massachusetts these problems 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

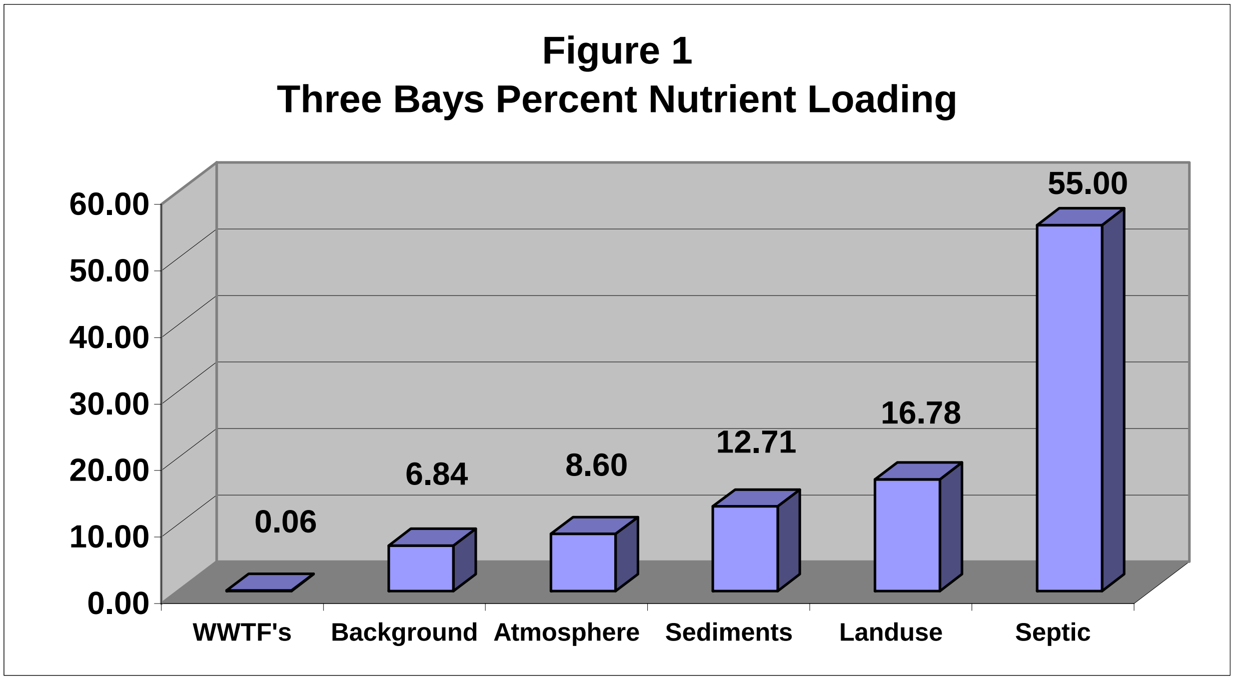
Coastal communities, including Barnstable, Sandwich and Mashpee, rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as for commercial fin fishing and shellfishing. Failure to reduce and control N loadings 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 Three 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

Most of the present N load originates from individual subsurface wastewater disposal (septic) systems, primarily serving individual residences, as seen in Figure 1.




**Target Threshold Nitrogen Concentrations and Loadings**

The N loadings (the quantity of nitrogen) from the watersheds of the sub-embayments of the Three Bays "system" range from 3.8 kg/day in Seapuit River, to 35.2 kg/day in Prince Cove. The resultant concentrations of N in the areas studied range from 0.32 mg/L (milligrams of nitrogen per liter) in the Seapuit River to 0.70 mg/L in Prince Cove.

In order to restore and protect areas contained within Three Bays, 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. The Department has determined that, for the waters contained within the Three Bays project area, N concentrations in the range from 0.38 to 0.50 mg/L are protective. The mechanism for achieving these target threshold N concentrations is to reduce the N loadings to the sub-embayments. The Massachusetts Estuaries Project (MEP) has determined through mathematical modeling, of each of the sub-embayment watersheds, which the Total Maximum Daily Loads (TMDL) of N that will meet the target thresholds range from 2-54 kg/day. The purpose of this document is to present TMDLs for the major sub-embayments 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 sewering with nitrogen removal technology, advanced treatment of septage, and/or installation of N-reducing on-site systems.

These strategies, plus ways to reduce N loadings from stormwater runoff and fertilizers, are explained in detail in the "MEP Embayment Restoration Guidance for Implementation Strategies", which is available on the DEP 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 Barnstable, Sandwich, and Mashpee (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.

# Table of Contents

| Contents: | Page: |
|---|---|

# List of Tables



# List of Figures

## 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. MassDEP will work with 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 Three Bays System, the pollutant of concern for this TMDL (based on observations of eutrophication) is the nutrient N. 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 coastal sub-embayments within the Three Bays 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, and others, as part of the Massachusetts Estuaries Project (MEP). The data were collected over a study period from 1999 to 2004. This study period will be referred to as the "Present Conditions" in the TMDL since it contains the most recent data available. The accompanying MEP Technical Report presents the results of the analyses of these coastal sub-embayments using the MEP Linked Watershed-Embayment Nitrogen Management Model (Linked Model). The accompanying MEP Technical Report can be found at http://www.oceanscience.net/estuaries/reports.htm. 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 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 each sub-embayment. 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 Barnstable, Sandwich and Mashpee.

## Description of Water Bodies and Priority Ranking

The Three Bays System in Barnstable, Sandwich, and Mashpee, Massachusetts, at the southern 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 (Figure 2 and 3). The 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. Several waterbodies within the Three Bays system are already listed as waters requiring TMDLs (Category 5) in the MA 2004 Integrated List of Waters, as summarized in Table 1A. Several others were not listed because data was not available at that time. New data collected as part of this TMDL effort has indicated additional impaired segments. Table 1B identifies these segments previously listed by MassDEP and additional segments that were observed to be impaired through the MEP analysis.

**Table 1A. Three Bays Waterbody Segments in Category 5 of the Massachusetts 2004 Integrated List[1]**

| NAME | WATERBODY SEGMENT | DESCRIPTION | SIZE | Pollutant Listed |
|---|---|---|---|---|
| **Three Bays System** | | | | |
| Cotuit Bay | MA96-63_2004 | From North Bay at Point Isabella oceanward to a line extended along Oyster Harbors Beach, Barnstable. | 0.85 sq mi | -Nutrients<br>-Pathogens[1] |
| North Bay | MA96-66_2004 | From Fox Island to just south of Bridge Street and separated from Cotuit Bay at a line from Point Isabella southward to the opposite shore (including Dam Pond), Barnstable. | 0.47 sq mi | -Nutrients<br>-Pathogens[1] |
| Prince Cove | MA96-07_2004 | Includes adjacent unnamed cove east of Prince Cove to North Bay at Fox Island, Barnstable. | 0.14 sq mi | -Nutrients<br>-Pathogens[1] |
| Seapuit River | MA96-64_2004 | South of Osterville Grand Island to Cotuit Bay and West Bay, Barnstable. | 0.06 sq mi | -Pathogens[1] |
| West Bay | MA96-65_2004 | South of the Bridge Street bridge to Nantucket Sound including Eel River, Barnstable | 0.52 sq m | -Nutrients |

[1]Pathogens are not addressed as part of this TMDL analysis.

A complete description all sub-embayments is presented in Chapters I and IV of the accompanying MEP Technical Report from which the majority of the following information is drawn. Chapter VI and VII of the MEP Technical report provide assessment data on the individual waterbody segments listed in Table 1B (below). Please note that pathogens are listed in Tables 1A for completeness. Further discussion of pathogens is beyond the scope of this TMDL. TMDLs were prepared for Cotuit Bay, West Bay, Seapuit River, North Bay, Prince Cove, Warren Cove, and Prince Cove Channel.

The sub-embayments addressed by this document are determined to be high priorities based on three significant factors: (1) the initiative that these Towns have taken to assess the conditions of the entire Three Bays embayment system, (2) the commitment made by these Towns to restore and preserve 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

**Figure 2 Overview of the Sub-embayments in Three Bays**


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.

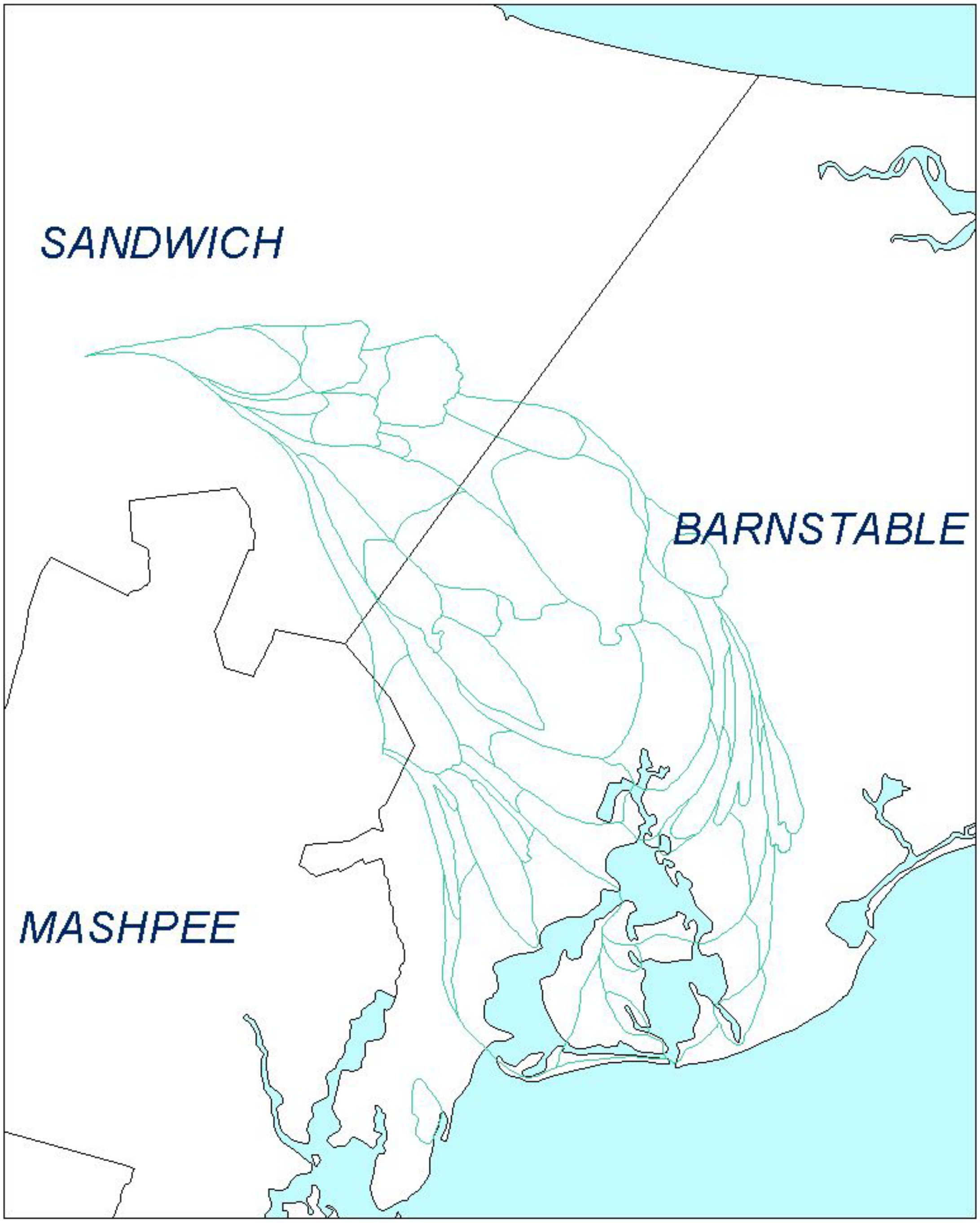



Figure 3 Three Bays Subwatershed Delineation

**Table 1B. General summary of conditions related to the major indicators of habitat impairment observed in the Three Bays System**

| Embayment/ Sub-embayment | Eelgrass Loss[1] | Dissolved Oxygen Depletion | Chlorophyll *a*[2] | Macro-algae | Benthic Fauna[3] |
|---|---|---|---|---|---|
| | | | | | |
| Prince Cove | 100% | <6 mg/L up to 60% of time<br><4 mg/L up to 27% of time<br>SI/SD | >10ug/L up to 93% of time<br>>20 ug/L up to 63% of time<br>SI | MI | SD |
| North Bay | | | | | |
| Upper | 100% | <6 mg/L up to 66% of time<br><4 mg/L up to 24% of time<br>SI/SD | >10ug/L up to 68% of time<br>>20 ug/L up to 10% of time<br>MI/SI | No data | SD |
| Lower | 100% | <6 mg/L up to 46% of time<br><4 mg/L up to 1% of time<br>MI/SI | >10ug/L up to 24% of time<br>>20 ug/L 0% of time<br>MI/SI | No data | MI/SI |
| Cotuit Bay | 100% | <6 mg/L up to 73% of time<br><4 mg/L up to 1% of time<br>MI/SI | >10ug/L up to 32% of time<br>>20 ug/L up to 2% of time<br>MI | MI | GF/MI |
| West Bay | 100% | <6 mg/L up to 49% of time<br><4 mg/L up to 19% of time<br>SI | >10ug/L up to 14% of time<br>>20 ug/L 0% of time<br>GF/MI | MI | GF/MI |
| Warrens Cove | 100% | SI/SD | SI | SD | SD |

[1]Based on comparison of present conditions to 1951 Survey data.
[2]Algal blooms are consistent with chlorophyll *a* levels above 20ug/L
[3]Based on observations of the types 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*
* - 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).

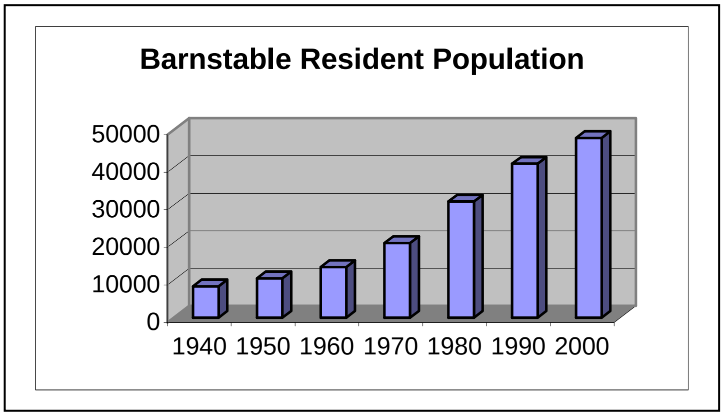
## Problem Assessment

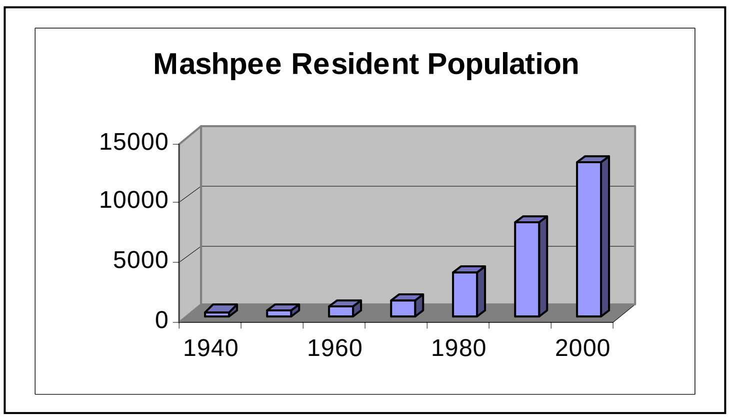
The watersheds of Three Bay's embayments have all had rapid and extensive development of single-family homes and the conversion of seasonal into full time residences. This is reflected in a substantial transformation of land from forest to suburban use between the years 1951 to 2000. Water quality problems 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.

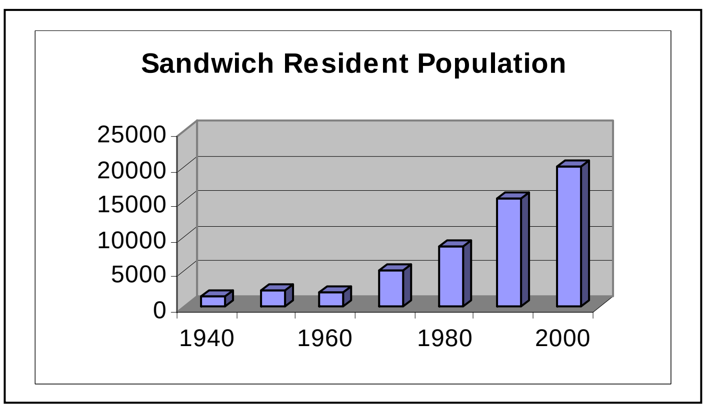
On-site subsurface wastewater disposal system effluents discharge to the ground, enter the groundwater system and eventually enter the surface water bodies. In the sandy soils of Cape Cod, effluent that has entered the groundwater travel towards the coastal waters at an average rate of one foot per day. 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 Barnstable, Sandwich and Mashpee, 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/CapeIsl-Population1930-2000.pdf and http://www.capecodcommission.org/data/trends98.htm#population).

The increase in year round residents is illustrated in the following figure:

Figure 4




Dramatic declines in water quality, and the quality of the estuarine habitats, throughout Cape Cod, have paralleled its population growth. 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 shown a 100% reduction in area. Furthermore, the eelgrass was replaced by macro algae, which are undesirable, because they do not provide high quality habitat for fish and invertebrates. In the most severe cases there are 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 Barnstable, Sandwich, and Mashpee, 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 throughout the Three Bays system based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. At present, the Three Bays system is showing significantly impaired to severely degraded habitat quality in the Prince Cove and Warrens Cove sub-embayments as well as the upper portion of North Bay. The lower portion of North Bay as well as Eel Pond are showing indications of moderate bordering on significant impairment while Cotuit Bay and West Bay are both showing signs of moderate impairment. All of the habitat indicators are consistent with this evaluation of the whole of the system.

The effect of nitrogen enrichment is to cause oxygen depletion; however, with increased phytoplankton (or epibenthic algae) production, oxygen levels will rise in daylight to above atmospheric equilibration levels. In shallow systems this generally equates to an increase of about 7-8 mg/l at the mooring sites. The clear evidence of oxygen levels above atmospheric equilibration indicates that the Three Bays system is eutrophic.

The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate highly nutrient enriched waters and impaired habitat quality within the estuary. The major sub-embayments to the Three Bays system (Cotuit Bay, West Bay, North Bay and Prince cove) are currently under seasonal oxygen stress, consistent with nitrogen enrichment. Nitrogen enrichment is supported by parallel observations of elevated chlorophyll a. Currently there are no eelgrass beds within the Three Bays System. However, it appears that all of the major sub-embayments had water quality conditions capable of supporting eelgrass beds in 1951 although it appears that eelgrass was restricted to the shallows (North and Cotuit Bays) or to Prince Cove and West Bay basin. Based on this analysis it appears that the post 1951 losses are associated with nitrogen enrichment.

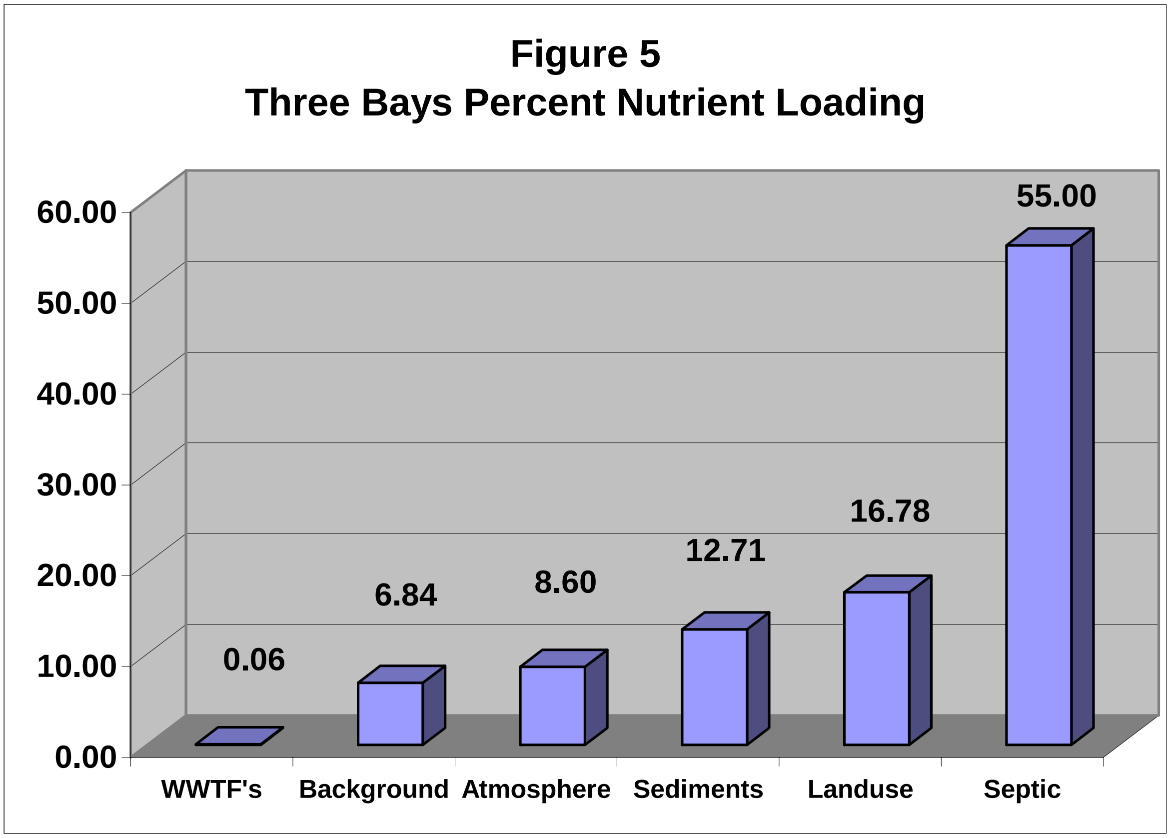
## Pollutant of Concern, Sources, and Controllability

In the coastal embayments of the Towns of Barnstable, Sandwich, and Mashpee, 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 towns, 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 total disappearance of eelgrass from 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 5, most of the N affecting the sub-embayments to Three Bays originates from on-site subsurface wastewater disposal systems, with considerably less N originating from natural background sources, runoff, fertilizers, wastewater treatment facilities, and atmospheric deposition.




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 significant 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 form 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: 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 nitrogen-reducing on-site wastewater treatment systems.

WWTF's effluent nitrogen can be reduced by advanced treatment processes that include denitrification.

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

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 the MassDEP, with the technical support of SMAST, is employing to develop nutrient TMDLs for coastal waters.

## 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 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 eel grass 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. This approach 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 numerous 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 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 (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" 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 which will achieve the target threshold N concentration at the sentinel station. 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 N 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 threshold N concentrations

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

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 1999 through 2004. Concentrations of N are the highest in Prince Cove (0.70 mg/L). Nitrogen in the other sub-embayments ranges in concentration from 0.32 to 0.64 mg/L, resulting in overall ecological habitat quality ranging from moderately high to poor. The individual yearly means and standard deviations of the averages are presented in Appendix A.

**Table 2. Observed present nitrogen concentrations for the major Sub-embayments of the Three Bays System**

| Three Bay System Sub-embayment | Observed TN Concentration (mg/L) [1] | Threshold TN Concentration (mg/L) |
|---|---|---|
| Cotuit Bay | 0.39 – 0.44 | |
| West Bay | 0.38 – 0.48 | |
| Seapuit River | 0.32 | |
| North Bay | 0.50 – 0.52 | |
| Prince Cove | 0.60 – 0.70 | |
| Warren Cove | 0.64 | |
| Prince Cove Channel | 0.64 | |
| Three Bays Sentinel Station | | 0.38 [2] |
| Nantucket Sound (Boundary Condition) | 0.28 | |

[1] ranges represent the upper to lower regions (highest – lowest) of a sub-embayment, calculated as the average of the separate yearly means of 1999-2004 data. Individual yearly means and standard deviations of the average are presented in Tables A-1 Appendix A
[2] at the sentinel station located between Cotuit Bay and North Bay

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.

The findings of the analytical and modeling investigations for this embayment system are discussed and explained below:

The threshold N concentrations represent the tidally-averaged 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/or diverse benthic animal communities as described below. Dissolved oxygen and chlorophyll *a* were also considered in the assessment.

Watershed N loads (Tables ES-1 and ES-2 of the MEP Technical Report) for the Towns of Barnstable, Sandwich and Mashpee Three Bays embayment system were comprised primarily of wastewater N. Land-use and wastewater analysis found that generally 76% of the controllable watershed N load to embayment was from septic system effluent.

The threshold N levels for the Three Bays System were determined as follows:
The target N concentration for restoration of eelgrass in this system was determined to be 0.38 mg/L Total Nitrogen (TN) at the sentinel location and 0.40 mg/l TN within the marginal regions (shallows) of North Bay. This secondary level to check restoration of marginal beds in North Bay (0.40 mg/l TN) is consistent with the analysis of restoration of fringing eelgrass beds in nearby Great Pond, and analysis where eelgrass beds in deep waters could not be supported at a tidally averaged TN of 0.41 mg/l TN at depths of 2 meters. Similarly prior MEP analysis in Bournes Pond indicated that tidally averaged TN levels of 0.42 mg TN excluded beds from all but the shallowest water. The MEP Technical Team cannot specify the exact extent of marginal beds to be restored in the upper deep basins. At tidally averaged TN levels of 0.42 mg/l TN the eelgrass habitat would be restricted to very shallow waters, while at 0.40 mg/l TN the eelgrass habitat should reach to 1-2 meters depth, based upon the data from nearby systems. In additional, the persistence of eelgrass beds through 1995-2001 in the shallow waters of south Windmill Cove, but in a stable physical setting, were at nitrogen levels (tidally averaged TN ~0.40 mg/l).

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

Based upon sequential reductions in watershed N loading in the analysis described in the Section VIII-3 of the MEP Technical Report, the sentinel station was projected to achieve an average TN level of 0.38 mg/l, and 0.40 mg/l TN within the marginal regions (shallows) of North Bay.

It is important to note that the analysis of future N loading to the Three Bays System focuses upon additional shifts in land-use from forest/grasslands to residential and commercial development. However, the analysis (as described in Chapter VI of the accompanying technical report) indicates that significant increases in N loading can occur under present land-uses, 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 N management must include management approaches to prevent increased N loading from both shifts in land-uses (new sources) and from loading increases of current land-uses. The conclusion of the analysis of the Three Bays System is that restoration will necessitate a reduction in the present (2004) N inputs and management options to negate additional future N inputs.

Nitrogen loadings to the sub-embayments

a) Present loading rates:

In the Three Bays 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 system loadings range from 3 kg/day to as high as 25 kg/day. Nitrogen loading from the nutrient-rich sediments (referred to as benthic flux) is very significant in the North Bay sub-embayment. 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. A further breakdown of the total N loading, by source, is presented in Table 3.

**Table 3. Nitrogen loadings to the Three Bays sub-embayments**

| Sub-Embayments | Present Land Use[1] (kg/day) | Present Septic System Load (kg/day) | Present WWTF Load (kg/day) | Direct Atmospheric Deposition [2] (kg/day) | Present Benthic Load[3] (kg/day) | **Present Total Load** (kg/day) |
|---|---|---|---|---|---|---|
| Cotuit Bay | 5.52 | 20.23 | 0 | 5.79 | 0 | 31.53 |
| West Bay | 3.58 | 15.49 | 0 | 4.23 | 3.82 | 27.12 |
| Seapuit R | 0.85 | 2.92 | 0.02 | 0.45 | 0 | 4.24 |
| North Bay | 4.47 | 24.98 | 0 | 3.95 | 67.52 | 100.92 |
| Prince Cove | 10.34 | 24.84 | 0.09 | 1.23 | 0.51 | 37.01 |
| Warren Cove | 5.05 | 6.98 | 0 | -- | 8.83 | 20.86 |
| Prince Cove Channel | 0.77 | 4.77 | 0 | -- | 2.35 | 7.88 |

[1]Includes stormwater runoff and fertilizers

[2] Warren Cove and Prince Cove Channel loads are included in Prince Cove

[3] Nitrogen loading from sediments, negative fluxes have been set to zero

As previously indicated, the present N loadings to the three Three Bays 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.

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

Table 4 lists the present controllable watershed N loadings from Three Bays embayment system. The last two columns indicate one scenario of the reduced loads and percentage reductions that could achieve the target concentrations in the sentinel system (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 embayment, and/or modifying the tidal flushing through inlet reconfiguration (where appropriate). The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the communities involved. This presentation is to establish the general degree and spatial pattern of reduction that will be required for restoration of these N impaired embayments.

**Table 4. Present Controllable 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-embayments | Present Controllable Watershed Load [1] (kg/day) | Target Threshold Watershed Load [2] (kg/day) | Percent controllable watershed reductions needed to achieve threshold load levels |
|---|---|---|---|
| Cotuit Bay | 23.77 | 22.34 | 6 % |
| West Bay | 17.90 | 15.97 | 11 % |
| Seapuit River | 3.77 | 3.77 | 0 % |
| North Bay | 27.48 | 4.47 | 84 % |
| Prince Cove | 31.30 | 17.89 | 43 % |
| Warren Cove | 10.08 | 5.05 | 50 % |
| Prince Cove Channel | 5.02 | 0.77 | 85 % |

[1] Composed of combined fertilizer, runoff, WWTF, and septic system loadings.
[2] Target threshold watershed load is the load from the watershed needed to meet the embayment target threshold concentration

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 the target threshold concentrations range from 0% in the Seapuit River to 85 % in Prince Cove Channel. 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 the Three Bays embayment system, 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.

## 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 Three Bays 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:

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 estimates are presented in Table ES-1 of the accompanying MEP Technical Report. 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 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 total waste load allocation for these sources is considered to be insignificant. 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. Although most stormwater infiltrates into the ground on Cape Cod, some impervious areas within approximately 200 feet 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 calculated load is 0.23% of the total load or 124 kg/year as compared to the total nitrogen load of 54,657 kg/year to the embayments. Looking at individual sub-embayments this load ranged from 0.08-0.58%. (see Appendix C for details). This conservative calculated load is obviously negligible when compared to other sources.

EPA and MassDEP authorized the Towns of Barnstable, Sandwich and Mashpee for coverage under the NPDES Phase II General Permit for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems (MS4s) in 2003. While communities need to comply with the Phase II permit only in the mapped Urbanized Areas, the Towns of Barnstable and Sandwich have decided to extend all the stormwater permit requirements throughout the entire town, including this watershed area. The portion of the watershed, which is in Mashpee is entirely in the mapped Urbanized Areas.

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 the loading capacity allocated to existing and future nonpoint sources. In the case of the Three Bays 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 WWTF's 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 Barnstable, Sandwich, and Mashpee, 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 Wastewater Treatment Facilities (WWTFs) currently discharge about 0.11 kg N/day into the groundwater. If towns shifted loads from on-site systems to these 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:

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

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

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

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

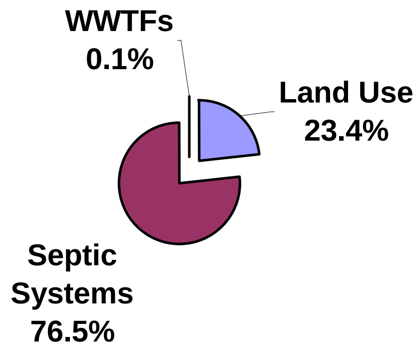
$$D_{PON} = (\text{PON}_{\text{present embayment}} - \text{PON}_{\text{present offshore}})$$

The benthic flux modeled for the Three Bays 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.

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 wastewater treatment facilities. Figure 6 emphasizes the fact that the overwhelming majority of locally controllable N comes from on-site subsurface wastewater disposal systems.

**Figure 6**
**Percent Contribution of Locally Controllable Sources of Nitrogen**




**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 Three Bays 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, 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 streamflow, 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, 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 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.

In the case of N attenuation by freshwater ponds, attenuation was derived from measured N concentrations, pond delineations and pond bathymetry. These attenuation factors were higher than that used in the land-use model. The reason was that the pond data were temporally limited and a more conservative value of 40% was more protective and defensible.

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 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 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.

<u>2. Conservative threshold sites/nitrogen concentrations</u>

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.

<u>3 Conservative approach</u>

The target loads were based on tidally 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.

**Seasonal Variation**

Since the TMDL for the waterbody segment is based on the most critical time period, i.e. the summer growing season, the TMDL is 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 nitrogen on a seasonal basis and nitrogen sources can take considerable time to migrate to impacted waters.

**TMDL Values for Three Bays Sub-Embayments**

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 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 WWTP's, on-site subsurface wastewater disposal systems, stormwater runoff, and fertilizers. In the case of the Three Bays sub-embayments, which 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 target threshold N concentration at the identified sentinel station. 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. These waterbody segment TMDLs are also presented in Appendix D.

**Table 5. The Total Maximum Daily Loads (TMDL) for the Three Bays System, represented as the sum of the calculated target thresholds loads (from controllable watershed sources), atmospheric deposition, and sediment sources (benthic load).**

| Three Bay System Sub-embayment | Target Threshold Watershed Load [1] (kg/day) | Atmospheric Deposition [2] (kg/day) | Benthic load [3] (kg/day) | TMDL [4] (kg/day) |
|---|---|---|---|---|
| Cotuit Bay | 22.34 | 5.79 | 0 | 28 |
| West Bay | 15.97 | 4.23 | 3.47 | 24 |
| Seapuit River | 3.77 | 0.45 | 0 | 4 |
| North Bay | 4.47 | 3.95 | 45.20 | 54 |
| Prince Cove | 17.89 | 1.23 | 0.32 | 19 |
| Warren Cove | 5.05 | -- | 6.23 | 11 |
| Prince Cove Channel | 0.77 | -- | 1.54 | 2 |
| | | | | |

[1] Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentrations identified in Table 2.
[2] Atmospheric deposition to embayment surfaces only. Warren Cove and Prince Cove Channel are included in Prince Cove
[3] 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. Negative loads have been set to zero.
[4] Sum of target threshold watershed load, atmospheric deposition load, and benthic load.

The waterbody segment, Seapuit River was not found to be impaired for nitrogen, but it was determined that a "pollution prevention" TMDL for nitrogen was needed since this waterbody segment is linked to the larger embayment system and any future impairment of this segment could further contribute to impairment of the segments at issue in this TMDL (Appendix D). A "pollution prevention" TMDL on this waterbody segment will encourage the maintenance and protection of existing water quality and help prevent further degradation to waterbodies that are downstream or linked. This pollution prevention TMDL will serve as a guide to help ensure that this waterbody does not become impaired for nitrogen.

## Implementation Plans

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

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 Bays sub-embayments. In order to achieve those target concentrations, N loading rates must be reduced throughout the Embayment System. Table 5, above, lists target watershed threshold loads for each sub-embayment. If those threshold loads are achieved, the sub-embayments studied will be protected.

This loading reduction scenario is not the only way to achieve the target threshold 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 Three Bays 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 DEP 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, sewering 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 Mashpee and Sandwich are in the watershed of the Three Bays sub-embayments. A very small portion of the upper western watershed is located in Mashpee. A significant portion of the upper watershed is in Sandwich. Thus the development of any implementation plan should keep in mind that Mashpee and Sandwich need to be included in coordinating efforts to maximize the reduction in TN loading.

MassDEP's MEP Implementation Guidance report (http://www.mass.gov/dep/smerp/restore.htm) provides N loading reduction strategies that are available to the Towns of Barnstable, Sandwich and Mashpee, 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 Barnstable, Sandwich and Mashpee are three of 237 communities in Massachusetts covered by the Phase II stormwater program requirements. Barnstable and Sandwich have extended the coverage to the entire area of the town.

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

MassDEP is of the opinion that there are two forms of monitoring that are useful to determine progress towards achieving compliance with the TMDL keeping in mind that MassDEP's position is that implementation will be needed along the way. The two forms of monitoring include 1) tracking implementation progress as approved in the Town CWMP plan and 2) monitoring ambient water quality conditions at the sentinel stations identified in the MEP Technical Report.

The CWMP will evaluate various options to achieve the goals set out in the TMDL and 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 load values are not fixed, the target threshold nitrogen concentrations at the sentinel stations are fixed. In addition, there are target threshold N concentrations that are provided for many other non-sentinel locations in subembayments to protect nearshore benthic habitat. These are the water quality targets, and a monitoring program should encompass these stations at a minimum. 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's current thinking is 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 Towns 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. Barnstable, Sandwich, and Mashpee 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 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.

As the towns implement this TMDL, the TMDL values (kg/day of nitrogen) will not be used by MassDEP as an enforcement tool by MassDEP, but may be used by local communities as a management tool. There will be slight variations in these values depending on the scenario the towns use to implement it. They are also modeled values and thus would be inappropriate to use as an enforcement tool. There could also be slight variations between the actual nitrogen concentration at the sentinel stations and the site-specific target threshold nitrogen concentration at the sentinel stations as the nitrogen load is reduced and the waterbodies begin to approach the water quality standards (Description of the Applicable Water Quality Standards section**).** It will be these latter two standards, the nitrogen concentration at the sentinel station and more importantly, the applicable water quality standards that will be used as the measure of full implementation and compliance with these water quality standards.

## Appendix A

Summarizes the nitrogen concentrations for Three Bays sub-embayments (from Chapter VI of the accompanying MEP Technical Report)

Table VI-1. Measured data and modeled Nitrogen concentrations for the Three Bays estuarine system used in the model calibration plots of Figures VI-2 and VI-3. All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means. Data represented in this table were collected in the summers of 1999 through 2004, except the Vineyard sound station, which covers a longer time period.

| Sub-Embayment | monitoring station | data mean | s.d. all data | N | model min | model max | model average |
|---|---|---|---|---|---|---|---|
| Mill Pond (fresh water) | TB1 | 1.022 | 0.246 | 36 | - | - | - |
| Prince Cove - south | TB2 | 0.699 | 0.192 | 38 | 0.685 | 0.699 | 0.695 |
| Prince Cove - north | TB3 | 0.602 | 0.131 | 37 | 0.612 | 0.666 | 0.639 |
| Warrens Cove | TB4 | 0.642 | 0.151 | 36 | 0.561 | 0.642 | 0.595 |
| North Bay - north | TB5 | 0.498 | 0.135 | 105 | 0.504 | 0.531 | 0.518 |
| North Bay - south | TB6 | 0.515 | 0.129 | 36 | 0.483 | 0.517 | 0.500 |
| North Windmill Cove | TB7 | 0.511 | 0.120 | 103 | 0.498 | 0.523 | 0.511 |
| West Bay - north | TB8 | 0.383 | 0.117 | 34 | 0.327 | 0.418 | 0.363 |
| West Bay - west | TB9 | 0.376 | 0.078 | 38 | 0.299 | 0.362 | 0.327 |
| Eel River | TB10 | 0.481 | 0.125 | 34 | 0.468 | 0.500 | 0.486 |
| Seapuit River | TB11 | 0.322 | 0.068 | 67 | 0.287 | 0.305 | 0.295 |
| Cotuit Bay - north | TB12 | 0.438 | 0.076 | 64 | 0.364 | 0.484 | 0.414 |
| Cotuit Bay - south | TB13 | 0.389 | 0.077 | 75 | 0.298 | 0.350 | 0.321 |
| South Windmill Cove | TB15 | 0.431 | 0.090 | 27 | 0.369 | 0.467 | 0.402 |
| Mellon Cove | TB16 | 0.411 | 0.094 | 24 | 0.369 | 0.417 | 0.392 |
| Dam Pond | TB17 | 0.508 | 0.073 | 5 | 0.513 | 0.531 | 0.523 |
| Vineyard Sound | NS | 0.280 | 0.065 | 196 | - | - | 0.280 |

## Appendix B

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.

Table VIII-2. Comparison of sub-embayment watershed *septic loads* (attenuated) used for modeling of present and threshold loading scenarios of the Three Bays system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

| sub-embayment | present septic load (kg/day) | threshold septic load (kg/day) | threshold septic load % change |
|---|---|---|---|
| Cotuit Bay | 17.022 | 13.618 | -20.0% |
| West Bay | 15.490 | 12.392 | -20.0% |
| Seaptuit River | 2.921 | 2.921 | 0.0% |
| North Bay | 24.978 | 0.000 | -100.0% |
| Prince Cove | 11.192 | 0.000 | -100.0% |
| Warrens Cove | 6.975 | 0.000 | -100.0% |
| Prince Cove Channel | 4.767 | 0.000 | -100.0% |
| Marstons Mills Crescent | 3.573 | 0.000 | -100.0% |
| Surface Water Sources | | | |
| Marstons Mills River | 10.071 | 7.553 | -25.0% |
| Little River | 3.203 | 3.203 | 0.0% |

**Appendix C**

The Three Bays Embayment System estimated wasteload allocation (WLA) from runoff of all impervious areas within 200 feet of waterbodies.

| Subwatershed Name | Impervious subwatershed buffer areas[1] | | Total subwatershed Impervious areas | | Total Impervious subwatershed load | Total subwatershed load | Impervious subwatershed buffer area WLA | |
|---|---|---|---|---|---|---|---|---|
| | Acres | % | Acres | % | Kg/year | Kg/year | Kg/year[2] | %[3] |
| Cotuit Bay | 17.6 | 11.4 | 153.7 | 9.6 | 589 | 11653 | 67.45 | 0.58 |
| Seapuit River | 3.7 | 9.2 | 18.9 | 9.1 | 39 | 1540 | 7.63 | 0.50 |
| West Bay | 10.9 | 10.8 | 114.5 | 13.1 | 260 | 8505 | 24.75 | 0.29 |
| North Bay | 11.7 | 10.9 | 159.5 | 12.2 | 477 | 12191 | 34.99 | 0.29 |
| Princes Cove | 8.0 | 6.5 | 737.6 | 8.7 | 1463 | 20768 | 15.87 | 0.08 |
| TOTAL | 51.9 | 11.6 | 1184.2 | 9.2 | 2828 | 54657 | 123.94 | 0.23 |

[1]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 200 feet of the shoreline discharge directly to the waterbody.

[2]The impervious subwatershed buffer area (acres) divided by total subwatershed impervious area (acres) then multiplied by total impervious subwatershed load (kg/year).

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

# Appendix D
# 6 Total Nitrogen TMDLs, 1 Pollution Prevention TMDLs

| Sub-Embayment | Segment ID | Description | TMDL (kg/day) |
|---|---|---|---|
| **Cotuit Bay**[1] | MA96-63_2004 | Previously determined to be impaired for nutrients by MassDEP. | 28 |
| **West Bay**[1] | MA96-65_2004 | Previously determined to be impaired for nutrients by MassDEP. | 24 |
| **Seapuit River** | MA96-64_2004 | Not impaired for total nitrogen, but a nitrogen TMDL needed since embayments are linked. (Pollution Prevention TMDL) Previously determined to be impaired for pathogens by MassDEP. | 4 |
| **North Bay**[1] | MA96_66_2004 | Previously determined to be impaired for nutrients by MassDEP. | 54 |
| **Prince Cove**[1] | MA96-07_2004 | Previously determined to be impaired for nutrients by MassDEP. | 19 |
| **Warren Cove** | | Determined to be impaired for nutrients during the development of this TMDL. | 11 |
| **Prince Cove Channel** | | Determined to be impaired for nutrients during the development of this TMDL. | 2 |

[1]Impaired for nutrients on 2002 , 2004, and proposed 2006 CWA §303(d) list.

# Appendix E