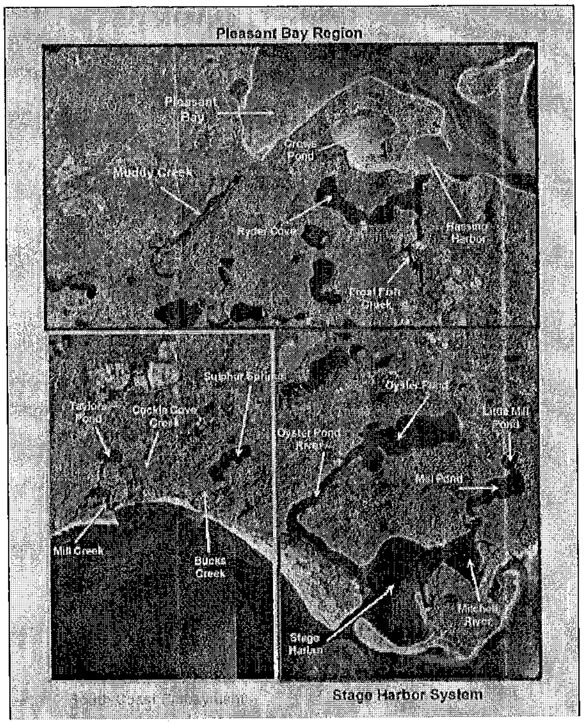
# Stage Harbor, Sulphur Springs, Taylors Pond, Bassing Harbor and Muddy Creek Total Maximum Daily Loads For Total Nitrogen

**(Report # MA96-TMDL-3**
**Control # CN206.0)**

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November 17, 2004

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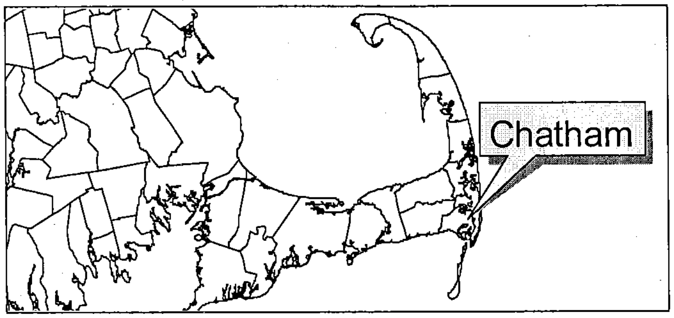
Front Cover

Town of Chatham Major Embayment Systems

# Chatham Embayments Total Maximum Daily Loads For Total Nitrogen




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

| | | | |
|---|---|---|---|
| Oyster Pond | MA96-45_2002 | 0.21 sq mi | Nutrients & Pathogens |
| Oyster Pond R | MA96-46_2002 | 0.14 sq mi | Nutrients & Pathogens |
| Stage Harbor | MA96-11_2002 | 0.58 sq mi | Nutrients & Pathogens |
| Mill Pond | MA96-52_2002 | 0.06 sq mi | Nutrients |
| Harding Beach Pd | MA96-43_2002 | 0.07 sq mi | Pathogens |
| Bucks Creek | MA96-44_2002 | 0.02 sq mi | Pathogens |
| Mill Creek | MA96-41_2002 | 0.03 sq mi | Pathogens |
| Taylors Pond | MA96-42_2002 | 0.02 sq mi | Pathogens |
| Crows Pond | MA96-47_2002 | 0.19 sq mi | Nutrients |
| Ryder Cove | MA96-50_2002 | 0.17 sq mi | Nutrients & Pathogens |
| Frost Fish Creek | MA96-49_2002 | 0.02 sq mi | Nutrients & Pathogens |
| Muddy Creek | MA96-51_2002 | 0.05 sq mi | Pathogens |

**Data Sources:** University of Massachusetts – Dartmouth/School for Marine Science and Technology; US Geological Survey; Applied Coastal Research and Engineering, Inc.; Cape Cod Commission, Town of Chatham
**Data Mechanism:** Massachusetts Surface Water Quality Standards, Ambient Data, and Linked Watershed Model
**Monitoring Plan:** Town of Chatham monitoring program (possible assistance from SMAST)
**Control Measures:** Comprehensive Wastewater Management Plan, Sewering, Storm Water Management, Attenuation by Impoundments and Wetlands, Fertilizer Use By-laws

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## EXECUTIVE SUMMARY

### Problem Statement

Excessive nitrogen (N) originating primarily from septic systems has led to significant decreases in the "environmental quality" of coastal rivers, ponds, and harbors in many communities in southeastern Massachusetts. In Chatham the problems in coastal waters include:

- Loss of some 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

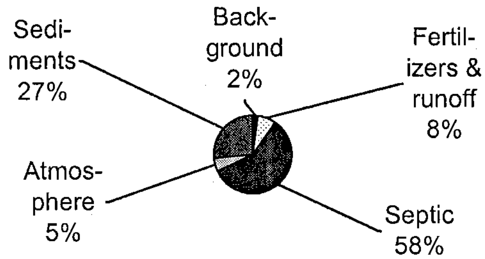
Coastal communities, including Chatham, rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as for commercial fin fishing and shellfishing. Failure to reduce and control N loadings will result in complete 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 Chatham'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
    - Septic systems
    - Natural background
    - Runoff
    - Fertilizers
- 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 the following figure.




**Target "Threshold" Nitrogen Concentrations and Loadings**

The N loadings (the quantity of nitrogen) to Chatham's embayments presently range from 3.45 kg/day in Frost Fish Creek, to 39.9 kg/day in Oyster Pond. The resultant concentrations of N in the embayments range from 0.42 mg/L (milligrams of nitrogen per liter) in Ryder Cove to 1.69 mg/L in the Sulphur Springs system.

In order to restore and protect Chatham's embayments, N loadings, and subsequently the concentrations of N in the water, must be reduced to levels below the "thresholds" that cause the observed environmental impacts. The Department has determined that, for Chatham, N concentrations in the range from 0.38 to 0.552 mg/L are protective. The mechanism for achieving these target N concentrations is to reduce the N loadings to the embayments. The Department has determined through mathematical modeling that the total maximum daily loads (TMDL) of N that would result in the "safe" target concentrations range from 1.85 to 13.82 kg/day. The purpose of this document is to present TMDLs for each embayment and to provide guidance to the Town on possible ways to reduce the N loadings to meet, or "implement", these proposed TMDLs.

**Implementation**

The primary vehicle for developing strategies to implement the TMDL is the Town's Comprehensive Watewater Management Plan (CWMP). The CWMP will evaluate alternative ways to significantly reduce the N loadings from septic systems through a variety of centralized or decentralized methods such as sewering with N removal technology, advanced treatment of septage, upgrade/repairs of failed on-site systems, and/or N-reducing on-site systems. Guidance on 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", available on the DEP website at http://www.mas.gov/dep/smerp/smerp.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.

There is presently only one municipal wastewater treatment facility in Chatham, which discharges approximately 3 kg N/day into the groundwater adjacent to Cockle Cove Creek. Indications are that maintaining the present loading rates from the treatment facility will protect the well- functioning salt marshes along Cockle Cove Creek, as well as the rest of the Sulphur Springs embayment system. The Department will, however, allow additional loading if data indicate that there would be no negative impacts to the adjacent salt marshes or groundwater supplies in the area.

Finally, growth within Chatham, which would exacerbate the problems associated with N loadings, should be guided by considerations of water quality-associated impacts.

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## Introduction

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

1. Description of water bodies and priority ranking: determination and documentation of whether or not a water body is presently meeting its water quality standards and designated uses.

2. Problem assessment: assessment of present water quality conditions in the water body, including estimation of present loadings of pollutants of concern from both point (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. Linking water quality and pollutant sources: 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. Total maximum daily loads: 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 DEP 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 Chatham embayments, the pollutant of concern, for this TMDL (based on observations of eutrophication), is the nutrient nitrogen. Nitrogen is the limiting nutrient in coastal and marine waters, which means that as its concentration is increased, so is the amount of plant matter. This can lead to nuisance populations of macro-algae, increased concentrations of phytoplankton and epiphyton (which impair eelgrass beds) - all of which combine to imperil the ecological health of the affected water bodies.

The TMDLs for total N for the five coastal embayments within the Town of Chatham, Massachusetts are based primarily on data collected, compiled, and analyzed by the University of Massachusetts Dartmouth's School of Marine Science and Technology (SMAST), the Cape Cod Commission, and others, as part of the Massachusetts Estuaries Program (MEP). The data were collected, primarily, over a study period from 1997 to 2003. This study period will be referred to as the "present conditions" in the TMDL because it is generally the most recent data available. The accompanying MEP Technical Report presents the results of the analyses of these five coastal embayments using the MEP Linked Watershed-Embayment N Management Model (Linked Model). The analyses were performed to assist the Town with decisions on current and future wastewater planning, wetlands restoration, anadromous fish runs, shell-fisheries, 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 were conducted on each 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 embayment. Thus, the MEP offers a science-based management approach to support the Town of Chatham's wastewater management planning and decision-making process.

## Description of Water Bodies and Priority Ranking

Chatham Massachusetts, at the eastern end of Cape Cod, is surrounded by water on three sides, with Nantucket Sound to the south, the Atlantic Ocean and Chatham Harbor to the east, and Pleasant Bay to the north. Much of the shoreline, especially to the north and south, consists of a number of small embayments of varying size and hydraulic complexity, characterized by limited rates of flushing, shallow depths and heavily developed watersheds. These embayments constitute important components of the Town'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 embayments along Chatham's shore are at risk of further eutrophication from high nutrient loads in the groundwater and runoff from their watersheds. Because of excessive nutrients many embayments or sub-embayments are already listed as waters requiring TMDLs (Category 5) in the MA 2002 Integrated List of Waters, as summarized in Table 1a.

A complete description of the water bodies is presented in Chapters I and IV of the Technical Report from which the majority of the following information is drawn. TMDLs were prepared for 17 ponds, rivers, creeks, and harbors listed below. Analytical and modeling efforts were conducted by grouping these 17 "sub-embayments", where appropriate, into embayment systems in which all the sub-embayments of an individual watershed combine to flow into either Nantucket Sound to the south or Pleasant Bay to the North.

- Stage Harbor System:
  - Oyster Pond
  - Oyster Pond River
  - Stage Harbor
  - Mitchell River
  - Mill Pond
  - Little Mill Pond
- Sulphur Springs System:
  - Sulphur Springs
  - Bucks Cr
  - Cockle Cove Cr
- Taylors Pond System:
  - Mill Cr
  - Taylors Pond
- Bassing Harbor System:
  - Crows Pond
  - Ryder Cove
  - Frost Fish Cr
  - Bassing Harbor
- Muddy Creek
  - Lower Muddy Cr
  - Upper Muddy Cr

The embayments addressed by this document are determined to be high priorities based on three significant factors: 1) the initiative that the Town has taken to assess the conditions of embayments, 2) the commitment made to restoring and preserving their embayments, and 3) because of the extent of eutrophication in the embayments. In particular, the embayments within the Town of Chatham are at risk of further degradation from increased N loads entering through groundwater and surface water from their increasingly developed watersheds. In both marine and freshwater systems, an excess of nutrients results in degraded water quality, adverse impacts to ecosystems, and limits on the use of water resources.

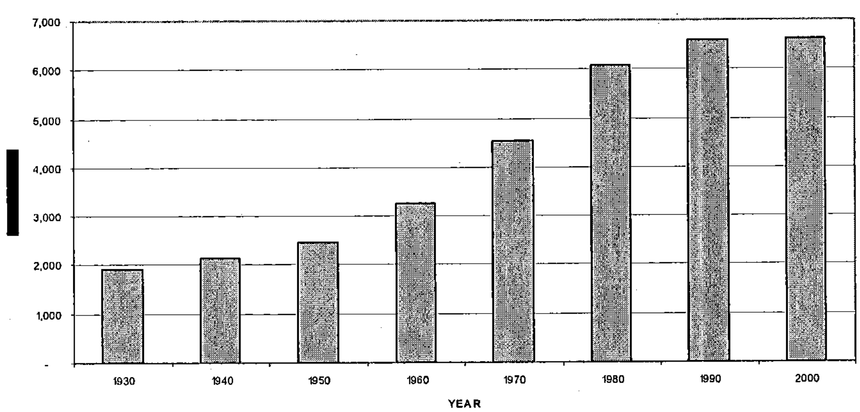
The general conditions related to the major indicators of habitat impairment, due to excess nutrient loadings, are tabulated in Table 1b. Observations are summarized in the Problem Assessment section below, and detailed in Chapter VII, Assessment of Embayment Nutrient Related Ecological Health, of the accompanying Technical Report.

## Problem Assessment

The watersheds of Chatham's estuaries 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.

Septic 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 travels 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 Chatham, as with all of Cape Cod, has increased markedly since 1950. In the particular case of the Town of Chatham, the increase is on the order of 250% since 1950. In addition, summertime residents and visitors swell the population of the entire Cape by about 300% according to the Cape Cod Commission (http://www.capecodcommission.org/data/trends98.htm#population). The increase in year round residents is illustrated in the following graph:

CHATHAM'S YEAR ROUND POPULATION



Based on current local zoning, the populations in the various embayments discussed here could increase from a low of about 4 % to a high of 20% depending on the particular water body.

**Table 1 a. Chatham embayments in Category 5 of the Massachusetts 2002 Integrated List[1]**

| NAME | SEGMENT ID | DESCRIPTION | SIZE | Pollutant Listed |
|---|---|---|---|---|
| **Stage Harbor** | | | | |
| Oyster Pond | MA96-45_2002 | Including Stetson Cove | 0.21 sq mi | Nutrients & Pathogens |
| Oyster Pond River | MA96-46_2002 | Outlet of Oyster Pd to confluence with Stage harbor, Chatham | 0.14 sq mi | Nutrients & Pathogens |
| Stage Harbor | MA96-11_2002 | From the outlet of Mill Pd (including Mitchell River) to the Confluence with Nantucket Sound at a line from the southernmost point of Harding Beach southeast to the Harding Beach Point, Chatham | 0.58 sq mi | Nutrients & Pathogens |
| Mill Pond | MA96-52_2002 | Including Little Mill Pond (PALIS #96174), Chatham | 0.06 sq mi | Nutrients |
| **Sulphur Springs** | | | | |
| Harding Beach Pond | MA96-43_2002 | Locally known as Sulphur Springs (northeast of Bucks Cr), Chatham | 0.07 sq mi | Pathogens |
| Bucks Creek | MA96-44_2002 | Outlet from Harding Beach Pond (locally known as Sulphur Springs) to confluence with Cockle Cove, Chatham | 0.02 sq mi | Pathogens |
| **Taylors Pond** | | | | |
| Mill Creek | MA96-41_2002 | Outlet of Taylors Pond to confluence with Cockle Cove, Chatham | 0.03 sq mi | Pathogens |
| Taylors Pond | MA96-42_2002 | Chatham | 0.02 sq mi | Pathogens |
| **Bassing Harbor** | | | | |
| Crows Pond | MA96-47_2002 | To Bassing Harbor, Chatham | 0.19 sq mi | Nutrients |
| Ryder Cove | MA96-50_2002 | Chatham | 0.17 sq mi | Nutrients & Pathogens |
| Frost Fish Creek | MA96-49_2002 | Outlet from cranberry bog northwest of Stony Hill Road to Confluence with Ryder Cove, Chatham | 0.02 sq mi | Nutrients & Pathogens |
| **Muddy Creek** | MA96-51_2002 | Outlet of small unnamed pond south of Countryside Drive and north-northeast of Old Queen Anne Road to mouth at Pleasant Bay, Chatham | 0.05 sq mi | Pathogens |

[1] This list was developed prior to the completion of data collection activities and will be reassessed based on the data and information collected during this project.

**Table 1 b. General summary of conditions related to the major indicators of nutrient over-enrichment /habitat impairment observed in Chatham embayments.** The table does not include the salt marsh habitats of Cockle Cove, Mill, or Frost Fish Creeks because, unlike embayments listed below, they are highly tolerant of watershed N loading. The examples of Chlorophyll and dissolved oxygen conditions are based on data from continuous DO and Chlorophyll monitoring during summer, 2002.

| Embayments | Eel Grass Loss (1951 – 2000) | Dissolved Oxygen Depletion | Chlorophyll *a* [2] |
|---|---|---|---|
| **Stage Hbr** | | | |
| Oyster Pond | Complete loss | Insignificant [1] | Generally 5 – 15 ug/L |
| Oyster River | Half lost | Insignificant | Generally 5 – 15 ug/L |
| Stage Harbor | Slight decline | Insignificant | Generally 5 – 15 ug/L |
| Mitchell river | Beds declining | Insignificant | No blooms reported |
| Mill Pond | Complete loss | <4 mg/L 30 % of study period<br><3 mg/L 16% of study period | Generally 5 – 20 ug/L<br>occasionally > 20 ug/L |
| Little Mill Pd | Complete loss | Presumed same as Mill Pond | Generally 5 – 20 ug/L<br>occasionally > 20 ug/L |
| **Sulphur Spr** | | | |
| Sulphur Springs | Complete loss | < 4 mg/L 12% of study period<br>< 3 mg/L 6% of study period | Frequently > 20 ug/L<br>Occasionally > 25 ug/L |
| Bucks Cr | Complete loss | < 4 mg/L 12% of study period<br>< 3 mg/L 6% of study period | Frequently > 20 ug/L<br>Occasionally > 25 ug/L |
| **Taylors Pd** | | | |
| Taylors Pond | Complete loss | < 4 mg/L 2% of study period | Frequently 10 – 20 ug/L |
| **Bassing Hbr** | | | |
| Crows Pd | moderate loss, density sparse | Consistently > 5 mg/L | Generally 10 – 15 ug/L |
| Ryder Cove, U | 75% lost | < 4 mg/L 7% of study period<br><3 mg/L 1% of study period | Frequently > 20 ug/L<br>Occasionally > 25 ug/L |
| Ryder Cove, L | Slight loss | Insignificant | Generally 10 – 20 ug/L |
| Bassing Harbor | No loss | Insignificant | Typically 5 – 10 ug/L |
| **Muddy Cr.** | | | |
| Lower Muddy Cr. | Near- complete loss | <4 mg/L 60 % of study period<br>< 3 mg/L 49 % of study period | Frequently > 50 ug/L |
| Upper Muddy Cr. | Unknown | < 4 mg/L 76 % of study period<br>< 3 mg/L 69% of study period | Frequently > 50 ug/L |

[1] insignificant defined as a slight lowering of DO, but no observations of ecologically significant reductions (below 4 mg/L)

2 nuisance algal blooms: chlor a = 15 – 20 ug/L; significant algal blooms = chlor *a* > 20ug/L)

Dramatic declines in water quality, and the quality of the estuarine habitats, throughout Chatham, have paralleled the population growth of the Town. The problems in these embayments 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 significantly declined in these waters. Furthermore, eelgrass is being 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 would be 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 Chatham, 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 Chatham's coastal embayments, as described above, will significantly reduce the recreational and commercial value and use of these important environmental resources.

Habitat and water quality assessments were conducted on each embayment based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. The five-embayment systems in this study display a range of habitat quality, both between systems and along the longitudinal axis of the larger systems. In general, the habitat quality of the sub-embayments is highest near their mouths and poorest in the inland-most tidal reaches. This is indicated by longitudinal gradients of the various indicators. N concentrations are highest inland and lowest near the mouths. Eelgrass abundance is highest near the mouths of the embayments. Infaunal communities are more stressed in the inland reaches. Dissolved oxygen concentrations are lowest inland and highest near the mouths of the embayments. Chlorophyll *a* concentrations are the highest in the inland reaches.

The following is a brief synopsis of the present habitat quality within each of the five-embayment systems:

***Stage Harbor System*** – Little Mill Pond, Mill Pond, and Oyster Pond have elevated N concentrations and have lost historic eelgrass beds that once covered most of their respective basins. Oxygen depletion is observed during summer in each system with Mill Pond (and presumably Little Mill Pond) having ecologically significant declines (to less than 3 mg/L). Oyster Pond had less oxygen depletion possibly due to its greater fetch for ventilation from the atmosphere. Chlorophyll *a* concentrations were consistent with the observed oxygen depletion. The lower reaches of the Oyster River and Upper Stage Harbor show good habitat quality as evidenced by their persistent eelgrass beds, infaunal community structure and oxygen and chlorophyll *a* concentrations. The innermost high quality habitat is found in the lower Mitchell River/upper Stage Harbor.

***Sulphur Springs System*** – Cockle Cove consists primarily of a salt marsh and central tidal creek. Both types of habitat are not expected to support eelgrass even under natural conditions. This system contains little water at low tide. Even though the assimilative capacity of salt marsh is unknown, it appears to be higher than that of eelgrass habitats. Sulphur Springs is a shallow basin containing significant macro algal accumulations, no eelgrass, and appears to be transitioning to salt marsh. However, Sulphur Springs basin is still functioning as an embayment, but a eutrophic one. Nitrogen concentrations are high, oxygen concentrations become significantly depleted (6% of time <3 mg/L) and phytoplankton blooms are common and large (chlorophyll *a* concentrations >20 ug/L). Eelgrass has not been observed for over a decade.

***Taylors Pond System*** – Taylors Pond represents the inland-most sub-embayment and is a drowned kettle pond. The lower portion of this system is comprised of tidal salt marshes along Mill Creek. Like the Sulphur Springs System, the inner basin functions as an embayment and the tidal creek as a salt marsh with low sensitivity to N inputs. Taylors Pond is currently showing poor habitat quality. There is currently no eelgrass community and no record of eelgrass for over a decade. Water column N levels are enriched over incoming tidal waters and severe dissolved oxygen depletion to ~4 mg/L is common. Very high chlorophyll *a* concentrations of 10-15 ug/L are common during summer. The benthic infaunal community is impoverished, with a mean of only 43 individuals collected in the grab samples, compared to several hundred in the high quality sub-embayments.

***Bassing Harbor System*** – The innermost sub-embayments to this system contain high quality habitat that is currently becoming impaired by N enrichment. Ryder Cove receives the greatest watershed N load of the Bassing Harbor sub-systems. This sub-embayment has been losing its eelgrass over at least the last decade. In 1951 the full basin appears to have supported eelgrass beds, many of which do not exist today. Infaunal communities indicate a moderate quality system with relatively low diversity and evenness. This is consistent with a system whose habitat is in transition from high to moderate level of quality. Upper Ryder Cove is currently showing bottom water oxygen depletion, frequently to <4 mg/L and occasionally to < 3 mg/L. The periodic oxygen declines, loss of eelgrass, and watershed N loading is consistent with the observed phytoplankton blooms, which generally (>40% of time) are >15 ug/L and frequently >20 ug/L. In contrast, the outer reach of Ryder Cove still supports relatively high habitat quality with dissolved oxygen concentrations almost always above 5 mg/L (99%) and moderate chlorophyll *a* concentrations (<15 ug/L). These water column parameters are consistent with the high eelgrass coverage. Crows Pond is the other inland-most sub-embayment in this Y-shaped estuary. However, Crows Pond has a significantly lower watershed N load than that to Ryder Cove. Crows Pond currently supports a high level of habitat quality, with eelgrass beds surrounding the central basin and sparse coverage throughout. Infaunal diversity and evenness is consistent with a high quality habitat. Dissolved oxygen concentrations are consistently above 5 mg/L and chlorophyll *a* concentrations also are moderate (generally 10-15 ug/L). However, it appears that habitat quality currently is declining. Eelgrass coverage is less than in the 1951 and 1995 records. At present it appears the Crows Pond is slightly beyond its threshold N level and is beginning to decline in habitat quality. In addition, Frost Fish Creek is a tributary system to outer Ryder Cove, which functions primarily as a salt marsh with a central basin. The outer-most basin is Bassing Harbor, which receives tidal exchanges with Pleasant Bay. Bassing Harbor currently supports high habitat quality and based upon the eelgrass records has been relatively constant since 1951. The infaunal community is consistent with high habitat quality, the maintenance of "protective" dissolved oxygen concentrations, and moderate to low chlorophyll *a* concentrations (typically 5-10 ug/L). The Bassing Harbor sub-embayment appears to be a relatively stable high habitat quality system, with demonstrated good eelgrass and infaunal communities.

***Muddy Creek*** – Muddy Creek, like Bassing Harbor, exchanges tidal waters with the greater Pleasant Bay System. However, unlike Bassing Harbor, Muddy Creek is a highly eutrophic embayment. Muddy Creek does not support significant eelgrass beds; however, a small sparse bed has persisted adjacent to the inlet. Muddy Creek is divided into an upper and lower portion by a dike whose weir has been removed or washed away. Massachusetts Water Quality Standards designates the saltwater tributaries of Pleasant Bay, which includes Upper and Lower Muddy Creek, as SA waters designated for open shellfishing, and Outstanding Resource Waters. Presently both portions are highly eutrophic with frequent anoxia in bottom waters and large algal blooms (chlorophyll a frequently >50 ug/L). The upper portion has poorer habitat quality than the lower portion, most likely as a result of access to the better quality waters entering the lower portion from Pleasant Bay. An infaunal community persists but it is dominated by species tolerant of organic enrichment. Species diversity and evenness are low. The whole of Muddy Creek currently supports N-impaired habitat of poor quality.

## Pollutant of Concern, Sources, and Controllability

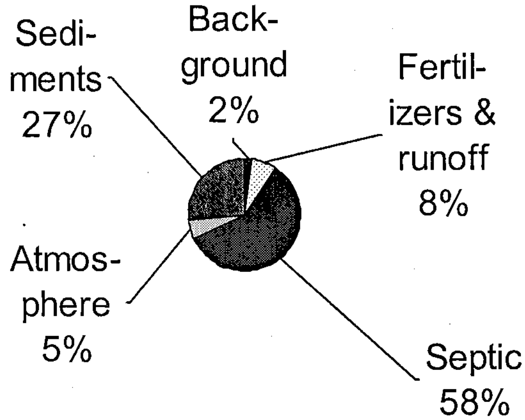
In the coastal embayments in the Town of Chatham, as in most marine and coastal waters, the limiting nutrient is nitrogen. Nitrogen concentrations beyond those expected naturally contribute to undesirable conditions, including the severe impacts described above, through the promotion of excessive growth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

Each of the embayments covered in this TMDL has had extensive data collected and analyzed through the Massachusetts Estuaries Program (MEP) and with the cooperation and assistance from the Town of Chatham, 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 Technical Report.

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

As is illustrated by the following figure, most of the N affecting Chatham's embayments originate from septic systems and nutrient-rich benthic sediments, with considerably less N originating from natural background sources, runoff, fertilizers, and atmospheric deposition.

**Percent contribution of various sources of nitrogen in Chatham's embayments**




The level of "controllability" of each source, however, varies widely:

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

Sediment N 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;

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

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

Septic system sources of N 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, upgrading/repairing failed systems, transporting and treating septage at treatment facilities with N removal technology either in or out of the watershed, or installing N-reducing septic systems.

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 tend to 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 Department, 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 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) preserve the natural distribution of eelgrass because it provides valuable habitat for shellfish and finfish, 2) prevent algal blooms, 3) protect benthic communities from impairment or loss, and 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 the Technical Report in Chapters IV, V, VI, VII and VIII . The main aspects of the data evaluation and modeling approach are summarized below, taken from pages 4 and 5 of the Report:

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

- requires site-specific measurements within each watershed and 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 additional scenarios.

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

The Linked Model, when properly parameterized (values assigned for each variable), calibrated, and validated, for a given embayment, becomes a N management planning tool as described below. The Linked 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 the Linked 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 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 N Loading

  - watershed delineation
  - stream flow and N load
  - land-use analysis (GIS)
  - watershed N model

• Embayment TMDL - Synthesis

  - linked Watershed-Embayment N Model
  - salinity surveys (for Linked Model validation)
  - rate of N recycling within embayment
  - dissolved oxygen record
  - Macrophyte survey
  - Infaunal survey (benthic animals) 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 sub-embayments within each embayment system, located close to the inland-most reach or reaches, which typically has the poorest water quality within the system. These are called "sentinel" sub-embayments;

2) using site-specific information and 3 years of embayment-specific data to select target/threshold N concentrations for each embayment system. This is done by refining the draft or "threshold" N concentrations that were developed as the initial step of the MEP process. The target concentrations that were selected generally occur in higher quality waters near the mouths of the embayment systems;

3) running the calibrated water quality model using different watershed N loading rates, to determine the loading rate, which would result in achieving the target N concentration within the sentinel system. 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 nitrogen **concentration**:

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

and, two outputs are related N **loadings** in each of the Chatham embayment systems:

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

A brief overview of each of the outputs follows:

Total Nitrogen concentrations in the embayment systems

a) Observed "present" conditions:

Table 2 presents the average concentrations of total N (TN), measured in the sub-embayments from 1999 through 2002. Concentrations of N are the highest in Cockle Cove (1.69 mg/L) and Frost Fish (1.19 mg/L) Creeks, which are functioning salt marsh habitats where assimilative capacity is naturally high, and the highly eutrophic Muddy Creek (1.18 mg/L). N is also high in Crows Pond (0.93 mg/L), where historically good habitat has started to decline in recent years. Nitrogen in the other embayments ranges in concentration from 0.45 to 0.73 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 Tables A-1 and A-2 of Appendix A.

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 threshold N concentrations by using the specific physical, chemical and biological characteristics of each embayment.

As listed in Table 2, the site-specific target (threshold) N concentration is 0.38 mg/L for all of the Stage Harbor and South Coastal embayment systems that are located on Nantucket Sound, compared to threshold N concentrations of 0.527 to 0.552 mg/L in the embayments that are located along Pleasant Bay.

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

***Stage Harbor System*** – This embayment system has two upper reaches. Therefore, two sentinel sub-embayments were selected, mid-Oyster Pond and Mill Pond. Little Mill Pond could not be used because it is small and has steep horizontal N gradients (see Section VI of the accompanying report). Within the Stage Harbor System, the upper most sub-embayment supportive of high quality habitat was upper Stage Harbor (Section VII, VIII-1 of the accompanying report). Water column total N concentrations within this embayment region vary with the tidal stage due to high N out flowing waters and low N inflowing waters (Section VI of the accompanying report). Therefore, the TN concentration determined from the water quality model (that corrected for tidally driven variation in N concentration at each site) was used in the threshold development. The calibrated water quality model for this system indicates an average TN concentration in the upper Stage Harbor of 0.40 mg/L is most representative of the conditions within this sub-embayment. However, upper Stage Harbor does not appear to be stable based upon changes in eelgrass distribution. Therefore, a N concentration reflective of conditions closer to the inlet should achieve the stability required. The lower N concentration is equivalent to the tidally averaged TN concentration mid-way between upper Stage Harbor and Stage Harbor or 0.38 mg/L. This threshold selection is supported by the fact that the high quality and stable habitat near the mouth of the Oyster River (to the Stage Harbor basin) is also at a tidally averaged TN concentration of 0.37 mg/L. The 0.38 mg/L was used to develop watershed N loads required to reduce the average N concentrations in each sentinel system to this level. Tidal waters inflowing from Nantucket Sound have an average TN concentration of 0.285 mg/L.

***Sulphur Springs System*** – The Sulphur Springs basin is both the inland-most sub-embayment and also represents the largest component of this system. Since this system exchanges tidal waters with the Nantucket Sound (0.285 mg/L), as does Stage Harbor, and since there is currently no high quality habitat within this system, the tidally averaged N threshold concentration for Sulphur Springs was determined to be the same as for the sentinel sub-embayments to the Stage Harbor System, i.e., 0.38 mg/L. The 0.38 mg/L was used to develop watershed N loads required to reduce the average N concentrations in the Sulphur Springs sentinel system to this level. Cockle Cove Creek, on the other hand, is primarily a salt marsh system, which is not adequately addressed by this model. Therefore, the loading rate recommendations for Cockle Cove Creek (and the discharged groundwater effluent of the Chatham treatment plant) represent loadings that are protective of the Sulphur Springs system as a whole. It should be noted that the designated uses for Cockle Cove Creek, as well as a few of the other inland-most sub-embayments in Chatham (in which eelgrass habitat does not occur and therefore eelgrass is not an existing or potential use), will be protected at higher N concentrations than those which ensure preservation of eel grass.

Presently the salt marsh in Cockle Cove is a diverse and well functioning system. Since the Linked Model used in this analysis was not intended to address salt marsh systems, the N loading in Cockle Cove Cr. has been capped, and therefore any increases in the flows to the treatment plant would have to be accompanied by a proportional reduction of the N to maintain existing loads. The Department, however, will consider allowing increased loading to this system based on additional data that demonstrate that greater loadings will not result in unacceptable negative impacts within the adjacent salt marsh or to groundwater supplies in the area.

***Taylors Pond System*** – This system was approached in a similar manner to the Sulphur Springs System and for the same reasons. Taylors Pond represents the innermost and functional embayment within this system. This system also exchanges tidal waters with Nantucket Sound (0.285 mg/L), as does the Stage Harbor System and there is no high quality stable embayment habitat within this system. Therefore, the tidally averaged N threshold concentration for this system was determined to be the same as for the sentinel sub-embayments to the Stage Harbor System or 0.38 mg/L. The 0.38 mg/L was used to develop watershed N loads required to reduce the average N concentrations in Taylors Pond to this level.

***Bassing Harbor System*** – Although this system has two inland-most sub-embayments, Ryder Cove and Crows Pond, only Ryder Cove was selected as the sentinel system. This resulted from the fact that Crows Pond has a relatively low N load from its watershed and appears currently to support higher quality habitat than does Ryder Cove. Ryder Cove currently shows a gradient in habitat quality with lower quality habitat in the upper reach and higher quality in the lower reach. Ryder Cove represents a system capable of fully supporting eelgrass beds and stable high quality habitat. At present, this basin is in transition from high to low habitat quality in response to increased N loading. Reductions of N concentrations in upper Ryder Cove to levels supportive of high quality habitat should also result in the restoration and protection of the whole of the Bassing Harbor System.

Following the approach used for the Stage Harbor System, a region of stable high quality habitat was selected within the Bassing Harbor System. The region selected was Bassing Harbor that has both high quality eelgrass and benthic animal communities. Unfortunately, TN within this system is very high. In fact, the whole of lower Pleasant Bay contains very high concentrations of TN. Analysis of the composition of the water column N pool within these embayments revealed that the concentrations of dissolved inorganic nitrogen (DIN) and particulate organic nitrogen (PON) were the same as for the Stage Harbor System. In fact, the level of these combined pools (DIN+PON) was lower in Bassing Harbor (0.135 mg/L) than in the Stage Harbor (0.158 mg/L) and the mouth of Oyster River (0.160 mg/L). It appears that the reason for the higher TN concentrations in the Pleasant Bay waters results from the accumulation of DON. The bulk of DON is relatively non-supportive of phytoplankton production in shallow estuaries, although some fraction is made available through its breakdown by microorganisms (or chemical and biochemical processes). Based upon these site-specific observations, an adjusted N threshold was developed for the Bassing Harbor System. The approach was to determine the baseline DON level for the region (average of inner and outer Ryder Cove, Bassing Harbor, Frost Fish Creek, Tern Island, and Pleasant Bay), which was determined to be 0.394 mg/L. A threshold range was then developed using a conservative DIN+PON level from the Bassing Harbor sub-embayment plus the DON background and an upper threshold based upon the Stage Harbor DIN and PON values discussed above. The threshold range for this system was set as 0.527 mg/L to 0.552 mg/L and the higher threshold was used to develop watershed N loads required to reduce the average N concentrations in upper Ryder Cove to this level. The N boundary condition (the concentration of N in inflowing tidal waters from Pleasant Bay) for the Bassing Harbor System is 0.48 mg/L.

***Muddy Creek System*** – This system is highly eutrophic. Given the long narrow basin and the hydrodynamic evaluation (Section V of the accompanying technical report), it was decided to make lower Muddy Creek the sentinel system. This is based also upon the fact that the upper portion was historically a freshwater system. Following the approach for the Bassing Harbor System, the MEP Team considered the Ryder Cove threshold appropriate for application to Muddy Creek. Note that lower Muddy Creek recently supported a sparse eelgrass bed. The threshold was used to develop watershed N loads required to reduce the average N concentrations in lower Muddy Creek to this level. Attainment of this threshold in Upper Muddy Creek, which would result in its attainment of class SA waters, required a nearly complete load reduction. The N boundary condition (the concentration of N in inflowing tidal waters from Pleasant Bay) for the Muddy Creek System is 0.50 mg/L.

Nitrogen loadings to the sub-embayments

a) Present loading rates:

In Chatham, the highest N loading from controllable sources is from septic systems, and with a few exceptions is the highest N loading source overall. Septic system loadings range from 1.3 kg/day to as high as 20. 4 kg/day. Nitrogen loading from the nutrient-rich sediments (referred to as benthic flux) exceeds the N loading from septic systems in four out the six Stage Harbor sub-embayments. As discussed previously, however, the "direct" control of N from sediments is not considered feasible. However, the magnitude of the benthic contribution is related to the watershed load. Therefore, reducing the incoming load should reduce the benthic flux. The TN loading from all sources ranges from 3.5 kg/day in Frost Fish Creek, to 39.8 kg/day in Oyster Pond. A further breakdown of N loading, by source, is presented in Table 3.

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

As previously indicated, the present N loadings to the Chatham embayments 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 to achieve the target N concentrations. Table 4 lists the present controllable watershed N loadings and reduced watershed loadings that are necessary to achieve target concentrations (which will be described more fully in the following section). It should be noted once again that the goal of this TMDL is to achieve the target N concentration in the designated sentinel system. The loadings presented in Table 4 represent one, but not the only, loading reduction scenario that can meet the TMDL goal. In this scenario the percentage reductions to meet threshold concentrations range from 0 % at Cockle Cove Creek up to 84% at Oyster Pond. Tables VIII-2 and VIII- 3 of the Technical Report (and reproduced in Appendix B of this document) summarize the present loadings from septic systems, and the reduced loads that would be necessary to achieve the threshold N concentrations in each embayment if septic loads alone were targeted.

## 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. Because there are no "numerical" water quality standards for N, the TMDLs for the Chatham embayments are aimed at determining the loads that would correspond to 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 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 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.

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

**Table 2. Observed "existing" total nitrogen concentrations and calculated target threshold nitrogen concentrations derived for the Chatham embayment systems**

| Embayment Systems And Sub-embayments | Observed System Total Nitrogen Concentration [1] (mg/L) | System Threshold Nitrogen Concentration (mg/L) |
|---|---|---|
| **Stage Harbor** | | 0.38 |
| Oyster Pond | 0.51 - 0.67 | |
| Oyster River | 0.45 | |
| Stage Harbor | 0.47 – 0.60 | |
| Mitchell river | 0.45 | |
| Mill Pond | 0.46 | |
| Little Mill Pond | 0.73 | |
| **Sulphur Springs** | | 0.38 |
| Sulphur Springs | 0.45 | |
| Bucks Cr | 0.47 | |
| Cockle Cove Cr | 0.74 – 1.69 | |
| Wastewater TF | | |
| **Taylors Pond** | | 0.38 |
| Mill Cr | 0.51 | |
| Taylors Pond | 0.51 | |
| **Bassing Hbr** | | 0.527 - 0.552 |
| Crows Pd | 0.93 | |
| Ryder Cove | 0.42 – 0.57 | |
| Frost Fish Cr | 0.81 – 1.19 | |
| Bassing Harbor | 0.50 | |
| **Muddy Cr.** | | 0.552 |
| Lower Muddy Cr. | 0.59 | |
| Upper Muddy Cr. | 1.18 | |

[1] calculated as the average of the separate yearly means of 1999 – 2002 data. Individual yearly means and standard deviations of the average are presented in Tables A – 1 and A – 2 of Appendix A

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

| Embayment Systems and Sub-embayments | Natural Background [1] Watershed Load (kg/day) | Present Land Use Load [2] (kg/day) | Present Septic System Load (kg/day) | Present Atmospheric Deposition (kg/day) | Present Benthic Flux [3] (kg/day) | Total nitrogen load from all sources (kg/day) |
|---|---|---|---|---|---|---|
| **Stage Harbor** | | | | | | |
| Oyster Pond | 0.6 | 1.2 | 10.9 | 0.3 | 26.8 | 39.8 |
| Oyster River | 0.5 | 1.2 | 9.7 | 1.1 | 0.7 | 13.2 |
| Stage Harbor | 0.2 | 0.3 | 2.3 | 3.3 | 12.8 | 18.9 |
| Mitchell river | 0.2 | 0.7 | 5.4 | 0.9 | -3.4 | 3.8 |
| Mill Pond | 0.1 | 0.2 | 1.5 | 0.6 | 3.7 | 6.1 |
| Little Mill Pond | 0.0 | 0.3 | 1.3 | 0.1 | 2.0 | 3.7 |
| **Sulphur Springs** | | | | | | |
| Sulphur Springs | 0.5 | 1.1 | 13.8 | 0.4 | -3.6 | 12.2 |
| Bucks Cr | 0.2 | 0.4 | 3.6 | 0.1 | 2.9 | 7.2 |
| Cockle Cove Cr | 0.2 | 0.7 | 5.8 | 0.1 | - 0.9 | 8.9[4] |
| Wastewater TF | 0.00 | | 3.0 | - | - | |
| **Taylors Pond** | | | | | | |
| Mill Cr | 0.2 | 0.7 | 5.4 | 0.2 | -0.3 | 6.2 |
| Taylors Pond | 0.3 | 0.8 | 7.3 | 0.2 | 1.7 | 10.3 |
| **Bassing Hbr** | | | | | | |
| Crows Pd | 0.1 | 0.5 | 5.1 | 1.4 | 3.5 | 10.6 |
| Ryder Cove | 0.5 | 0.8 | 11.3 | 1.3 | 7.4 | 21.3 |
| Frost Fish Cr | 0.1 | 0.4 | 3.1 | 0.1 | -0.2 | 3.5 |
| Bassing Harbor | 0.1 | 0.2 | 2.4 | 1.1 | -0.1 | 3.7 |
| **Muddy Cr.** | | | | | | |
| Lower Muddy Cr. | 0.1 | 1.8 | 13.4 | 0.2 | -1.9 | 13.6 |
| Upper Muddy Cr. | 0.9 | 1.5 | 20.4 | 0.2 | 4.7 | 27.7 |

1 assumes entire watershed is forested (i.e., no anthropogenic sources)
2 composed of fertilizer and runoff
3 nitrogen loading from the sediments
4 includes the 3.0 kg/day from the wastewater treatment facility

### Background loading

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

### Wasteload Allocations

Wasteload allocations identify the portion of the loading capacity allocated to existing and future point sources of wastewater. There are no point source discharges directly to surface waters in Chatham. The Town does operate a wastewater treatment facility that discharges to groundwater in the Cockle Cove sub-watershed but this is not considered a point source under EPA definition. EPA policy also requires that stormwater regulated under the NPDES program be identified and included as a wasteload allocation. As discussed below, for the purpose of this TMDL, stormwater loadings are not differentiated into point and non-point sources.

**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.**

| Embayment Systems and Sub-embayments | Present controllable watershed load [1] (kg/day) | Target Threshold Watershed Load [2] (kg/day) | Percent watershed load reductions needed to achieve threshold loads |
|---|---|---|---|
| **Stage Harbor** | | | |
| Oyster Pond | 12.2 | 2.0 | 84 % |
| Oyster River | 11.0 | 2.8 | 75 % |
| Stage Harbor | 2.6 | 0.4 | 85 % |
| Mitchell river | 6.0 | 3.5 | 42 % |
| Mill Pond | 1.7 | 0.8 | 53 % |
| Little Mill Pond | 1.6 | 0.9 | 44 % |
| Embayment system total: | 35.0 | 10.4 | 70 % |
| **Sulphur Springs** | | | |
| Sulphur Springs | 15.0 | 8.3 | 45 % |
| Bucks Cr | 4.0 | 2.2 | 45 % |
| Cockle Cove Cr | 6.5 | 6.7 | 0 % [4] |
| Wastewater TF | 3.0 [3] | 3.0 | 0 % |
| Embayment system total: | 28.5 | 20.2 | 29 % |
| **Taylors Pond** | | | |
| Mill Cr | 6.1 | 3.0 | 51 % |
| Taylors Pond | 8.1 | 4.0 | 51 % |
| Embayment system total: | 14.2 | 7.0 | 51 % |
| **Bassing Hbr** | | | |
| Crows Pd | 5.6 | 4.0 | 28 % |
| Ryder Cove | 12.0 | 6.9 | 43 % |
| Frost Fish Cr | 3.5 | 2.7 | 23 % |
| Bassing Harbor | 2.6 | 1.7 | 35% |
| Embayment system total: | 23.7 | 15.3 | 35 % |
| **Muddy Cr.** | | | |
| Lower Muddy Cr. | 15.2 | 6.6 | 57 % |
| Upper Muddy Cr. | 21.9 | 9.4 | 57 % |
| Embayment total: | 37.1 | 16.0 | 57 % |

[1] Composed of combined fertilizer, runoff, and septic system loadings

[2] Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentrations identified in Table 2 above.

[3] This target could change (increase) if additional data on loading capacity within Cockle Cove are presented in the future.

[4] Difference is not significantly different from 0 %

**Load Allocations**

Load allocations identify the portion the loading capacity allocated to existing and future nonpoint sources. In the case of the Chatham embayments, the nonpoint source loadings are primarily from septic systems. Additional N sources include: natural background, stormwater runoff (including N from fertilizers), the Chatham wastewater treatment facility ( WWTF) groundwater discharge, 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". On Cape Cod however 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 Chatham, 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 WWTF currently discharges about 3 kg N/day into the groundwater adjacent to the extensive salt marshes of Cockle Cove Creek. This marsh system is functioning well and there are no observed indications that it is impaired by the current N loadings. Therefore, to preserve the existing status of these salt marshes, and to protect the rest of the Sulphur Springs embayment system, the N loadings to Cockle Cove Creek, including those from the wastewater treatment facility, should not exceed the present levels, unless additional studies indicate that increased loadings would have no unacceptable environmental impacts.

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:

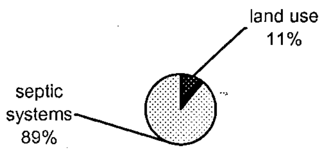
$$D_{PON} = (\text{PON}_{\text{present embayment}} - \text{PON}_{\text{present offshore}})$$

Since benthic loading varies throughout the year and the values shown represent 'worst-case' summertime conditions, loading rates are presented in kilograms per day (Table VIII-3 of the accompanying Technical Report). The benthic flux for the MEP modeling effort 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 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 septic system wastes and "land use", which includes stormwater runoff and fertilizers. The following figure emphasizes the fact that the overwhelming majority of locally controllable N comes from septic systems.

**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 Chatham 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

In the Chatham embayments, where most of the current N load does not pass through surface water features which reduce N concentrations, the attenuation factor becomes important only when the loads are greatly reduced, as they will be when the recommended TMDL values are achieved. At present loads, attenuation represents only a small fraction of the entire load and has little if any influence on the current water column concentrations. The load model uses attenuation factors for ground water passing through surface water features lower than those actually measured. Attenuation factors of 40% are used in the model when measured factors are in the vicinity of 60%. However, for the TMDL, a smaller than expected attenuation factor makes the allowable loading lower than it would otherwise be and constitutes a portion of the factor of safety.

In addition, using sub-embayments that are at, or near, the inland-most tidal reaches as sentinels for establishing the acceptable nitrogen load (i.e., the TMDL) provides a major margin of safety for "downstream" embayments which are closer to the mouths. Finally, decreases in air deposition through continuing air pollution control efforts, are uncounted in this TMDL, and are thus another component of the margin of safety.

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.

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Similarly, the water column N validation dataset was also conservative. The Linked 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, it is important to note that 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 denitrified or buried. The regeneration rate projected under reduced N loading conditions was based upon two assumptions:

a) the PON in the embayment in excess of that of inflowing tidal water (boundary condition) results from production supported by watershed N inputs and

b) the presently enhanced production would decrease in proportion to the reduction in the sum of watershed N inputs + plus direct atmospheric N input. The latter condition would result in equal embayment versus boundary condition production and PON levels if watershed N loading + direct atmospheric deposition could be reduced to zero (an impossibility of course).

This proportional reduction assumes that the proportion of remineralized N will be the same as under present conditions, which is almost certainly an underestimate. As a result future N regeneration rates are overestimated, which adds to the margin of safety.

2. Conservative threshold sites/nitrogen concentrations

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

3 Conservative approach

Cockle Cove Creek marsh - the area in which the Chatham WWTF groundwater discharge plume enters marine waters - was given a threshold equal to its current load. The reason is that the system is a salt marsh, which appears to be functioning well. While this system might take additional N load without significant impairment, the evidence is not yet available to support increased loadings. In addition, the target loads were based on tidal averaged N concentrations on the outgoing tide, which is the "worst case" because that is when the N concentrations are the highest. The N concentrations will be lower on the flood tides, due to dilution by incoming sea water, therefore this approach is conservative, and adds to the margin of safety.

**Seasonal Variation**

Nutrient loads to embayments are based on annual loads for two reasons. The first is that primary production in coastal waters can peak in both the late winter-early spring and in the late summer-early fall periods. Thus, nutrient loads must be controlled on an annual basis. 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.

**TMDL Values for Chatham Embayments**

As outlined above, the total maximum daily loadings of N that would provide for the restoration and protection of each 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 WWTF, septic systems, stormwater runoff, and fertilizers. In the case of Chatham, the TMDLs were calculated by projecting reductions in locally controllable septic system, stormwater runoff, and fertilizer sources.

**Table 5. The total maximum daily loads (TMDL) for the Chatham embayment systems, represented as the sum of the calculated target thresholds loads (from controllable watershed sources), atmospheric deposition, and sediment sources (benthic flux).**

| Embayment Systems and Sub-embayments: | Target Watershed Threshold Load [1] (kg/day) | Atmospheric Deposition (kg/day) | Benthic Flux [2] (kg/day) | **TMDL [3] (kg/day)** |
|---|---|---|---|---|
| **Stage Harbor** | | | | |
| Oyster Pond | 2.0 | 0.3 | 10.2 | **13** |
| Oyster River | 2.8 | 1.1 | 0.3 | **4** |
| Stage Harbor | 0.4 | 3.3 | 4.9 | **9** |
| Mitchell river | 3.5 | 0.9 | -1.3 | **3** |
| Mill Pond | 0.8 | 0.6 | 1.4 | **3** |
| Little Mill Pond | 0.9 | 0.1 | 0.8 | **2** |
| | | | | |
| **Sulphur Springs** | | | | |
| Sulphur Springs | 8.3 | 0.4 | -2.3 | **6** |
| Bucks Cr | 2.2 | 0.1 | 1.9 | **4** |
| Cockle Cove Cr | 6.7 | 0.1 | -0.6 | **6** |
| Wastewater TF | 3.0 | - | - | **3** [4] |
| | | | | |
| **Taylors Pond** | | | | |
| Mill Cr | 3.0 | 0.2 | -0.2 | **3** |
| Taylors Pond | 4.0 | 0.2 | -0.9 | **3** |
| | | | | |
| **Bassing Hbr** | | | | |
| Crows Pd | 4.0 | 1.4 | 2.6 | **8** |
| Ryder Cove | 6.9 | 1.3 | 5.6 | **14** |
| Frost Fish Cr | 2.7 | 0.1 | -0.1 | **3** |
| Bassing Harbor | 1.7 | 1.1 | -0.1 | **3** |
| | | | | |
| **Muddy Cr.** | | | | |
| Lower Muddy Cr. | 6.6 | 0.2 | -0.9 | **6** |
| Upper Muddy Cr. | 9.4 | 0.2 | 2.3 | **12** |
| | | | | |

[1] Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentrations identified in Table 2. Once again the goal of this TMDL is to achieve the identified N threshold concentration in the identified sentinel system. The target load identified in this table represents one alternative loading scenario to achieve that goal but other scenarios may be possible and approvable as well.

[2] 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.

[3] Rounded off Sum of target threshold watershed load, atmospheric deposition load, and benthic flux.

[4] The combined TMDL for the system is 9 kg/day. This target could change (increase) if additional data on loading capacity within Cockle Cove are presented in the future.

## Implementation Plans

The critical element of this TMDL process is achieving the embayment-specific nitrogen concentrations presented in Table 2 above, that are necessary for the restoration and protection of water quality and eelgrass habitat within the Chatham embayments. In order to achieve those "target" concentrations, N loading rates must be reduced throughout the embayment systems. Table 5, above, lists target watershed threshold loads for each sub-embayment. If those threshold loads are achieved, the overall embayment will be protected. This loading reduction scenario is not the only way to achieve the target N concentrations. The Town is 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 embayment systems, 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 Town planning effort 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 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. The Town, however, 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 stormwater runoff, controls of fertilizer use within the watershed through the establishment of local by-laws, wetlands restoration or other hydraulic alterations to reduce N loadings or mitigate the impacts of loading, implementation of stormwater BMPs, in addition to reductions in septic system loadings.

The EPA and the DEP recognize that effluent trading may provide a cost-effective means for the Town of Chatham to achieve the overall TMDL objectives. The EPA Water Quality Trading Policy Statement (http://www.epa.govowow/watershed/trading/finalpolicy2003.html) encourages trading programs that facilitate implementation of TMDLs, reduce the costs of compliance with the Clean Water Act regulations, establish incentives for voluntary reductions, and promote watershed-based nutrient load reduction initiatives.

The MEP Implementation Guidance report provides N loading reduction strategies that are available to the Town of Chatham, and could be incorporated into the Town's implementation plans. The following topics related to N reduction are discussed in the Guidance report:

- 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 Town of Chatham is one of 237 communities in Massachusetts covered by the phase II stormwater program requirements.

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

The Department recommends that the Town of Chatham develop a detailed monitoring plan as part of the Comprehensive Wastewater Management Planning process and as part of the detailed plan for TMDL implementation. The monitoring plan should be designed to determine if water quality improvements occur as a result of implementing this TMDL, and should be developed and conducted in phases according to the identification of N reduction options. The Department recognizes the long-term nature of the time horizon for full implementation of the TMDL, however, reasonable milestones in the shorter term are necessary. At a minimum, the baseline monitoring that was conducted by the town to assess dissolved oxygen, N and chlorophyll *a* concentrations in the water column should be continued, as well as benthic macro-invertebrate community structure and eelgrass habitat distribution analyses (possibly conducted by the MEP).

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

## Reasonable Assurances

DEP possesses the statutory and regulatory authority, under the water quality standards and/or the State Clean Water Act, to implement and enforce the provisions of the TMDL, including requirements for N loading reductions from septic systems. However, because most non-point source controls are voluntary, reasonable assurance is based on the commitment of the locality involved. Chatham 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 its citizens to take the necessary steps to remedy existing problems related to N loading from septic 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 septic systems, and other local regulations such as the Town of Rehoboth's stable regulations. Financial incentives include federal funds available under Sections 319, 604 and 104(b) programs of the CWA, which are provided as part of the Performance Partnership Agreement between MA DEP 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 septic system upgrades available through municipalities participating in this portion of the state revolving fund program.

In addition to the margin of safety within the context of setting the N threshold levels, described above, reasonable assurance 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.

## Appendix A

Tables A – 1 and A – 2: Summaries of nitrogen concentrations for Bassing Harbor and Muddy Creek sub-embayments (from Chapter VI of the accompanying MEP Technical Report)

Table A – 1.

Table VI-1a. Measured and modeled Nitrogen concentrations for Bassing Harbor and Muddy Creek, used in the model calibration plots of Figures VI-3 (Bassing Harbor total N),VI-4 (Bassing Harbor bio-active N), and VI-5 (Muddy Creek). All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means.

| System | Embayment | 1999 mean | 2000 mean | 2001 mean | 2002 mean | Overall mean | s.d. | N | model min | model average | model max |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bassing Harbor (TOTAL N) | Ryder Cove (inner) | - | 0.465 | 0.634 | 0.653 | 0.569 | 0.183 | 46 | 0.556 | 0.564 | 0.573 |
| | Ryder Cove (outer) | - | 0.437 | 0.391 | 0.427 | 0.419 | 0.067 | 47 | 0.493 | 0.522 | 0.551 |
| | Frost Fish Cr. (inner) | - | 0.915 | 0.684 | 0.788 | 0.809 | 0.218 | 18 | 0.676 | 0.724 | 0.792 |
| | Frost Fish Cr. (outer) | - | 1.244 | 0.867 | 1.379 | 1.187 | 0.435 | 23 | 0.535 | 0.605 | 0.818 |
| | Crows Pond | - | 0.755 | 0.936 | 1.135 | 0.929 | 0.346 | 44 | 0.576 | 0.585 | 0.591 |
| | Bassing Harbor | - | 0.543 | 0.462 | 0.482 | 0.499 | 0.172 | 23 | 0.480 | 0.497 | 0.532 |
| Bassing Harbor (Bio-Active N) | Ryder Cove (inner) | - | 0.178 | 0.168 | 0.242 | 0.189 | 0.067 | 46 | 0.192 | 0.200 | 0.208 |
| | Ryder Cove (outer) | - | 0.167 | 0.139 | 0.191 | 0.163 | 0.036 | 47 | 0.129 | 0.158 | 0.187 |
| | Frost Fish Cr. (inner) | - | - | 0.364 | 0.409 | 0.387 | 0.065 | 10 | 0.312 | 0.360 | 0.428 |
| | Frost Fish Cr. (outer) | - | 0.391 | 0.307 | 0.290 | 0.338 | 0.173 | 23 | 0.171 | 0.241 | 0.454 |
| | Crows Pond | - | 0.220 | 0.200 | 0.232 | 0.218 | 0.095 | 44 | 0.212 | 0.221 | 0.227 |
| | Bassing Harbor | - | 0.156 | 0.108 | 0.131 | 0.133 | 0.037 | 23 | 0.116 | 0.133 | 0.168 |
| Muddy Creek | Lower Muddy Cr. | - | 0.569 | 0.591 | 0.622 | 0.586 | 0.092 | 21 | 0.557 | 0.597 | 0.658 |
| | Upper Muddy Cr. | - | - | - | 1.184 | 1.184 | 0.501 | 6 | 1.179 | 1.205 | 1.232 |

Table A – 2..

Table VI-1b. Measured and modeled Nitrogen concentrations for Stage Harbor, Sulphur Springs, and Taylors Pond, used in the model calibration plots of Figures VI-6 (Stage Harbor total N),VI-7 (Sulphur Springs), and VI-8 (Taylors Pond). All concentrations are given in mg/L N. "Data mean" values are calculated as the average of the separate yearly means.

| System | Embayment | 1999 mean | 2000 mean | 2001 mean | 2002 mean | data mean | s.d. | N | model min | model average | model max |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stage Harbor* | Oyster Pond | 0.597 | 0.786 | 0.708 | 0.604 | 0.667 | 0.252 | 63 | 0.671 | 0.678 | 0.687 |
| | Lower Oyster Pond | - | - | 0.552 | 0.498 | 0.505 | 0.083 | 8 | 0.371 | 0.547 | 0.658 |
| | Oyster River | 0.451 | 0.457 | 0.386 | 0.536 | 0.457 | 0.103 | 28 | 0.286 | 0.374 | 0.568 |
| | Stage Harbor | 0.425 | 0.664 | 0.632 | 0.677 | 0.597 | 0.182 | 58 | 0.288 | 0.339 | 0.427 |
| | Upper Stage Harbor | 0.418 | 0.457 | 0.503 | 0.548 | 0.474 | 0.116 | 62 | 0.382 | 0.401 | 0.423 |
| | Mitchell River | - | - | 0.429 | 0.487 | 0.451 | 0.092 | 13 | 0.403 | 0.432 | 0.467 |
| | Mill Pond | 0.471 | 0.503 | 0.418 | 0.507 | 0.463 | 0.102 | 70 | 0.466 | 0.473 | 0.485 |
| | Little Mill Pond | 0.792 | 0.690 | 0.742 | 0.741 | 0.733 | 0.226 | 60 | 0.696 | 0.711 | 0.723 |
| Sulphur Springs | Mid Cockle Cove Cr. | - | 1.492 | 2.043 | 1.613 | 1.685 | 0.698 | 18 | 0.704 | 1.378 | 2.493 |
| | Cockle C. Cr. mouth | - | 0.890 | 0.687 | 0.636 | 0.742 | 0.213 | 23 | 0.266 | 0.472 | 0.988 |
| | Bucks Creek | - | 0.401 | 0.479 | 0.576 | 0.473 | 0.139 | 20 | 0.285 | 0.337 | 0.508 |
| | Sulphur Springs | - | 0.360 | 0.453 | 0.584 | 0.451 | 0.123 | 23 | 0.288 | 0.369 | 0.498 |
| Taylors Pond | Mill Creek | - | 0.491 | 0.508 | 0.530 | 0.507 | 0.105 | 23 | 0.284 | 0.326 | 0.584 |
| | Taylors Pond | - | 0.509 | 0.487 | 0.530 | 0.508 | 0.122 | 48 | 0.424 | 0.467 | 0.517 |

* Stage Harbor also included the limited sampling data (N=4) from 1998.

**Appendix B**

Table B – 1.
Present septic system nitrogen loading rates, calculated loading rates from septic systems that are necessary to achieve target threshold nitrogen concentrations, and the percent reductions of the existing loads necessary to achieve the target threshold loadings by reducing septic system loadings, ignoring all other sources.

| Embayment Systems and Sub-embayments | Present Septic System load (kg/day) | Target septic system Load (kg/day) | Percent septic system load reductions needed to achieve target loads |
|---|---|---|---|
| **Stage Harbor** | | | |
| Oyster Pond | 10.94 | 0.11 | 99 % |
| Oyster River | 9.73 | 0.79 | 92 % |
| Stage Harbor | 2.30 | 0.00 | 100 % |
| Mitchell river | 5.37 | 2.66 | 51 % |
| Mill Pond | 1.53 | 0.59 | 61 % |
| Little Mill Pond | 1.3 | 0.65 | 50 % |
| | | | |
| **Sulphur Springs** | | | |
| Sulphur Springs | 13.84 | 6.67 | 52 % |
| Bucks Cr | 3.61 | 1.62 | 55 % |
| Cockle Cove Cr | 5.75 | 5.75 | 0 % |
| Wastewater TF | 3.03 | 3.03 | 0 % |
| | | | |
| **Taylors Pond** | | | |
| Mill Cr | 5.4 | 2.14 | 60 % |
| Taylors Pond | 7.31 | 2.91 | 60 % |
| | | | |
| **Bassing Hbr** | | | |
| Crows Pd | 5.06 | 3.32 | 34 % |
| Ryder Cove | 11.27 | 5.71 | 49 % |
| Frost Fish Cr | 3.05 | 2.17 | 29 % |
| Bassing Harbor | 2.42 | 1.48 | 39 % |
| | | | |
| **Muddy Cr.** | | | |
| Lower Muddy Cr. | 13.39 | 4.71 | 65 % |
| Upper Muddy Cr. | 20.41 | 7.07 | 65 % |
| | | | |

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## Attachment 1

**Response to Comments on the Chatham Nitrogen TMDL**
**November 9, 2004**

## General

**Comment/Question:** The number and type of impairment on each water body should be stated in the document (e.g., nitrogen, dissolved oxygen, eutrophication, etc) and the document should state what and how many impairments the TMDL covers.

Response: Table 1a of the TMDL document lists impairments for each segment that appears in the Integrated List. Table 1b provides a general summary of the nutrient-related impairments observed in all the water bodies covered by this TMDL. This TMDL is for nutrients (specifically total nitrogen) only.

**Comment/Question:** Estuaries and embayments other than the five water bodies studied for the Chatham TMDL, such as the Red River, need attention, including watershed delineations and reductions of nitrogen loading from their watersheds. How will this be accomplished?

Response: The Town should include all water bodies in the Comprehensive Wastewater Management Plan (CWMP). The Red River system was not included in this round of evaluations; however, it is, at present, anticipated to be included when MEP evaluates systems in Harwich. The Department recognizes that although this is a reasonable expectation scientifically, it may be problematic relative to the Town gaining support to move forward. However, the Department suggests that the Town move forward with controlling nitrogen in the watersheds where they can, and through adaptive management, fine tune the target concentrations and target watershed loading rates at a later date.

**Comment/Question:** Why has it taken so long to complete planning for wastewater management given that Chatham started over four years ago? The Town was awaiting completion of this effort to incorporate the results into its CWMP.

Response: Part of the timeframe is simply the complicated nature of the issue. Another part is that the Massachusetts Estuaries Program (MEP) is using the most up to date information and science to develop as accurate a target for water quality as possible. This has required field measurements of water movement within the various tidal water bodies in Chatham in order to construct the most reliable model of nitrogen concentrations, both existing and predicted for various scenarios, so that as accurate as possible allowable loads can be estimated. Nitrogen control is expensive and the most cost effective options are the ones desired. Also, the MEP process is only 3 years old and its protocol requires 3 years of data.

**Comment/Question:** The Department's TMDL development process needs to be better defined and clearly articulated as this program moves forward.

Response: The Department, in collaboration with SMAST and officials of the Cape Cod Communities, is continually refining the public communication and outreach aspects of the Mass Estuary Program. These efforts, to date, have included revisions of data and draft report delivery schedules to facilitate municipal reviews, and the production and distribution of fact sheets to better explain compliance-related issues, and other aspects of the TMDL process.

**Comment/Question:** Will all of the waters (in Chatham's embayments) considered impaired be on the 303(d) (now the Integrated) List?

Response: Those embayments with total nitrogen concentrations higher than the threshold conditions will be listed. Those embayments that currently meet the threshold conditions should be considered "protective" TMDLs.

**Comment/Question:** Total year round population is not an adequate measure of nitrogen loads from people. A quantitative measure is needed.

Response: DEP agrees and noted in the presentation that the population on Cape Cod about doubles in the main tourist season. However, the population statistics used in our presentation are solely to demonstrate population trends over time. A more rigorous estimate for Chatham (and other communities) was made for the modeling effort through the use of potable water distribution statistics (metered water use readings). These figures yield reasonable science based estimates of the seasonal population figures because 90% of the town is on public water. MEP believes that use of better distribution statistics provides a more accurate accounting to estimate nitrogen loads for modeling purposes.

**Comment/Question:** It was stated in the public meeting that the TMDLs were not being proposed on a sub-embayment level, and that the sentinel monitoring points would be utilized as the representative point within the embayment system. However, the document has several tables that refer to a TMDL value for individual embayments.

Response: The approach is to protect each embayment system, overall, by reducing loadings at each sub embayment. The various tables in the TMDL present one suggested loading alternative, that if achieved, will reduce N concentrations in both the sentinel systems, and sub embayments, to the target concentrations. Other alternatives may be possible and can be explored by the Town using the model.

**Comment/Question:** Accurate loading data is so important, DEP and the Cape Cod Commission are urged to press Chatham's neighboring towns of Harwich and Orleans to participate in a data collection program similar to Chatham's. Because water quality is a regional interest, regional data collection is important for achieving all Cape Cod Towns' TMDL limits.

Response: All the towns on Cape Cod, including those mentioned, are involved to varying extents, with the collection of water use and water quality data. Similar to Chatham, both Orleans and Harwich provided water use data that were used to generate nitrogen-loading rates. Data from Chatham and Harwich were used for the Chatham embayments loading rates. Data from Orleans will be used in future reports on Orleans embayments and Pleasant Bay. DEP recognizes the need for a comprehensive approach to watershed-wide issues. DEP further recognizes that some communities are doing more than others. We anticipate that the significant implications of efforts by the more active towns will encourage the less active towns to recognize that it is in their own best interest to do more. In addition, DEP will continue to urge all towns to address this pressing issue.

**Comment/Question:** Are there any Wasteload Allocations in Chatham? The town of Chatham is subject to Phase II of the storm water program.

Response: Wasteload allocations identify the portion of the loading capacity allocated to existing and future point sources of wastewater. There are no point source discharges directly to surface waters in Chatham. The Town does operate a wastewater treatment facility that discharges to groundwater in the Cockle Cove sub-watershed but this is not considered a point source under EPA definition. EPA policy also requires that stormwater regulated under the NPDES program be identified and included as a wasteload allocation. For the purpose of this TMDL, stormwater loadings are not differentiated into point and non-point sources since the majority of these loads enter into the embayments via groundwater.

## Pleasant Bay

**Comment/Question:** It is premature to submit the TMDL for Chatham's Pleasant Bay sub-embayments until the entire Pleasant Bay system has been evaluated.

Response: DEP recognizes that the Pleasant Bay TMDL may impact the Pleasant Bay sub-embayments. It is possible that SMAST will have to re-run the model for the Pleasant Bay sub-embayments after the Pleasant Bay TMDL is determined. Although the loading estimates may be refined with this new information, the data indicates that significant reductions will be needed to meet water quality goals and the existing loading rates recommended in this TMDL are necessary to achieve that goal. Taking steps to achieve these reductions will improve water quality and should be undertaken as quickly as possible. Therefore the Chatham TMDL for these sub-embayments are considered interim loadings.

### Implementation

**Comment/Question:** The TMDL for Chatham and other communities in the region should be more specific to clarify how the TMDL will be implemented, regulated, and enforced in the future.

Response: The Department has provided a guide to implementing TMDLs, which discusses many options for reducing nitrogen in coastal watersheds. However, the Department gives communities great latitude to choose and develop implementation strategies. The regulatory and enforcement aspects of TMDLs are discussed below, and in TMDL fact sheets available to the public and municipal officials.

**Comment/Question:** Will compliance with the TMDL be determined by measuring the nitrogen concentrations in the water column, or by evaluating the eelgrass? If nitrogen is measured, will it be in the sub-embayments or just the sentinel embayment?

Response: Compliance will be determined by measuring water column nitrogen in the sentinel sub-embayment. The MEP process is based on reducing the loadings in the sub-embayments until the target water column concentration is achieved in the sentinel sub-embayment. The target concentrations were chosen because they have been observed to support eelgrass and other desirable habitat within each estuary system. The monitoring program should include eelgrass and other indicators of desirable habitat and water quality conditions. If eelgrass and other environmental indicators of healthy environments are restored, but the nitrogen concentrations in the water column remain higher than the target threshold values, those targets will be re-evaluated, and most likely, revised site-specific target values will be established.

**Comment/Question:** What is the expected timeframe to revise the TMDL and obtain EPA approval?

Response; DEP will require approximately 2 months to submit the TMDL to EPA. It is not uncommon for EPA to take several months to review. Overall, it is likely that it will take 3 – 6 months to finalize the TMDL.

**Comment/Question:** How long will implementation take?

Response: This question is better directed to the town than to DEP because the overall strategy, phasing, and scheduling will be developed as part of the Comprehensive Wastewater Management Plan. There are many factors that play a role in implementing a Town-wide program. One variable is the age of the neighborhood. Retrofitting is usually more time-consuming and costly than is providing the same controls for a new neighborhood as it is built. In addition, smaller community based or cluster systems generally take shorter amounts of time than do town-wide sewering and treatment plant construction. So for some of the smaller projects, 2 to 3 years may be required whereas large projects, that are typically phased, may require a decade or more to fully evaluate, design and construct, even assuming a minimal amount of technical or political controversy. Projects often can proceed in parallel, however, so several efforts can be underway at once, especially if they are independent of one another. The Town should be consulted relative to its proposed approach, however, it is critical to note that it will take time, after construction is completed, for the nitrogen reductions to begin to appear in the embayments.

**Comment/Question:** What will having the TMDL do for SRF funding?

Response: Additional priority points are awarded for having a completed TMDL. In addition, CWMPs that address regional or watershed-wide TMDL implementation are awarded additional priority points.

**Comment/Question:** Is the option of an ocean outfall precluded by the Ocean Sanctuaries Act?

Response: Yes, any option for locating such a discharge would require approval by the legislature.

**Comment/Question:** What happens when two (or more) towns contribute load to a given water body and load reductions are necessary?

Response: The Commonwealth will work with all communities to encourage optimal solutions. Regulatory tools are not the Commonwealth's first choice given the complexity of the problem.

**Comment/Question:**

A) It is difficult to see how the "adaptive management" approach is an appropriate concept in the implementation of solutions to achieve the TMDLs. To achieve the TMDLs, the Town of Chatham must implement costly solutions (involving "bricks and mortar") which may take from one to three years to put in place. Once these are in place, it may take another three to five years before the Town will know whether or not the solution is producing the desired result, i.e., lower nitrogen concentrations in the embayments. What opportunity will there be to "adapt" given travel time in groundwater and the overall length of the implementation process.

Response: This point is well taken, however, it is possible to prioritize projects or "phase" implementations in a way that eliminates sources closest to each embayent (shorter travel time) that can result in improved water quality conditions in shorter periods of time. The model can be used to assess the benefits of each potential option. Also, since concentration targets have been selected based on those waterbodies meeting water quality objectives, there is a fair amount of confidence that nearly all practical controls are needed.

B) As a consequence of the timing issues stated in A) above, the Town needs to have complete confidence that the work done by the MA Estuaries Project (MEP) is sufficiently accurate to justify the spending of tens of millions of dollars by Chatham to achieve the TMDLs.

Response: No process will eliminate all uncertainty, however DEP recognizes the issue of uncertainly and initiated the MEP to provide the best science- based guidance possible. Load reductions of nitrogen clearly are needed so that all efforts to accomplish this are steps in the right direction and the objective is to provide as much information as possible to choose the most cost effective options. DEP believes that the tools developed through the MEP process is based on solid science and is sufficiently accurate to make wastewater management decisions.

**Comment/Question:** The TMDL document indicates that a Town bylaw to regulate the use of nitrogen fertilizer can be used to manage watershed nitrogen loads in the future. This appears to be a change in DEP policy which did not allow a proposed Falmouth fertilizer bylaw to manage fertilizer nitrogen in the West Falmouth Harbor watershed.

Response: The Department encourages efforts to reduce any source of nitrogen loading and does not have a policy which disallows fertilizer management bylaws or regulations. In the case of Falmouth, the town requested a nitrogen credit for instituting a fertilizer management bylaw. However, the Department felt that there was no quantifiable credit that could be established due to questions of efficacy of enforcement, the exact nature and quantity of fertilizer loading, and other uncertainties. The Department did leave open the possibility that if such a bylaw were instituted and after a period of time the town could document its effectiveness, the issue of a fertilizer management credit could be revisited.

**Comment/Question:** How would adaptive management work in the case of non-traditional means of nitrogen control: For example, if a town planned on significantly reducing nitrogen loading from fertilizer use, how would the town and DEP know the real effectiveness of the fertilizer control program?

Response : Determining nitrogen reductions from reduced fertilizer use will be difficult at best. First, planned reductions would have to be based on appropriate data that support the proposed reductions. A program would have to be proposed by the Town and accepted by DEP as plausible. Second, it should be noted that significantly reducing nitrogen loading from fertilizer use, although beneficial, will not significantly reduce the overall nitrogen loading until the primary source (i.e. septic systems) has been addressed. Third, compliance will be a function of actual concentrations of nitrogen in the water column, that will to be determined by the compliance monitoring program.

**Comment/Question:** Table 4 should be revised to illustrate the percentage of the 'controllable" nitrogen that needs to be removed to more accurately represent the efforts that the Town will need to make to meet the TMDLs. At present, the watershed load includes sources that cannot be controlled by the Town.

Response: Table 4 has been revised as per this comment.

**Comment/Question:** The Town and the USEPA need to know how the TMDLs will be regulated (permitting and regulatory actions) in the future.

Response: In most cases, particularly when the pollution addressed in the TMDL is caused by non-point sources, DEP prefers to work cooperatively with the community in question to address the issues. Thus enforcement is only considered if absolutely necessary. DEP possesses the statutory and regulatory authority to implement and enforce the provisions of the TMDL if that becomes necessary in the future, however this is not our preferred approach.

**Comment/Question:** The implementation monitoring program should be identified as part of this TMDL, to clearly indicate how the TMDL will be monitored in the future.

Response: At a minimum the baseline studies, previously conducted, should be continued. This will be incorporated in the TMDL.

**Comment/Question:** The TMDL document encourages the concept of nutrient trading within the embayment systems, yet indicates that the water quality in the individual sub-embayments cannot be allowed to degrade to a point that affect natural systems. To what level can an individual sub-embayment system receive a nitrogen load from wastewater systems to allow a reduction in another sub-embayment to meet the TMDL at a sentinel location?

Response: The loading rates that are suggested in the TMDL document represent one approach to reducing nitrogen loading and restoring water quality in the embayment systems. It is possible that "redistributing" the load reductions (i.e., greater reductions in one sub-embayment and lesser reductions in another sub-embayment, within the same embayment system) could result in a more cost effective improvement in the overall embayment. However, the "success" of such an approach would have to be verified by additional model runs, and it would have to be determined that revisions to the current plan would not result in poor water quality.

**Comment/Question:** MADEP's permit system currently allows for a 5 year permit to be issued. It is conceivable for a TMDL to be established and the reduction in nitrogen loading not to reach the sentinel monitoring point in excess of three permit cycles. The permitting uncertainties need to be resolved before the TMDL is approved by USEPA.

Response: DEP does not agree that permitting uncertainties need to be resolved before the TMDL is approved by EPA. The TMDL is intended to identify the "goal or target" that needs to be achieved and is independent of the permitting or regulatory mechanism used to meet that goal. There is the ability within the permitting program for establishing schedules for compliance and interim limits. Point discharges to surface waters, other than from storm-water sewer systems, are not present in Chatham and therefore discharge permits are not the primary regulatory control for Cape Cod estuaries in general. A portion of Chatham is subject to the Phase II general permit for storm water. However, storm water is not a primary source of nitrogen in this situation. Chatham does have a state permit for its ground water discharge. While it does not have a nitrogen limit right now, nitrogen is removed during treatment, resulting in relatively low concentrations for a wastewater effluent. How much lower a concentration can be achieved needs to be assessed in the wastewater management study the Town is conducting.

**Comment/Question:** If a town were to successfully complete a flushing enhancement program, such as through a culvert replacement, it would seem that the TMDL would then change (presumably the allowable watershed loads would increase). How would the town adapt its management of watershed loads in this case? Would it necessitate re-modeling of the embayment, and would that remodeling occur during the CWMP process based on the presumed success of the flushing enhancement, or would it wait until the actual success of the flushing enhancement is demonstrated?

Response: When an action, such as enhanced flushing, is proposed in the CWMP, modeling would have to be conducted in order to predict the resulting water column nitrogen concentrations that would occur after enhanced flushing. Revised loads throughout the embayment (that would be needed to meet the target water column concentrations in the sentinel sub-embayment) would have to be calculated by additional modeling.

**Comment/Question:** At a prior presentation on the MEP work, it was noted that there is a range of water quality and habitat status that a town may find acceptable. That is, a town might choose to provide a lower level of protection than that considered in the TMDL. Would such an action constitute a violation?

Response: The level of protection is set by the State Water Quality Standards. Since the State standards relative to eutrophication are narrative rather than numeric they are subject to interpretation and provide some flexibility. The Town however, could not choose a lower level of protection than is provided by the water quality standards without first making a demonstration that the designated uses cannot be achieved. If such a demonstration could be made and DEP agreed then a water quality standard change would have to be proposed through a public process.

**Comment/Question:** One of your slides implied that DEP permitting would be based on the Comprehensive Wastewater Management Plan. This is contrary to traditional practice: typically, the CWMP evaluates options for meeting permit provisions that are known in advance. While I understand and agree with the "adaptive management" approach, I am concerned that a permit issued after CWMP completion may not be acceptable to a town and may require additional planning to find other acceptable solutions. Towns need to move ahead quickly to implement solutions: what steps can DEP take to streamline the process and avoid potential delays?

Response: It is DEP's (and MEP's) goal to provide information necessary to make local decisions. The TMDL and subsequent modeling by SMAST will prescribe the nitrogen concentrations that must be achieved, and sub-embayment- specific target loads are suggested as means of achieving the target concentrations. With that said, however, additional analysis and information may be needed to make final permitting decisions. Examples include evaluating potential groundwater impacts from a new or increased discharge. This information is normally collected during the CWMP and permitting process. DEP and SMAST will be available to assist the towns in order to avoid potential delays wherever possible. We recognize that Chatham's CWMP process was slowed to some extent waiting for the MEP process to reach its conclusions. However, this was necessary in order to provide as complete information as possible. DEP is providing as complete answers as it can on water quality requirements and recognizes Chatham's and other towns' need to have this information in as timely a manner as possible.

**Comment/Question:** Why is the percent reduction in load so high for outer Stage Harbor given that it has relatively good water quality (especially when compared to some of its sub-embayments)?

Response: The TMDL for Stage Harbor is actually three to four times higher than those of the upstream sub-embayments. However, the higher percent reduction needed in Stage Harbor reflects the need to compensate for the much higher atmospheric inputs and the very high sediment flux in Stage Harbor as compared to some of the sub-embayments (due, in part, to the large size of Stage Harbor). Furthermore, the TMDL document recommendations represent only one loading reduction scenario for each embayment system. Other options may exist and can be explored by the Town using the Linked Model.

**Comment/Question:** Why does nitrogen loading in Bassing Harbor have to be reduced when the Harbor's nitrogen concentrations are currently less than the target threshold concentrations?

Response: Suggesting nitrogen loading reductions in Bassing Harbor is a way of spreading the effort out over a larger area. If no loading reductions were to be made in Bassing Harbor, then more loading reductions would have to be made in the sub-embayments in order to achieve the total loading reduction goal for the embayment system. Also, since this system is tidal, water and its nitrogen moves inland as well as seaward. Hence, water quality in "downstream" embayments can have an impact on "upstream" embayments. This is a major aspect addressed by the linked model applied as part of the MEP program.

**Comment/Question:** The section on Reasonable Assurance should include a discussion of DEPs authority under the water quality standards and/or State Clean Water Act to require nitrogen loading reductions from septic systems.

Response: A statement to that effect has been added to the TMDL document.

## Muddy Creek

**Comment/Question:** The status of Upper Muddy Creek is not clear. Reference is made to this being historically a fresh water system but no further discussion is provided. A discussion of the designated uses of Upper Muddy Creek and projected water quality as a result of the targeted nitrogen reductions should be included in the TMDL.

Response: These issues were clarified in the TMDL document.

**Comment/Question:** A concern is that the report recommends that Muddy Creek be dammed and turned into a fresh water pond. The best thing to do for Muddy Creek would be to open up the culvert to a reasonable size or build a bridge over the creek at the entrance to Pleasant Bay.

Response: Opening the culvert to increase flushing at the lower end of the creek, as suggested, is currently being considered. In addition, repair of the dyke located midway up the creek is being considered as a means to restore the freshwater environment in hopes to enhance nitrogen removal from groundwater. Additional consideration must also be given to the potential impact on downstream shellfish resources below Route 28. Presently the upper portion of Muddy Creek (above Route 28) is impaired due to elevated levels of bacteria. Opening the Route 28 culvers would allow bacteria to contaminate the shellfish areas, resulting in closure, thus having an additional negative impact. All potential impacts need to be considered before decisions are made.

**Comment/Question:** Would changes in regulations be needed to allow hydrologic modifications in Muddy Creek?

Response: Existing authority seems to contain at least one or two paths for approving such an option, so changing the regulations may not be necessary. If a proposal involving hydrologic modification(s) is (are) promising and in the unlikely situation that changes in regulations are necessary, DEP will consider and likely support their modification.

## Salt Marshes / Cockle Cove Creek

**Comment/Question:** The breakdown of loadings to Cockle Cove Creek from the watershed and the wastewater treatment facility is unclear...sometimes the loads are combined and sometimes they are listed separately...this needs to be clarified.

Response: The tables and footnotes have been edited to clarify this issue. In addition, during our efforts to develop acceptable loads to the Cockle Cove watershed, MEP identified a transcription error that has been corrected in table 3 - the present septic system load is 5.8 kg/day not 2.8 kg/day.

**Comment/Question:** When will criteria for nitrogen loads to salt marshes be developed? There is deep concern for the lack of a "Marsh Model", for want of a better title. Model results in marsh estuaries can not be viewed the same as the rest of the embayments, because marshes handle nutrients in a different manner. There is no disagreement on these facts, but the long promised marsh model of analysis is no where on the horizon. Furthermore, the indicators of the "health" of a marsh have never been explained, and thus, are not part of the existing sampling protocol. These facts have huge implications for setting standards of any embayment. The Pleasant Bay complex is made up of many acres of marsh in a variety of locations. The Nauset estuary is predominantly marsh and the many tributaries feeding into Cape Cod Bay are 99% marsh. This is true for most of the 89 MEP embayments. It is very worrisome to kick this project off with the #1 MEP report and have such a significant piece missing.

Response: Scientific studies are underway in a variety of salt marshes that should help to provide a framework for establishing limits for nitrogen loads. However, in the meantime, where there are no indications of problems in a salt marsh, it is prudent to keep loads at their present values and not increase them since the consequences are unclear. In specific instances where towns may want to increase loadings to a salt marsh, further analyses of potential impacts will be required. DEP is presently discussing the potential options to evaluate this issue with the Towns.

**Comment/Question:** DEP is urged to do everything it can to support Chatham's effort to evaluate, as quickly as possible, Cockle Cove's capacity to handle greater volumes of effluent from an expanded WWTF.

Response: The wording in the TMDL document is being modified to indicate that the DEP will entertain proposals for increased loadings from the WWTP provided new information demonstrates that the additional load will not have a negative impact on salt marshes along Cockle Cove Cr. The DEP will work with salt marsh scientists (Massachusetts Coastal Zone Management and SMAST) to determine if loadings, proposed by the Town in the CWMP process, will be detrimental to the salt marshes adjacent to Cockle Cove Creek. However, existing information is being compiled so that if a reasonable estimate of the acceptable load can be made, it will be.

**Comment/Question:** The Draft TMDL document needs to be revised on the top of page 14 and page 20 ($2^{nd}$ paragraph) to clarify the discussion on loading to Cockle Cove Creek from the WWTF. Comments made by DEP at the public meeting indicated that the intent was to highlight the need for further study of the future capacity of the Cockle Cove Creek wetlands to manage additional nitrogen, not to arbitrarily limit additional effluent as implied in the document.

Response: The suggested changes have been made in the TMDL.

**Comment/Question:** Will soluble refractory organic nitrogen be considered and addressed in future discharge permits to meet a future TMDL for the Cockle Cove Watershed?

Response: Just as non-bio-available organic nitrogen was taken into consideration in the Pleasant Bay estuaries, it will be considered anywhere its presence influences environmental responses of nitrogen inputs to coastal systems. Note that the present concentration in Chatham's wastewater treatment plant's effluent is about 4 to 7 mg/L, which is well below the 15 to 20 mg/L usually present in the effluent from a secondary wastewater treatment facility. With regard to the permit, limits will be set on the basis of a variety of factors including groundwater standards, total nitrogen needed to meet target concentrations in Cockle Cove Creek, and the loadings necessary to protect the salt marshes along Cockle Cove.

**Comment/Question:** Cockle Cove Creek is slated for a 0% reduction in load, but there are high concentrations of bacteria from about where Chatham's wastewater treatment plant is located and persist downstream.

Response: Nitrogen and bacteria have some common sources but also, some separate sources. The call for no reduction of nitrogen in Cockle Cove Creek is because it is a salt marsh and thus far seems unaffected by the current nitrogen load. At the same time, the Creek is slated not to receive more nitrogen until additional information concludes that the salt marshes would not be negatively impacted. The bacteria need to be assessed separately. Given the type of technology employed at the treatment plant it is extremely unlikely that this is the source of bacteria. Other sources need to be evaluated. Some matching funds from the state may be available to pursue and correct problems causing the high bacteria concentrations. Such an effort could be pursued through Chatham by its Board of Health or other agency or by a local citizen's group.

**Model – general**

**Comment/Question:** The Linked Model has been calibrated by adjusting a dispersion coefficient so that the model's output nitrogen concentration was a "best fit" with the actual measured nitrogen concentration in the water of each embayment. To help to have greater confidence in the validity of the Linked Model, it is suggested that DEP further validate the model by using it to predict the nitrogen loading in a watershed that would generate the actual measured nitrogen concentration in a sub-embayment. For example, the actual measured nitrogen concentration in Crows Pond is given in Table 2 as 0.93 mg/l. With this as input to the model, use the model to predict the watershed nitrogen loading that would generate this measured nitrogen concentration in Crows Pond and compare this loading with the loading calculated independently for the Crows Pond watershed. In doing this, the value of the dispersion coefficient used in the model for Crows Pond should be exactly the same as that used in generating the TMDL for Crows Pond. If the Crows Pond watershed nitrogen loading predicted by the model is reasonably close to the calculated watershed nitrogen loading based on actual water usage, this would, in our view, validate the model and greatly increase confidence in the accuracy of the TMDLs generated by the model.

Response: It is not clear that this actually achieves the goal stated. The process suggested in this comment seems to be a circular argument in that the concentration is derived from the load, so that back-calculating the load from the concentration would produce the original load.

**Comment/Question:** Modeling results should have confidence limits just as field data have standard deviations because of their variability.

Response: DEP agrees that there is some uncertainty (variability) in the target concentrations and allowable loads presented in the TMDL. Although loadings from the headwaters of the embayments, and the boundary conditions at the mouths of the embayments, are fairly constant, variation occurs as a function of the tidal range. Therefore, tidally averaged nitrogen concentrations were used to generate the target concentrations and the "single load" TMDLs. In using a single load as the TMDL rather than a range, the Department considers the average concentrations derived from waters meeting standards as the best estimate of an acceptable load since nutrient impacts tend to be the result of integration over time rather than from short term variations in concentrations. For this reason, DEP considers it appropriate to use a single value for the target load. In addition, the adaptive management approach will allow for any refinement of the load.

**Comment/Question:** Will the final septic loadings reflect the 3 quarters water consumption data, or 4 quarters of data?

Response: Even though the original agreement was to use the 3 quarters of data, the TMDL implementation is expected to be a quite lengthy process, and consequently, there will be time for the Town to retain SMAST to conduct model runs that include additional data not contained in the original agreement.

**Comment/Question:** Please summarize the documentation and review of the Linked Watershed Model.

Response: Attachment 2 describes the processes by which the component models were developed, reviewed, and documented, and provides an extensive bibliography of documentation, review, and use of the models.

## Margin of Safety

**Comment/Question:** The Margin of Safety (MOS), as described, remains a quantity unknown to the reader. Without some quantitative expression of the MOS, it is difficult for us (and other readers, too) to have confidence in the TMDLs established by DEP. How large is the MOS in relation to the total of the other nitrogen sources? How are we to know whether or not the MOS is reasonable and not an excessive amount? We recommend that DEP make a best-effort attempt to quantify the MOS included in each sub-embayment TMDL.

Response: 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 Chatham TMDL is implicit, and the conservative assumptions in the analyses that account for the MOS are described below.

In addition to the conservative elements related to the modeling effort, atmospheric deposition is being addressed on the national level and is expected to be under more stringent control in the future. This factor was not included in the TMDL and is part of the implicit margin of safety.

The MEP Model is comprised of 3 basic components: 1) a watershed land-use model, 2) a hydrodynamic model and 3) a water quality model. The watershed land-use model is based upon parcel by parcel analysis of land-use with wastewater loads being determined from water use data for each parcel. The lawn fertilizer usage rates are determined from extensive surveys of Cape Cod communities. Atmospheric deposition and impervious surface N loads were determined from measured precipitation, measured nitrogen concentrations from runoff generated by impervious surface areas, and regional studies of nitrogen deposition.

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 negligible aquifer attenuation, i.e. 100% of load enters the embayment. This is a conservative estimate of loading. Nitrogen from the upper watershed regions, which travel through ponds or wetlands, almost always enter the embayment via stream flow, are directly measured (over 12-16 months) to determine attenuation. In these cases the land-use model has shown a slightly higher predicted N load than the measured discharges in the ~10 streams/rivers which have been assessed to data. Therefore, the watershed model as applied to the surface water watershed areas again presents a conservative estimate of N loads.

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 the baseline data in the recent Popponesset Bay Technical Report. In this system, 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 addition, the target loads were based on tidally averaged nitrogen concentrations on the outgoing tide, which is the "worst case" because that is when the nitrogen concentrations are the highest. The nitrogen concentrations will be lower on the flood tides, due to dilution by incoming seawater. Therefore DEP believes this approach is conservative.

**Comment/Question:** Reference is made to the margin of safety including the conservative assumptions inherent to the model. Typically, models consist of both conservative and non-conservative assumptions and if there is an imbalance of conservative and non-conservative assumptions, the model will not calibrate and verify to existing data. One assumption cited as an example of a conservative assumption is the nitrogen attenuation factors. However, if the nitrogen attenuation rates are underestimated and the model calibrates and verifies to existing data, then other sources of nitrogen may be underestimated. While this may impact the potential for success of a given implementation strategy, it does not seem to constitute a margin of safety. Additionally, some discussion of the role of existing eutrophication levels on attenuation in the freshwater systems is warranted. As watershed controls are implemented and the eutrophication levels of these fresh water systems reduced, will there be a reduction in attenuation that affects the ability to achieve the thresholds?

Response: It should be noted that the attenuation factors are validated from direct measurements in lakes/ponds and from long-term stream flow/N load. The coefficients of attenuation used in the watershed model are always less than the estimates from the field data, typically by >20%.

The question of reduced attenuation under lower nitrogen loading rates is an interesting one. However, it appears that attenuation mechanisms tend to become less efficient as loading rates increase. This has been put forward for denitrification in estuarine sediments, where the data indicates that under eutrophic conditions, denitrification as a percentage of the N load, decreases over lower loading rates. In measurements of freshwater river/stream attenuation of nitrogen, the direct uptake of nitrogen by plants is saturated at high loading rates with the only significant mechanism for further nitrogen removal being direct denitrification (nitrate to dinitrogen). Therefore, as nitrogen loads decrease, these systems tend to become more retentive of nitrogen.

In some systems nitrogen removal stays constant to very high rates of N loading. In vegetated salt marsh sediments where studies have been adding nitrogen over the past 30 years, the system has been able to denitrify virtually all of the nitrogen added, above plant demand, at rates up to 7 times the natural loading rate (the highest rate applied). In short, we expect the retention of nitrogen by aquatic systems to increase as loading decreases and the amount of excess nitrogen is reduced. Based upon these considerations, we would expect the present level of attenuation (that is carried forward in our analysis) to underestimate nitrogen attenuation as management actions are implemented.

**Comment/Question:** A margin of safety should be established relative to the targeted nitrogen load reductions necessary to achieve the threshold levels. This is particularly important in the Bassing Harbor and Stage Harbor systems where achieving the targeted thresholds is highly dependant on the assumption that there will be a corresponding significant reduction in sediment nitrogen flux rates associated with nitrogen loading reductions.

Response: See the first and second responses of this section (above) relative to conservative assumptions and margin of safety. It is important to note that the reductions in benthic regeneration of nitrogen are most likely underestimates, i.e. conservative. The reduction is based solely on a reduced deposition of particulate organic nitrogen (PON), due to lower primary production rates under the reduced N loading in these systems where phytoplankton production remains nitrogen limited. As the nitrogen loading decreases it is likely that rates of coupled remineralization-nitrification-denitrification will increase, as sediment oxidation increases (due to reduced organic matter inputs). Benthic regeneration of nitrogen 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 forecast based upon (1) that the PON in the embayment in excess of that of inflowing tidal water (boundary condition) results from production supported by watershed nitrogen inputs and (2) that the presently enhanced production would decrease in proportion to the reduction in the sum of watershed N inputs plus direct atmospheric N input. The latter condition would result in equal embayment versus boundary condition production and PON levels if watershed N loading + direct atmospheric deposition could be reduced to zero (an impossibility of course). An assumption in this proportional reduction is that the proportion of remineralized nitrogen will be the same as under present conditions, almost certainly an underestimate which results in an overestimate of future N regeneration rates, thus presenting an added margin of safety.

**Comment/Question:** A margin of safety should be established for the threshold targets and/or the targeted nitrogen load reductions necessary to achieve the thresholds. While some of the threshold levels may be conservative since they are based on current nitrogen levels in relatively healthy embayment reaches, this would seem difficult to verify with the existing data.

Response: As stated above, EPA guidance allows for an implicit margin of safety, which DEP believes is appropriate for this project.

**Comment/Question:** Reference is made to high and low values being thrown out of the validation data set but it is not clear why this results in a margin of safety.

Response: The Department agrees with this comment and the TMDL document has been modified accordingly. The intent was that evaluation of the data prevent the skewing of the analyses based upon a few spurious points. Although the removal of outliers would not necessarily affect an explicit margin of safety, "improving" the validity of a data set does increase our confidence in the outcome of the modeling based on that "improved" dataset, and thus the implicit margin of safety is indirectly improved.

## Comments on Specific Report Text

**Comment/Question:** Page i. The Problem Statement should explain that the decrease in environmental quality of saltwater embayments and fresh water ponds is occurring not only in Chatham but in many coastal communities in southeastern MA.

Response: the suggested wording was added to the text as recommended.

**Comment/Question:** Page 11. The words listed under the four "bullet" points are too cryptic to help the reader understand how the target nitrogen concentrations were determined and how the Linked Model calculates the TMDLs. A sentence explaining each of the terms given here would be very instructive as would a schematic diagram of the inputs to and the outputs from the Linked Model. This additional text would support the explanations of the MEP's methodology presented on pages 12 – 15.

Response: Some explanatory language was added and some of the terminology was defined. It is pointed out that additional explanations are provided in the text of the technical document that accompanies the TMDL document.

**Comment/Question:** Have the nitrogen loading values been revised for the error made in assuming that Chatham's water usage data were reported in units of thousands of gallons when, in fact, the data were reported in units of hundreds of cubic feet?

Response: The tables in the TMDL have been corrected.

**Comment/Question:** Have the septic system loads for the Mill Pond and Mitchell River watersheds been adjusted to correct for the error made by including the sub-watersheds Mill Pond Salt 10E and Mill Pond Salt 10W (see watershed map in MEP Report, Figure III-2, page 20) as part of the Mitchell River watershed instead of the Mill Pond Salt watershed?

Response: The MEP team is in the process of evaluating whether or not the sub-watershed loading change is significant. MEP will provide a supplemental document providing corrections.

**Comment/Question:** In Table 3, the Present Septic System Load for Lower Muddy Creek (13.39 kg/day) and Upper Muddy Creek (20.41 kg/day) differ considerably from the values given in Table

VIII-3 of the MEP report for the same data for these two sub-embayments (11.49 and16.69 kg/day, respectively). Which figures are correct?

Response: The values in the TMDL are correct. The values in the technical report will be corrected in the final version.

**Comment/Question:** In Table 4, the Present Watershed Load for Cockle Cove Creek is given as 6.72 kg/day. However, in Table 3, the present watershed load is only 3.69 kg/day (0.18 + 0.73 + 2.78 kg/day). We suspect that the higher figure is correct since a similar higher figure (i.e., a septic wastewater load of 2094 kg/yr) is given in the MEP report in Table IV 3b. This discrepancy should be resolved.

Response: The discrepancy has been resolved and the tables have been corrected. See response to similar question under the "Salt Marsh/ Cockle Cove Creek" section above.

**Comment/Question:** Page 22. In Table 5, it is not clear how the Benthic Flux values are calculated. There doesn't seem to be a constant proportional reduction in all sub-embayments as implied by Footnote 2 of the Table. For example, the nitrogen reduction to achieve the target threshold load for Oyster Pond is a reduction of 85% and the corresponding Benthic Flux reduction from 26.8 kg/day to 10.2 kg/day is 62%. However, for Ryder Cove, the nitrogen reduction to achieve the target threshold load is 45% while the corresponding reduction in Benthic Flux is only 24%. These calculations need to be explained in greater detail.

Response: Benthic nitrogen flux is a function of nitrogen loading and particulate organic nitrogen (PON). Projected benthic fluxes are based upon projected PON concentrations and watershed nitrogen 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:

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

Since benthic loading varies throughout the year and the values shown represent 'worst-case' summertime conditions, loading rates are presented in kilograms per day as submitted in the Chatham TMDL Technical Report as Table VIII-3. The benthic flux for the MEP modeling effort is reduced from existing conditions based on the load reduction and the observed particulate organic nitrogen (PON) concentrations within each sub-embayment relative to Nantucket Sound (boundary condition). The benthic flux input to each embayment was reduced (toward zero) based on the reduction of nitrogen in the watershed load. Note that compared to the modeled present conditions and build-out scenario, atmospheric deposition directly to each sub-embayment becomes a greater percentage of the total nitrogen load as the watershed load and related benthic flux decrease.

**Attachment 2**

# Massachusetts Estuaries Project:

### Overview of Scientific and Engineering Publications Related to MEP Approach

October, 2004

This document is a presentation, prepared by SMAST, of the publications underpinning the key model components used in the MEP approach. It should be noted that all of the methods and procedures have been developed by the scientific and engineering communities over the past 3 decades and were reviewed at each step. Many of the techniques represent the state-of-the-art in coastal research and are generally accepted as such by the scientific, engineering and regulatory communities. It is the judgment of the Technical Team that the Linked Watershed-Embayment Model is among the most thoroughly reviewed approaches in current use. The MEP approach was scrutinized extensively by Technical Specialists at the US EPA and the DEP and selected outside agencies (Buzzards Bay Project, CZM, etc.) prior to there being an agreement on the part of all vested parties that the approach was scientifically rigorous, justifiable, and appropriate for meeting the objectives of the MEP. Note that the reviewers included experts on eutrophication and habitat, eelgrass, hydrodynamics, watershed nitrogen modeling, water quality, and TMDL development. As part of the review process for acceptance of the approach, SMAST in concert with engineers from Applied Coastal Research and Engineering (ACRE), who are members of the MEP Technical Team, completed a detailed uncertainty analysis presenting the strength and weaknesses of various nutrient modeling approaches in comparison to the Linked Watershed – Embayment Modeling Approach (*Howes, B.L., J.Ramsey, S. Kelley. 2002 Nitrogen modeling to support watershed management: comparison of approaches and sensitivity analysis. Final Report to MA Department of Environmental Protection and USEPA, 94 pp. Published by MADEP*). The 2002 report put forward many of the publications and much of the scientific and engineering background, as well.

The Linked Watershed-Embayment Modeling Approach is based upon a composite model which combines three accepted, heavily reviewed and published component models. The Linked Model uses the output from a land-use model and the numerical RMA-2 hydrodynamic model to support the RMA-4 water quality model. The water quality model is then used to predict the nitrogen distribution within an estuary under different loading/flushing conditions. Below we present the major publications, which put forward the models (watershed, hydrodynamic and water quality), the key data for their parameterization, and calibration/validation of model results. The publications presented below include those that are refereed (journal articles or USGS Reports) and those that have undergone extensive technical review (usually engineering reports). Also included are references to some of the manuals that explain the usage of the models. In addition, references used by regulatory agencies for the past decade for estimating nitrogen loading rates are included. These include a large number of references and equally important represent the previous approach used to regulate nitrogen in the coastal zone. Not included are all of the related scientific publications that deal with various coefficients as they are summarized (and referenced) in the documents listed:

# MEP Linked Watershed-Embayment Model

## *Watershed Nitrogen Loading Model:*

Determination of watershed nitrogen loading is based upon (1) defining the land area contributing to an embayment (includes USGS groundwater model), (2) sub-dividing the contributing land mass into sub-watersheds associated with lakes, ponds, streams/rivers, and regions of direct groundwater discharge to each major sub-embayment within the estuary, (3) determination of each nitrogen source, and (4) direct measurement of nitrogen loads from the upper watershed areas discharging to the estuary through stream/river flow.

***USGS Groundwater Model:*** Contributing areas to estuarine systems (primarily on Cape Cod) were delineated using a regional model. The USGS three-dimensional, finite-difference groundwater model MODFLOW-2000 was used to simulate groundwater flow in the aquifer. The USGS particle-tracking program MODPATH4, which uses output files from MODFLOW-2000 to track the simulated movement of water in the aquifer, was used to delineate the area at the water table that contributes water to wells, streams, ponds, and coastal water bodies. MODFLOW and MODPATH are widely used state-of-the-art groundwater models. Some of the summary publications relating the wider body of science to the MEP study area are given below:

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three dimensional finite-difference ground-water-flow-model: U.S. Geological Survey Techniques of Water Resources Investigations, book 6, chap. A1, 586p.

Harbaugh, A.W. and McDonald, M.G., 1996, User's Documentation for MODFLOW-96, an update to the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model: U.S. Geological Survey Open-File Report 96-485, 56p.

Masterson, J.P., P.M. Barlow. 1994. Effects of simulated groundwater pumping and recharge on groundwater flow in Cape Cod, Martha's Vineyard and Nantucket Island basins, MA. U.S. Geol. Surv. Open-file Rept. 94-36, 78p.

Masterson, J.P., B.D Stone, D.A. Walter and J. Savoie. 1997. Use of particle tracking to improve numerical model calibration and to analyze groundwater flow and contaminant migration, Massachusetts Military Reservation, Western Cape Cod, Massachusetts. U.S. Geological Survey Water Supply Paper 2482, 50p.

Pollock, D.W., 1994, User's Guide to MODPATH/MODPATH_PLOT, version 3 – A particle tracking post-processing package for MODFLOW, the U.S. Geological Survey modular three dimensional finite-difference ground-water-flow-model: U.S. Geological Survey Open-File Report 94-464, [variously paged].

***Watershed Model:*** The watershed loading model is based upon the identification of nitrogen sources (and their strengths) and nitrogen sinks within the contributing areas to ponds, streams, wetlands and embayments within the study area. The basic construct of the watershed loading model is similar to virtually all scientifically based land-use loading models, including those used for regulatory purposes within the region over the past 2 decades. The key refinements in the MEP watershed model is the parcel by parcel identification of loads, use of water meter data and the inclusion of natural attenuation (validated by direct measures). Some of the summary publications relating the wider body of science to the MEP study area are given below:

***Previous Regulatory Nitrogen Management Land-use Models:***


Costa, J.E., B.L. Howes, D. Janik, D. Aubrey, E. Gunn, A.E. Giblin. 1999. Managing anthropogenic nitrogen inputs to coastal embayments: Technical basis of a management strategy adopted for Buzzards Bay. Buzzards Bay Project Technical Report. Draft Final, September 24, 1999, 56pp.

Frimpter, M.H., J.J. Donohue and M.V. Rapacz. 1990. A mass-balance nitrate model for predicting the effects of land use on groundwater quality, *U. S. Geol. Surv. Open File Rep.,* 88-493.

Eichner, E.M., T.C. Cambareri, K. Livingston, C. Lawrence, B. Smith, G. Prahm and A. Carbonell. 1998. Cape Cod Embayment Project: Interim Final Report, September 1998. Cape Cod Commission Water Resources Office Publication, 129pp.

Eichner, E.M., and T.C. Cambareri. 1992. Nitrogen Loading. Cape Cod Commission Water Resources Technical Bulletin 91-001. 28pp

Koppelman, L.E. (Ed.). 1978. The Long Island comprehensive waste treatment management plan, vol II, Summary documentation report, Long Island Regulatory Planning Board, Hauppage, N.Y.


***MEP Watershed Land-Use Nitrogen Loading Model, Supporting Publications and Summaries:***


Costa, J., G. Heufelder, S. Foss, N. Millham, and B. Howes. 2002. Nitrogen removal efficiencies of three alternative septic technologies and a conventional septic system. *Environment Cape Cod* 5(1):15-24.

DeSimone, L.A. and B.L. Howes. 1998. Nitrogen transport and transformations in a shallow aquifer receiving wastewater discharge: a mass-balance approach. *Water Resources Research* 34:271-285.

DeSimone, L.A., B.L. Howes and P.M. Barlow. 1997. Mass-balance analysis of reactive transport and cation exchange in a plume of wastewater-contaminated groundwater. *Journal of Hydrology* 203:228-249.

DeSimone, L.A. and B.L. Howes. 1995. Hydrogeologic, water quality and geochemical data for the glacial aquifer at the site of a septage-treatment facility, Orleans, Massachusetts, October 1988 through December 1992. U.S. Geological Survey Open File Report 95-439.

DeSimone, L.A., P.M. Barlow and B.L. Howes. 1996. A nitrogen righ septage-effluent plume in a glacial aquifer, Cape Cod, Massachusetts, February 1990 through December 1992. U.S. Geological Survey Water-Supply Paper 2456, 89p.

DeSimone, L.A. and B.L. Howes. 1996. Denitrification and nitrogen transport in a coastal aquifer receiving wastewater discharge. *Environmental Science and Technology* 30:1152-1162.

DeSimone, L.A., B.L. Howes, D.D. Goehringer and P.K. Weiskel. 1998. Wetland Plants and Algae in a Coastal Marsh, Orleans, Cape Cod, Massachusetts. U.S. Geological Survey Water-Resources Investigations Report 98-4011, pp.33.

Hamersley, M.R. and B.L. Howes. 2003. Contribution of denitrification to nitrogen, carbon and oxygen cycling in tidal creek sediments of a New England salt marsh. *Marine Ecology Progress Series* 262:55-68.

Hess, K.M. 1986. Point-source groundwater contamination: sewage plume in a sand and gravel aquifer, Cape Cod, Massachusetts. National Water Summary 1986, Ground-Water Quality: Water Quality Issues. USGS Water Supply Paper 2325.

Howes, B.L. and J.M. Teal. 1995. Nitrogen balance in a Massachusetts cranberry bog and its relation to coastal eutrophication. *Environmental Science and Technology* 29:960-974.

Howes, B.L. and D.D. Goehringer. The Ecology of Buzzards Bay: An Estuarine Profile. National Biological Service Biological Report 31, pp. 141.

Howes, B.L. and D.D. Goehringer. 1997. Terrestrial nitrogen inputs to Buzzards Bay. *Environment Cape Cod* 1: 1-22.

Howes, B.L. 1998. Sediment metabolism within Massachusetts Bay and Boston Harbor: relating to system stability and sediment-watercolumn exchanges of nutrients and oxygen. Mass. Water Resources Authority Environmental Quality Report pp.85.

Howes, B.L. with Jacobs Engineering. 2000. Ashumet Pond Trophic Health Technical Memorandum. AFCEE/MMR Installation Restoration Program, AFC-J23-35S18402-M17-0005, 210pp.

Lohrenz, S.E., C.D. Taylor and B.L. Howes. 1987. Primary production of protein. II. Algal protein metabolism and its relationship to the composition of particulate organic matter in a well mixed euphotic system. Mar. Ecol. Prog. Ser. 40:175-183.

Millham, N.P. and B.L. Howes. 1994. Patterns of groundwater discharge to a shallow coastal embayment. *Marine Ecology Progress Series* 112:155-167.

Millham, N.P. and B.L. Howes. 1994. Freshwater flow into a coastal embayment: groundwater and surface water inputs. *Limnology and Oceanography* 39: 1928-1944.

Millham, N.P. and B.L. Howes 1994. A comparison of methods to determine K in a shallow coastal aquifer. *Groundwater* . 33:49-57.

Millham, N.P., G. Heufelder, B.L. Howes, J. Costa. 2000. Performance of Three Alternative Septic System Technologies and a Conventional Septic System. *Environment Cape Cod* 3(2):49-58.

Rengefors, K., K.C. Ruttenberg, C.L. Haupert, C. D. Taylor, B.L. Howes and D.M. Anderson. 2003. Experimental investigation of taxon-specific response of alkaline phosphatase activity in natural freshwater phytoplankton. *Limnology and Oceanography* 48:1167-1175.

Smith, R.L., B.L. Howes and J.H. Duff. 1991. Denitrification in nitrate-contaminated groundwater: occurrence in steep vertical geochemical gradients. *Geochimica Cosmochimica Acta* 55: 1815-1825.

Smith, R.L., B.L. Howes and J.H. Duff. 1991. Effects of denitrification on nitrogen geochemistry in a nitrate-contaminated sand and gravel aquifer, Cape Cod, Massachusetts. U.S.G.S. Toxic Substances Hydrology Program. Water Res. Inv. Rept. 91-4034.

Taylor, C.D. and B.L. Howes. 1994. Effect of sampling frequency on measurements of seasonal primary production and oxygen status in near-shore coastal ecosystems. *Marine Ecology Progress Series* 108: 193-203.

Taylor, C.D., B.L. Howes and K.W. Doherty. Automated instrumentation for time series measurement of primary production and nutrient status in production platform accessible environments. *Marine Technology Society Journal* 27(2): 32-44.

Weiskel, P.K. and B.L. Howes. 1991. Dissolved nitrogen flux through a small coastal watershed. *Water Resources Research* 27: 2929-2939.

Weiskel, P.K. and B.L. Howes. 1992. Differential transport of nitrogen and phosphorus from septic systems through a coastal watershed. *Environmental Science and Technology* 26: 352-360.

Weiskel, P.K., L.A. DeSimone and B.L. Howes. 1995. A nitrogen-rich septage-effluent plume in a coastal aquifer, marsh and creek system, Orleans, Massachusetts: project summary, 1988-1995, U.S. Geological Survey Open-File Report 96-11, 20p.

Weiskel, P.K., L.A. DeSimone and B.L. Howes. 1995. Transport of Wastewater nitrogen through a coastal aquifer and marsh, Orleans, MA, 1988-1995. U.S.G.S. Open-File Report.

Weiskel, P.K., B.L. Howes and G.R. Heufelder. 1996. Coliform contamination of a coastal embayment: sources and transport pathways. *Environmental Science & Technology* 30:1872-81.

Weiskel, P., L. DeSimone and B. Howes. 1997. The Namskaket Marsh Project: nitrogen transport and ecosystem characterization in a Cape Cod aquifer and salt marsh. *Environment Cape Cod* 1(2):10-27.

## Hydrodynamic and Water Quality Models:

*The RMA suite of models (including RMA-2 and RMA-4) were developed for the U.S. Army Corps of Engineers beginning in the early 1970s. These models represent the basis for evaluating two-dimensional steady and unsteady flow, as well as water quality, problems throughout the United States over the past 3+ decades. In the MEP approach, a site specific two dimensional finite element numerical hydrodynamic model (RMA-2 is developed for each system based upon: (1) measurement of the embayment bathymetry, (2) measurement of tides throughout the embayment and in the offshore waters, (3) determination of flows and circulation using the RMA-2, and (4) validation using measured flows over tidal cycles (ADCP). The Water Quality Model combines the hydrodynamics (RMA-2) and watershed nitrogen models for a two dimensional finite element water quality model (RMA-4). The Water Quality Model* *allows prediction of nitrogen levels over tidal cycles throughout the embayment and how these levels change with changing nitrogen loads and hydrodynamics.*

The following list is not intended to be an exhaustive literature review, but instead attempts to provide the wide acceptance of these models over a range of recent applications. For example, the list does not include the numerous reports generated by the U.S. Army Corps for specific projects. In addition to the U.S. Army Corps of Engineers, the RMA-2 and RMA-4 models are accepted by other federal agencies to evaluate hydrodynamics and constituent transport, including FEMA and EPA.


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Anderson, J.D., G.T. Orlob, and I.P. King, 1996, "Modeling Combined Stresses on Ecosystems", Proceedings of the ASCE Congress on Water Resources, Global '96, Anaheim, CA, June (On Proceedings CD ROM).

Anderson, J.D., G.T. Orlob, and I.P. King, 1997, "Linking Hydrodynamic, Water Quality and Aquatic Ecosystem Response to Stress", Proceedings of the IAHR Conference, "Water for a Changing Global Community", San Francisco, CA, August 1997.

Apicella, G., F. Schuepfer, R. O'Connor, J. Zaccagnino, and L. Kloman, 1993, "Water Quality Modeling of Combined Sewer Overflow Effects on Newtown Creek (NY)", Proceedings of the 66th Water Pollution Control Federation Annual Conference & Exposition, Anaheim, CA, October 3-7, pp. 39-50.

Apicella, G., R. Norris, J. Newton, W. Ewald, and A. Forndran, 1993, "East River Modeling of Water Quality for Multi-Project Assessments", Proceedings Third International Conference on Estuarine and Coastal Modeling, Oak Brook, Illinois, September 8-10, 1993.

Apicella, G., M.J. Skelly and R. Gaffoglio, 1994, "Developing CSO Management Plans to Meet Water Quality Improvement Objectives", Proceedings Water Environment Federation Conference A Global Perspective For Reducing CSOs: Balancing Technologies, Cost, and Water quality, Louisville, Kentucky, July 10-13, 1994, pp. 9-11 through 9-19.

Apicella, G., F. Brilhante, M. Lorenzo and V.J. DeSantis, 1996, "Watershed Planning in an Urban Area to Address Multiple Water Quality Objectives", Proceedings of Watershed'96 Moving Ahead Together, Baltimore, Maryland, June 8-12, 1996.

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Ariathurai, R., and R.B. Krone, 1976, "Finite Element Model for Cohesive Sediment Transport," *J. of the Hydraulics Division*, ASCE, vol. 102, no. hy3.

Ariathurai, R., et al, 1977, "Mathematical Model of Estuarial Sediment Transport," Technical Report D-77-12, Dredged Material research Program, U.S. Army Corps of Engineers Waterways Experiment Station.

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***Wetland Nitrogen Retention:*** Given the importance of nitrogen attenuation by wetlands, we include some additional references relating to the MEP approach. Note that there is significant literature on the nitrogen uptake and denitrification in salt marshes. For the most part, we include in this discussion the locally referenced studies. These publications relate local conditions to wetlands in general, and include references to the wider literature. Among the key projects generating this work has been the Great Sippewissett Salt Marsh Project (set up by WHOI/MBL and run by SMAST scientists since 1985). The results and models of salt marsh N cycling developed over the past 34 years by this Project are fully consistent with work throughout the US and Europe. In addition, research with the USGS in Namskaket Marsh documents the uptake of groundwater N by salt marshes. Relative to these "local" studies, there are more than a dozen papers detailing both the locations within the marsh (vegetated areas versus creek bottom) and the rates of uptake. These studies have evaluated both the interception of groundwater transported N and the processes which control the entry of groundwater into these systems. The spatial scales of study have ranged from whole marshes (Sippewisssett Marsh and Mashapaquit Creek Marsh) to small scales (m2) where denitrification can be measured by a variety of techniques. Some of the summary and key publications are listed below which bring the wider scientific background to regional applications:

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