DRAFT

Stage Harbor/Oyster Pond, Sulphur Springs/Bucks Creek, Taylors Pond/Mill Creek Total Maximum Daily Load Re-Evaluations For Total Nitrogen

(Report # MA 96-TMDL-3)
(Control # CN 206.0)

COMMONWEALTH OF MASSACHUSETTS
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Massachusetts Department of Environmental Protection
Division of Watershed Management
627 Main Street, 2nd Floor
Worcester, MA 01608

Please request Report Number: MA96-TMDL-3; Control Number CN 206.0

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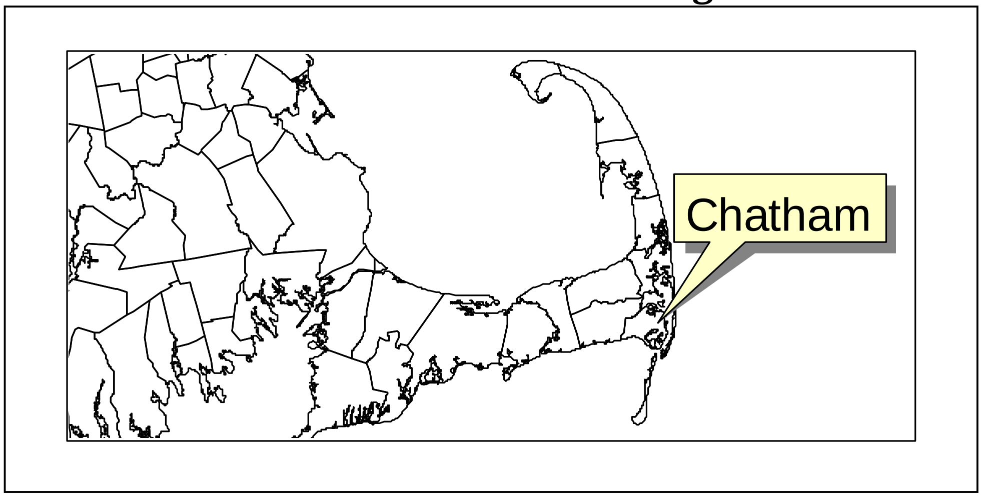
Front Cover

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 [1] :

Oyster Pond	MA96-45_2006	0.21 sq mi	Nutrients & Pathogens
Oyster Pond R	MA96-46_2006	0.14 sq mi	Nutrients & Pathogens
Stage Harbor	MA96-11_2006	0.58 sq mi	Nutrients & Pathogens
Mill Pond	MA96-52_2006	0.06 sq mi	Nutrients
Harding Beach Pd	MA96-43_2006	0.07 sq mi	Pathogens
Bucks Creek	MA96-44_2006	0.02 sq mi	Pathogens
Mill Creek	MA96-41_2006	0.03 sq mi	Pathogens
Taylors Pond	MA96-42_2006	0.02 sq mi	Pathogens

[1] all segments are in category 5 with the exception of Mill Pd, which is in category 4b

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

The data for determining the total maximum daily load of nitrogen to the southern Chatham embayments were collected, primarily, over a study period from 1997 to 2005. The results of these studies were published in the accompanying 2003 and 2007 MEP Technical Reports. After development of the 2003 report, additional water use data were obtained in order to refine the loadings estimates. Also, additional water quality data were collected and incorporated into the revised analyses. The revised analyses of these three coastal embayments, using the MEP Linked Watershed-Embayment N Management Model (Linked Model) are presented in the 2007 Re-evaluated Report.

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:

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

With proper management of nitrogen inputs these trends can be reversed. Without proper management more severe problems might develop, including periodic fish kills, unpleasant odors, scum , and benthic communities reduced to the most stress-tolerant species.

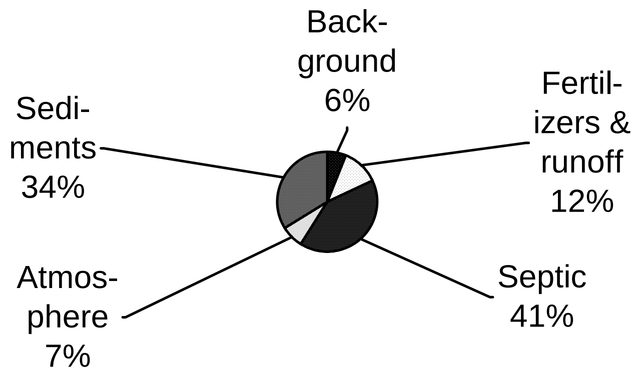
Coastal communities, including Chatham, rely on clean, productive, and aesthetically pleasing marine and estuarine waters for tourism, recreational swimming, fishing, and boating, as well as for commercial fin fishing and shellfishing. Failure to reduce and control N loadings will result in complete 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
    - Wastewater (Septic systems and Wastewater treatment plants)
    - 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 3.4 kg/day in Little Mill Pond, to 35.6 kg/day in Oyster Pond. The concentrations of N in the embayments range from 0.3 mg/L (milligrams of nitrogen per liter) in Mill Cr to 1.4 mg/L in Cockle Cove Cr.

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 MEP has determined that, for the three southern Chatham estuary systems, a target "system" N concentration of 0.38 mg/L is protective. The mechanism for achieving the target N concentrations is to reduce the N loadings to the embayments. The MEP has determined through mathematical modeling that the total maximum daily loads (TMDL) of N that would result in the "safe" target concentrations in the various embayments range from 1 to 18 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 Wastewater 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.mass.gov/dep/water/resources/coastalr.htm#guidance. The appropriateness of any of the alternatives will depend on local conditions, and will have to be determined on a case-by-case basis, using an "adaptive management" approach.

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. Recent studies indicated that as long as the existing concentrations of N in the marsh system are not exceeded, the well- functioning salt marshes along Cockle Cove Creek, as well as the rest of the Sulphur Springs embayment system, would be protected.

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 three southern Chatham estuaries 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 2005. This study period will be referred to as the "present conditions" in the TMDL because it is generally the most recent data available. The results of these studies were published in the accompanying 2003 and 2007 MEP Technical Reports. After development of the 2003 report, additional water use data were obtained in order to refine the loadings estimates. Also, additional water quality data were collected and incorporated into the revised analyses. The revised analyses of these three coastal embayments, using the MEP Linked Watershed-Embayment N Management

Model (Linked Model) are presented in the 2007 Re-evaluated Report. 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 in Chatham's southern three estuaries, 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. The estuaries that are subject to this report are indicated on the following map:

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.

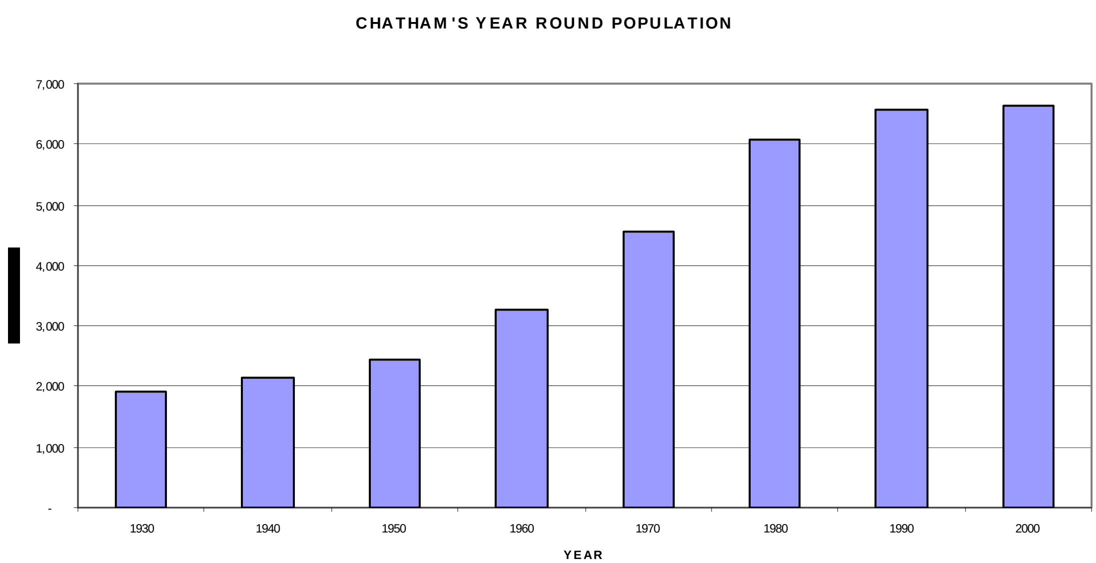
A complete description of the water bodies is presented in Chapter I of the 2003 Technical Report from which the majority of the following information is drawn. TMDLs were prepared for 11 ponds, rivers, creeks, and harbors. Analytical and modeling efforts were conducted by grouping these 11 "sub-embayments", where appropriate, into embayment systems in which all the sub-embayments of an individual watershed combine to flow into Nantucket Sound to the south.

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 2003 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. The population of Chatham, as shown in the following graph, has increased markedly since 1950.



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.

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).

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 listed in the Massachusetts 2006 Integrated List[1]

NAME	SEGMENT ID	DESCRIPTION	SIZE	Pollutant Listed
Stage Harbor				
Oyster Pond	MA96-45_2006	Including Stetson Cove	0.21 sq mi	Nutrients & Pathogens
Oyster Pond River	MA96-46_2006	Outlet of Oyster Pd to confluence with Stage harbor, Chatham	0.14 sq mi	Nutrients & Pathogens
Stage Harbor	MA96-11_2006	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_2006	Including Little Mill Pond (PALIS #96174), Chatham	0.06 sq mi	Nutrients
Sulphur Springs				
Harding Beach Pond	MA96-43_2006	Locally known as Sulphur Springs (northeast of Bucks Cr), Chatham	0.07 sq mi	Pathogens
Bucks Creek	MA96-44_2006	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_2006	Outlet of Taylors Pond to confluence with Cockle Cove, Chatham	0.03 sq mi	Pathogens
Taylors Pond	MA96-42_2006	Chatham	0.02 sq mi	Pathogens

[1] All segments are in Category 5, with the exception of Mill Pond, which is in Category 4b.

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, or Mill 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 <3 mg/L 16% of study period	Generally 5 – 20 ug/L occasionally > 20 ug/L
Little Mill Pd	Complete loss	Presumed same as Mill Pond	Generally 5 – 20 ug/L occasionally > 20 ug/L
Sulphur Spr			
Sulphur Springs	Complete loss	< 4 mg/L 12% of study period < 3 mg/L 6% of study period	Frequently > 20 ug/L Occasionally > 25 ug/L
Bucks Cr	Complete loss	< 4 mg/L 12% of study period < 3 mg/L 6% of study period	Frequently > 20 ug/L Occasionally > 25 ug/L
Taylors Pd			
Taylors Pond	Complete loss	< 4 mg/L 2% of study period	Frequently 10 – 20 ug/L
Mill Creek			

[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 three-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 three-embayment systems:

Stage Harbor System – Little Mill Pond, Mill Pond, and Oyster Pond have elevated nitrogen levels and have lost historic eelgrass beds which once covered most of their respective basins, although eelgrass beds within Oyster Pond appear to have been restricted to its lower ~1/3 with only fringing beds in the shallow areas of the upper portion and oxygen depletion is observed during summer in each system with Mill Pond (and presumably Little Mill Pond) having ecologically significant declines (<3 mg/L). Oyster Pond had less oxygen depletion possibly due to its greater fetch for ventilation with the atmosphere. Chlorophyll a levels 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 levels. The inner-most 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 a central tidal creek. This system contains little water at low tide and has a high assimilative capacity for nitrogen as do other New England salt marshes. The Cockle Cove tidal creek and its associated marsh area is functioning well as a salt marsh ecosystem. The nitrogen threshold established for the open water areas of the Sulphur Springs system is not applicable to the Cockle Cove salt marsh area. Based upon a detailed MEP site-specific investigation of the Cockle Cove salt marsh, it appears that the N load can be increased to this tidal creek as long as the nitrogen concentration does not increase significantly (see MEP Cockle Cove Creek Threshold Report 2006). However, potential negative effects of increased loading to Cockle Cove Creek on down-gradient Bucks Creek is a concern. This concern is addressed in a Town requested modeling scenario detailed in Section IX of re-evaluated Technical Report. Sulphur Springs is a shallow basin containing significant macroalgal 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 levels are high (Section VI), oxygen levels become significantly depleted (6% of time <3 mg/L) and phytoplankton blooms are common and large (chlorophyll a levels >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 a tidal salt marsh, 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 nitrogen 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 nitrogen levels are enriched over incoming tidal waters (Section VI) and dissolved oxygen depletion to ~4 mg/L is common. Chlorophyll a levels of 10-15 ug/L are common during summer. The benthic infaunal community is impoverished, with only a mean of 43 individuals collected in the grab samples, compared to several hundred in the high quality sub-embayments.

Pollutant of Concern, Sources, and Controllability

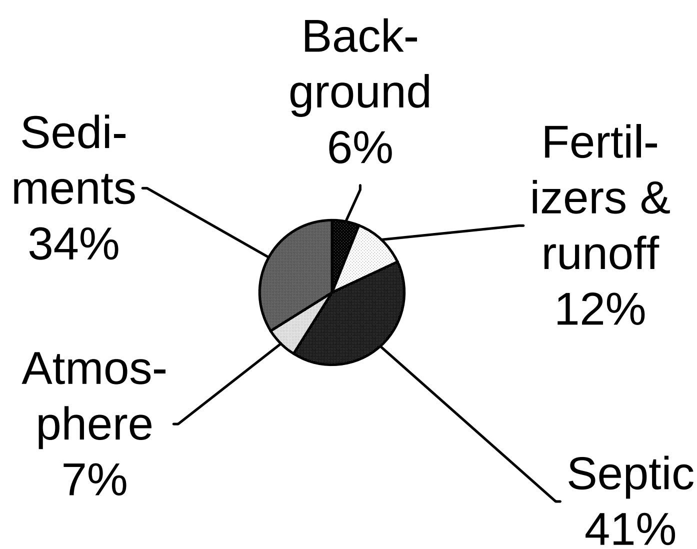
In the coastal embayments in the Town of Chatham, as in most marine and coastal waters, the limiting nutrient is nitrogen. Nitrogen concentrations beyond those expected naturally contribute to undesirable conditions, including the severe impacts described above, through the promotion of excessive growth 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, V, and VII of the 2003 Technical Report and Chapter IV of the 2007 re-evaluated 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:

<u>Atmospheric N</u> cannot be adequately controlled locally – it is through region- and nation-wide air pollution control initiatives that significant 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.

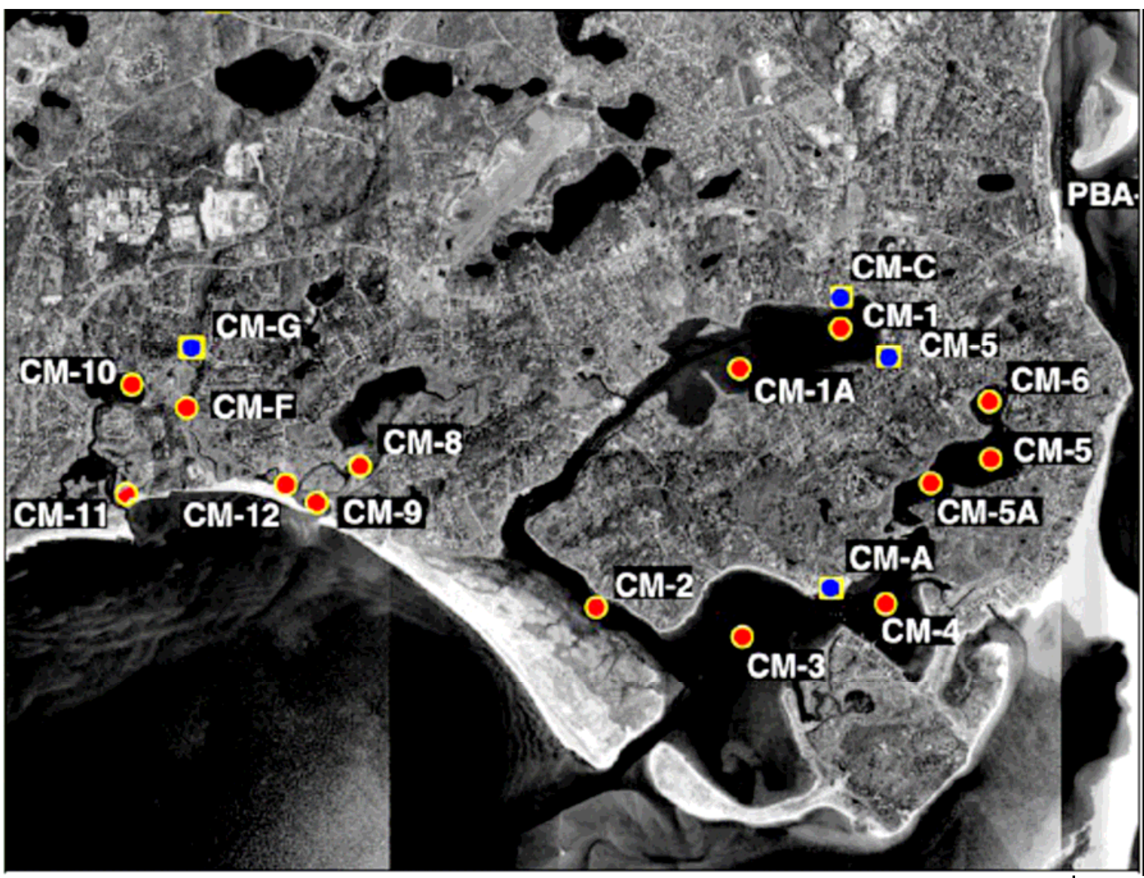
Thus, the assessment of eutrophication is based on site-specific information within a general framework that emphasizes impairment of uses and preservation of a balanced indigenous flora and fauna. This approach is recommended by the US Environmental Protection Agency in their draft Nutrient Criteria 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.

Sampling station locations are indicated in the following figure:



Map of freshwater discharge (blue squares) and estuarine (red circles) water quality monitoring stations within the Town of Chatham's southern 3 estuaries.

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 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 <u>within the sentinel system</u>. 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 2005. Concentrations of N are the highest in Cockle Cove Cr (1.37 mg/L) which is a functioning salt marsh habitat where assimilative capacity is naturally high. Nitrogen in the other embayments ranges in concentration from 0.33 to 0.71 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 the sentinel stations in each of the Stage Harbor and South Coastal embayment systems that are located on Nantucket Sound.

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

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

Embayment Systems And Sub-embayments	Observed System Total Nitrogen Concentration [1] (mg/L)	System Threshold Nitrogen Concentration (mg/L)
Stage Harbor		
Oyster Pond	0.53 - 0.71	0.38 (near sta CM1-A)
Oyster River	0.37	
Stage Harbor	0.34 – 0.40	
Mitchell river	0.44	0.38 (near sta CM5-A)
Mill Pond	0.47	
Little Mill Pond	0.67	
Sulphur Springs		
Sulphur Springs	0.45	
Bucks Cr	0.35	0.38 (sta CM 8)
Cockle Cove Cr	0.41 – 1.37	
Taylors Pond		
Mill Cr	0.329	
Taylors Pond	0.46	0.38 (sta CM 10)

[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

Stage Harbor System – This embayment system has two upper reaches. Therefore, two sentinel sub-embayments were selected, lower Oyster Pond and Mitchell River/Mill Pond. Little Mill Pond could not be used because it is small and has steep horizontal nitrogen gradients (see Section VI). Within the Stage Harbor System, the uppermost sub-embayment supportive of high quality habitat was upper Stage Harbor (Section VII, VIII-1). Water column total nitrogen levels within this embayment region vary with the tidal stage due to high nitrogen out-flowing waters and low nitrogen inflowing waters (Section VI). The calibrated water quality model for this system indicates an average total nitrogen level in the upper Stage Harbor of about 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 nitrogen level reflective of conditions closer to the inlet should achieve the stability required. The lower nitrogen level is equivalent to the tidally averaged total nitrogen 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 is also at a tidally averaged total nitrogen concentration of 0.37 mg N. The 0.38 mg/L was used to develop watershed nitrogen loads required to reduce the average nitrogen concentrations in each sentinel system to this level. Tidal waters inflowing from Nantucket Sound have an average concentration of total nitrogen of 0.285 mg/L. For the development of the Stage Harbor total nitrogen threshold, two sentinel stations were selected, one for each branch of the system. For the Mitchell River/Mill Pond branch, the existing CM5-A monitoring station was selected. For the Oyster Pond branch, the area between station CM1-A and the inlet to Oyster Pond was selected. In order for any loading scenario to meet the requirements of the threshold set for Stage Harbor, the TN concentration must be no more than 0.38 mg/L at both of these stations.

Sulphur Springs System – The Sulphur Springs basin is both the inland-most subembayment and also represents the largest component of the Sulphur Springs System (which also includes Mill Creek and Bucks Creek). Since this System exchanges tidal waters with Nantucket Sound (0.285 mg/L), as does Stage Harbor, and since there is currently no high quality habitat within this system, Stage Harbor habitat quality information was used to support the Sulphur Springs thresholds analysis. The tidally averaged nitrogen 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 nitrogen loads required to reduce the average nitrogen concentrations in the Sulphur Springs sentinel system to this level (CM8, in Bucks Creek). This 0.38 mg/L threshold concentration was developed for the open water portions of the system and as previously mentioned above is not applicable to the Cockle Cove subsystem as it is functioning well as a salt marsh. As such, the Cockle Cove Creek sub-system received its own nitrogen threshold analysis, which was provided previously to the Town of Chatham by the MEP (Howes, White & Samimy 2006) and which was supported by an appended companion habitat study by MCZM (Carlisle, Smith, Callahan 2005).

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 nitrogen threshold concentration for this system was determined to be the same as for the sentinel subembayments to the Stage Harbor System or 0.38 mg/L. The 0.38 mg/L was used to develop watershed nitrogen loads required to reduce the average nitrogen concentrations in Taylors Pond to this level.

<u>Nitrogen loadings to the sub-embayments</u>

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 0.9 kg/day to as high as 8.1 kg/day. Nitrogen loading from the nutrient-rich sediments (referred to as benthic flux) exceeds the N loading from septic systems in five 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 3.4 kg/day in Little Mill Pond, to 35.6 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 and Bucks Creeks up to 81% at Oyster Pond. Table VIII-2 of the 2007 Re-evaluated 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 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	1.2	1.9	8.1	1.8	22.6	35.6
Oyster River	1.6	2.3	7.1	1.1	1.0	13.1
Stage Harbor	0.3	0.5	1.5	3.2	4.1	9.6
Mitchell river	0.2	0.4	2.2	0.9	4.0	7.7
Mill Pond	0.4	0.6	3.0	0.6	3.5	8.1
Little Mill Pond	0.2	0.4	0.9	0.1	1.8	3.4
Sulphur Springs						
Sulphur Springs	1.0	1.7	7.9	0.4	0	11.0
Bucks Cr	0.4	0.6	2.8	0.1	2.9	6.8
Cockle Cove Cr	0.5	4.1	4.3	0.1	0	12.2 [4]
Wastewater TF			3.2	-	-	3.2
Taylors Pond						
Mill Cr	0.6	1.0	3.6	0.2	0	5.4
Taylors Pond	0.7	1.2	5.0	0.2	1.4	8.5

[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 3.2 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. EPA interprets 40 CFR 130.2(h) to require that allocations for NPDES regulated discharges of storm water be included in the waste load component of the TMDL. On Cape Cod the vast majority of storm water percolates into the ground and aquifer and proceeds into the embayment systems through groundwater migration. The Linked Model accounts for storm water loadings and groundwater loading in one aggregate allocation as a non-point source – combining the assessments of waste water and storm water (including storm water that infiltrates into the soil and direct discharge pipes into water bodies) for the purpose of developing control strategies. Although the vast majority of storm water percolates into the ground, there are a few storm water pipes that discharge directly to water bodies that are subject to the requirements of the Phase II Storm Water NPDES Program. Therefore, any storm water discharges subject to the requirements of storm water Phase II NPDES permit must be treated as a waste load allocation. Since the majority of the nitrogen loading comes from septic systems, fertilizer and storm water that infiltrates into the groundwater, the allocation of nitrogen for any storm water pipes that discharge directly to any of the embayments is insignificant as compared to the overall groundwater load. Based on land use, the Linked Model accounts for loading for storm water, but does not differentiate storm water into a load and waste load allocation. Nonetheless, based on the fact that there are few storm water discharge pipes within NPDES Phase II communities that discharge directly to embayments or waters that are connected to the embayments, the waste load allocation for these sources is estimated to be less than 0.3% of the total nitrogen load from the watershed to the embayments. The percentage for individual sub-embayments ranged from 0.15% - 0.55% (Appendix C). This is based on the percent of impervious surface within 200 feet of the waterbodies and the relative load from this area compared to the overall load (Table IV-4 of the 2007 MEP Re-evaluated Technical Report). Although most stormwater infiltrates into the ground on Cape Cod, some impervious areas within approximately 200 feet of the shoreline may discharge stormwater via pipes directly to the waterbody. For the purposes of waste load allocation it was assumed that all impervious surfaces within 200 feet of the shoreline discharge directly to the waterbody. This load is obviously negligible when compared to other sources.

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. The results of a study conducted on Cockle Cove Cr and the surrounding marsh (MEP Technical Memorandum, Nov 30, 2006) indicate that as long as the existing concentrations of N are maintained in the marsh system, the marsh will be protected.

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

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	10.0	1.9	81%
Oyster River	9.4	2.3	76%
Stage Harbor	2.0	.5	75%
Mitchell river	2.6	1.5	42%
Mill Pond	3.6	2.1	42%
Little Mill Pond	1.3	0.8	38%
Sulphur Springs			
Sulphur Springs	9.5	4.6	52%
Bucks Cr	3.4	3.4	0%
Cockle Cove Cr	8.4	8.4	0%
Wastewater TF	3.2	3.2	0%
Taylors Pond			
Mill Cr	4.6	1.0	78%
Taylors Pond	6.2	4.2	32%

[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.

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:

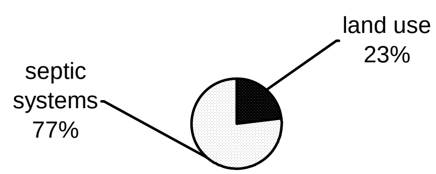
$$D_{PON} = (\text{PON}_{\text{present embayment}} - \text{PON}_{\text{present offshore}})$$

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 $\geq$95%. Field measurement of instantaneous discharge was performed using acoustic Doppler current profilers (ADCP) at key locations within the embayment (with regards to the water quality model, it was possible to conduct a quantitative assessment of the model results as fitted to a baseline dataset - a least squares fit of the modeled versus observed data showed an R^2>0.95, indicating that the model accounted for 95% of the variation in the field data). Since the water quality model incorporates all of the outputs from the other models, this excellent fit indicates a high degree of certainty in the final result. The high level of accuracy of the model provides a high degree of confidence in the output, therefore, less of a margin of safety is required.

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	1.9	1.8	14.1	**18**
Oyster River	2.3	1.1	0.7	**4**
Stage Harbor	0.5	3.2	2.3	**6**
Mitchell river	1.5	0.9	3.4	**6**
Mill Pond	2.1	0.6	2.9	**6**
Little Mill Pond	0.8	0.1	1.4	**2**
Sulphur Springs				
Sulphur Springs	4.6	0.4	0	**5**
Bucks Cr	3.4	0.1	2.5	**6**
Cockle Cove Cr	8.4	0.1	0	**9**
Wastewater TF	3.2	-	-	
Taylors Pond				
Mill Cr	0.9	0.2	0	**1**
Taylors Pond	4.2	0.2	1.1	**6**

[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.

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

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

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

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

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

Reasonable Assurances

MassDEP possesses the statutory and regulatory authority, under the water quality standards and/or the State Clean Water Act (CWA), to implement and enforce the provisions of the TMDL through its many permitting programs, including requirements for N loading reductions from on-site subsurface wastewater disposal systems. However, because most non-point source controls are voluntary, reasonable assurance is based on the commitment of the locality involved. Chatham has demonstrated this commitment well before the generation of the TMDL. The Towns expect to use the information in this TMDL to generate support from their citizens to take the necessary steps to remedy existing problems related to N loading from on-site subsurface wastewater disposal systems, stormwater, and runoff (including fertilizers), and to prevent any future degradation of these valuable resources. Moreover, reasonable assurances that the TMDL will be implemented include enforcement of regulations, availability of financial incentives and local, state and federal programs for pollution control. Storm water NPDES permit coverage will address discharges from municipally owned storm water drainage systems. Enforcement of regulations controlling non-point discharges include local implementation of the Commonwealth's Wetlands Protection Act and Rivers Protection Act; Title 5 regulations for on-site subsurface wastewater disposal systems, and other local regulations such as the Town of Rehoboth's stable regulations. Financial incentives include federal funds available under Sections 319, 604 and 104(b) programs of the CWA, which are provided as part of the Performance Partnership Agreement between MassDEP and EPA. Other potential funds and assistance are available through Massachusetts' Department of Agriculture's Enhancement Program and the United States Department of Agriculture's Natural Resources Conservation Services. Additional financial incentives include income tax credits for Title 5 upgrades and low interest loans for Title 5 on-site subsurface wastewater disposal system upgrades available through municipalities participating in this portion of the state revolving fund program.

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

Appendix A

Table A: Summaries of nitrogen concentrations for Stage Harbor, Sulpher Springs, and Taylors Pond systems. (from Chapter VI of the 2007 MEP re-evaluation tech report)

Table VI-1. 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 all measurments.

System	Embayment	1999 mean	2000 mean	2001 mean	2002 mean	2003 mean	2004 mean	2005 mean	data mean	s.d.	N	model min	model average	model max
Stage Harbor*	Oyster Pond	0.597	0.786	0.708	0.604	0.770	0.671	0.761	0.735	0.227	45	0.708	0.721	0.714
	Lower Oyster Pond	-	-	0.552	0.498	0.482	0.580	0.447	0.513	0.135	27	0.372	0.652	0.534
	Oyster River	0.451	0.457	0.386	0.536	0.458	0.609	0.491	0.489	0.121	39	0.287	0.546	0.367
	Stage Harbor	-	-	-	-	-	-	0.385	0.385	0.062	29	0.288	0.415	0.336
	Upper Stage Harbor	0.418	0.457	0.503	0.548	0.500	0.500	0.467	0.503	0.136	103	0.381	0.425	0.403
	Mitchell River	-	-	0.429	0.487	0.477	0.494	0.400	0.459	0.087	29	0.409	0.463	0.435
	Mill Pond	0.471	0.503	0.418	0.507	0.520	0.390	0.553	0.485	0.123	96	0.458	0.474	0.466
	Little Mill Pond	0.792	0.690	0.742	0.741	0.805	0.764	0.554	0.736	0.232	97	0.653	0.675	0.666
Sulphur Springs	Mid Cockle Cove Cr.	-	1.492	2.043	1.613	2.115	1.499	1.901	1.857	0.531	36	0.606	1.373	2.482
	Cockle C. Cr. mouth	-	0.890	0.687	0.636	0.973	0.620	0.536	0.730	0.242	38	0.275	0.410	0.813
	Bucks Creek	-	0.401	0.479	0.576	0.561	0.573	0.621	0.516	0.149	38	0.282	0.347	0.684
	Sulphur Springs	-	0.360	0.453	0.584	0.623	0.643	0.768	0.584	0.179	39	0.270	0.452	0.906
Taylors Pond	Mill Creek	-	0.491	0.508	0.530	0.546	0.484	0.534	0.516	0.124	75	0.284	0.329	0.630
	Taylors Pond	-	0.509	0.487	0.530	0.575	0.568	0.528	0.525	0.099	37	0.414	0.455	0.502

Appendix B

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.

Table VIII-2. Comparison of sub-embayment watershed septic loads used for modeling of present and threshold loading scenarios of the South Coastal embayments and Stage Harbor systems. These loads represent groundwater load contribution from septic systems only, and do not include runoff, fertilizer, atmospheric deposition and benthic flux loading terms.

Sub-embayment	Present Septic Load g/day)	New Septic Load (kg/day)	Threshold % Change
Stage Harbor			
Oyster Pond	8.099	0.000	-100.0%
Oyster River	7.052	0.000	-100.0%
Stage Harbor	1.523	0.000	-100.0%
Mitchell River	2.170	1.085	-50.0%
Mill Pond	2.956	1.478	-50.0%
Little Mill Pond	0.904	0.452	-50.0%
Sulphur Springs			
Sulphur Springs	7.863	2.971	-62.2%
Bucks Creek	2.767	2.767	0.0%
Cockle Cove Creek	4.282	4.282	0.0%
Waste Water TF	-	-	-
Taylors Pond			
Mill Creek	3.584	0.000	-100.0%
Taylors Pond	5.019	3.012	-40.0%

Appendix C

Chatham estimated wasteload allocation (WLA) from runoff of all impervious areas within 200 feet of waterbodies.

Subwatershed Name	Impervious subwatershed buffer areas[1]		Total Subwatershed Impervious areas		Total Impervious subwatershed load	Total subwatershed load	Impervious subwatershed buffer area WLA	
	Acres	%	Acres	%	Kg/year	Kg/year	Kg/year	%
Oyster Pond	5.9	9.7	150.4	18	248	4465	9.7	0.22
Oyster River	5.3	7.6	99.9	11.8	223	3901	11.8	0.30
Stage Harbor	5.8	8.2	28.3	5.1	51	1914	10.5	0.55
Mill Pond	4.9	11.4	65.3	19.2	135	2045	10.1	0.50
Harding Beach Pond	2.7	6.7	99.7	15.4	206	3667	5.6	0.15
Bucks Creek	1.8	9.2	45.2	8.1	63	1334	2.5	0.19
Mill Creek	0.5	1.3	35.5	13	113	1786	1.6	0.09
Taylors Pond	3.4	14.6	61.4	18.2	151	2446	8.4	0.34
TOTAL						21558	60.2	0.28

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

Attachment 1

Response to Comments on the Chatham Nitrogen TMDL

General

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.

Anderson, J.D., and Orlob, G.T, 1994, "Modeling Temperature Impacts on Salmon Survival," Proceedings 21st Annual Conference, ASCE Division of Water Resources Planning and Management, Denver, CO, pp. 323-326.

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.

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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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