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Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Popponesset Bay, Mashpee and Barnstable, Massachusetts

Executive Summary

1. Background

This report presents the results generated from the implementation of the Massachusetts Estuaries Project's Linked Watershed-Embayment Approach to the Popponesset Bay System a coastal embayment within the Towns of Mashpee and Barnstable, Massachusetts. Analyses of the Popponesset Bay System was performed to assist the Towns with up-coming nitrogen management decisions associated with the Towns' current and future wastewater planning efforts, as well as wetland restoration, anadromous fish runs, shell fishery, open-space, and harbor maintenance programs. As part of the MEP approach, habitat assessment was conducted on the embayment based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. Nitrogen loading thresholds for use as goals for watershed nitrogen management are the major product of the MEP effort. In this way, the MEP offers a science-based management approach to support the Towns of Mashpee and Barnstable resource planning and decision-making process. The primary products of this effort are: (1) a current quantitative assessment of the nutrient related health of the Popponesset Bay System, (2) identification of all nitrogen sources (and their respective N loads) to Bay waters, (3) nitrogen threshold levels for maintaining Massachusetts Water Quality Standards within embayment waters, (4) analysis of watershed nitrogen loading reduction to achieve the N threshold concentrations in Bay waters, and (5) a functional calibrated and validated Linked Watershed-Embayment modeling tool that can be readily used for evaluation of nitrogen management alternatives (to be developed by the Towns) for the restoration of the Popponesset Bay System.

Wastewater Planning: As increasing numbers of people occupy coastal watersheds, the associated coastal waters receive increasing pollutant loads. Coastal embayments throughout the Commonwealth of Massachusetts (and along the U.S. eastern seaboard) are becoming nutrient enriched. The elevated nutrients levels are primarily related to the land use impacts associated with the increasing population within the coastal zone over the past half-century.

The regional effects of both nutrient loading and bacterial contamination span the spectrum from environmental to socio-economic impacts and have direct consequences to the culture, economy, and tax base of Massachusetts's coastal communities. The primary nutrient causing the increasing impairment of our coastal embayments is nitrogen, with its primary sources being wastewater disposal, and nonpoint source runoff that carries nitrogen (e.g. fertilizers) from a range of other sources. Nitrogen related water quality decline represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their shallow nature and large shoreline area, are generally the first coastal systems to show the effect of nutrient pollution from terrestrial sources.

In particular, the Popponesset Bay System within the Towns of Mashpee and Barnstable is at risk of eutrophication (over enrichment) from enhanced nitrogen loads entering through groundwater and surface water from its increasingly developed watersheds. Eutrophication is a process that occurs naturally and gradually over a period of tens or hundreds of years. However, human-related (anthropogenic) sources of nitrogen may be introduced into ecosystems at an accelerated rate that cannot be easily absorbed, resulting in a phenomenon known as cultural eutrophication. In both marine and freshwater systems, cultural eutrophication results in degraded water quality, adverse impacts to ecosystems, and limits on the use of water resources.

The Town of Mashpee has recognized the severity of the problem of eutrophication and the need for watershed nutrient management and is currently developing a Comprehensive Wastewater Management Plan, which it plans to rapidly implement. The Town of Barnstable has already completed and implemented wastewater planning in other regions of the Town not associated with Popponesset Bay. Both Towns have nutrient management activities related to their tidal embayments, which have been associated with the MEP effort in Popponesset Bay. These groups have recognized that a rigorous scientific approach yielding site-specific nitrogen loading targets was required for decision-making and alternatives analysis. The completion of this multi-step process has taken place under the programmatic umbrella of the Massachusetts Estuaries Project, which is a partnership effort between all MEP collaborators and the Towns. The modeling tools developed as part of this program provide the quantitative information necessary for the Towns' nutrient management groups to predict the impacts on water quality from a variety of proposed management scenarios.

Nitrogen Loading Thresholds and Watershed Nitrogen Management: Realizing the need for scientifically defensible management tools has resulted in a focus on determining the aquatic system's assimilative capacity for nitrogen. The highest-level approach is to directly link the watershed nitrogen inputs with embayment hydrodynamics to produce water quality results that can be validated by water quality monitoring programs. This approach when linked to state-of-the-art habitat assessments yields accurate determination of the "allowable N concentration increase" or "threshold nitrogen concentration". These determined nitrogen concentrations are then directly relatable to the watershed nitrogen loading, which also accounts for the spatial distribution of the nitrogen sources, not just the total load. As such, changes in nitrogen load from differing parts of the embayment watershed can be evaluated relative to the degree to which those load changes drive embayment water column nitrogen concentrations toward the "threshold" for the embayment system. To increase certainty, the "Linked" Model is independently calibrated and validated for each embayment.

Massachusetts Estuaries Project Approach: The Massachusetts Department of Environmental Protection (DEP), the University of Massachusetts – Dartmouth School of Marine Science and Technology (SMAST), and others including the Cape Cod Commission (CCC)

have undertaken the task of providing a quantitative tool to communities throughout southeastern Massachusetts (the Linked Watershed-Embayment Management Model) for nutrient management in their coastal embayment systems. Ultimately, use of the Linked Watershed-Embayment Management Model tool by municipalities in the region results in effective screening of nitrogen reduction approaches and eventual restoration and protection of valuable coastal resources. The MEP provides technical guidance in support of policies on nitrogen loading to embayments, wastewater management decisions, and establishment of nitrogen Total Maximum Daily Loads (TMDLs). A TMDL represents the greatest amount of a pollutant that a waterbody can accept and still meet water quality standards for protecting public health and maintaining the designated beneficial uses of those waters for drinking, swimming, recreation and fishing. The MEP modeling approach assesses available options for meeting selected nitrogen goals that are protective of embayment health and achieve water quality standards.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach, which links watershed inputs with embayment circulation and nitrogen characteristics.

The Linked Model builds on well-accepted basic watershed nitrogen loading approaches such as those used in the Buzzards Bay Project, the CCC models, and other relevant models. However, the Linked Model differs from other nitrogen management models in that it:

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

The Linked Model Approach’s greatest assets are its ability to be clearly calibrated and validated, and its utility as a management tool for testing “what if” scenarios for evaluating watershed nitrogen management options.

For a comprehensive description of the Linked Model, please refer to the *Full Report: Nitrogen Modeling to Support Watershed Management: Comparison of Approaches and Sensitivity Analysis*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm. A more basic discussion of the Linked Model is also provided in Appendix F of the *Massachusetts Estuaries Project Embayment Restoration Guidance for Implementation Strategies*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm. The Linked Model suggests which management solutions will adequately protect or restore embayment water quality by enabling towns to test specific management scenarios and weigh the resulting water quality impact against the cost of that approach. In addition to the management scenarios modeled for this report, the Linked Model can be used to evaluate additional management scenarios and may be updated to reflect future changes in land-use with an embayment watershed or changing embayment characteristics. In addition, since the Model uses a holistic approach (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. Unlike many approaches, the Linked Model accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics and accommodates the spatial distribution of these processes. For an overview of several management scenarios that may be employed to restore embayment water quality, see *Massachusetts Estuaries Project Embayment Restoration Guidance for Implementation Strategies*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm.

Application of MEP Approach: The Linked Model was applied to the Popponesset Bay embayment system using site-specific data collected by the MEP and water quality data from the Popponesset Bay Water Quality Monitoring Program (see Chapter 2). Evaluation of upland nitrogen loading was conducted by the MEP, data was provided by the Town of Mashpee Planning Department and Town of Barnstable, and watershed boundaries delineated by USGS. This land-use data was used to determine watershed nitrogen loads within Popponesset Bay and its sub-embayments (current and build-out loads are summarized in Table IV-3). Water quality within each sub-embayment is the integration of nitrogen loads with the site-specific estuarine circulation. Therefore, water quality modeling of these tidally influenced estuaries included a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Once the hydrodynamics of the system was quantified, transport of nitrogen was evaluated from tidal current information developed by the numerical models.

A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents and water elevations was employed for the Popponesset Bay embayment system. Once the hydrodynamic properties of the estuarine system was computed, two-dimensional water quality model simulations were used to predict the dispersion of the nitrogen at current loading rates. Using standard dispersion relationships for estuarine systems of this type, the water quality model and the hydrodynamic model was then integrated in order to generate estimates regarding the spread of total nitrogen from the site-specific hydrodynamic properties. The distributions of nitrogen loads from watershed sources were determined from land-use analysis while nitrogen entering Mashpee's coastal embayment was quantified by direct measurement of stream nutrient concentrations and freshwater flow, predominantly groundwater, in streams discharging directly to the embayment. Boundary nutrient concentrations in Nantucket Sound source waters were taken from water quality monitoring data. Measurements of current salinity distributions throughout the estuarine waters of Popponesset Bay were used to calibrate the water quality model, with validation using measured nitrogen concentrations (under existing loading conditions). The underlying hydrodynamic model was calibrated and validated independently using water elevations measured in time series throughout the embayment.

MEP Nitrogen Thresholds Analysis: The threshold nitrogen level for an embayment represents the average water column concentration of nitrogen that will support the habitat quality being sought. The water column nitrogen level is ultimately controlled by the watershed nitrogen load and the nitrogen concentration in the inflowing tidal waters (boundary condition). The water column nitrogen concentration is modified by the extent of sediment regeneration. Threshold nitrogen levels for the embayment systems in this study were developed to restore or maintain SA waters or high habitat quality. High habitat quality was defined as supportive of eelgrass and infaunal communities. Dissolved oxygen and chlorophyll a were also considered in the assessment.

The tidally averaged total nitrogen thresholds derived in Section VIII-2 of this report were used to adjust the calibrated constituent transport model developed in Section V of this report. Watershed nitrogen loads were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold levels in each sentinel system within the embayment of interest. Water quality modeling results help to analyze whether a nutrient reduction approach will be effective in meeting a nutrient threshold for a specific embayment. However, the approach for any specific embayment discussed in this report serves as only one manner of achieving the selected threshold level for the sentinel sub-embayment within the estuarine system. The specific examples presented herein do not represent the only method for achieving this goal. It is certain that a more targeted nitrogen reduction program that incorporates more localized wastewater treatment and use of natural attenuation processes will result in the most cost-effective plan for restoring the Popponesset Bay embayment.

The Massachusetts Estuaries Project's thresholds analysis, as presented in this technical report, provides the site-specific nitrogen reduction guidelines for nitrogen management of the Popponesset Bay embayment in the Towns of Mashpee and Barnstable. Future water quality modeling scenarios should be run which incorporate the spectrum of strategies that result in nitrogen loading reduction to the embayment. The MEP analysis has initially focused upon nitrogen loads from on-site septic systems as a test of the potential for achieving the level of total nitrogen reduction for restoration of each embayment system. The concept was that since septic system nitrogen loads generally represent 75%-80% of the watershed load to the Popponesset Bay System and are more manageable than other of the nitrogen sources, the ability to achieve needed reductions through this source is a good gauge of the feasibility for restoration of these systems.

2. Problem Assessment (Current Conditions)

Habitat assessments were conducted on each sub-embayment to Popponesset Bay based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. The Popponesset Bay System and its sub-embayments (Pinquickset Cove, Ockway Bay, Shoestring Bay, Mashpee River, Popponesset Bay central basin) showed variations in habitat quality, both between sub-embayments and along the longitudinal axis of the larger sub-embayments such as Shoestring Bay. In general, sub-embayments show declining habitat quality moving from the inlet to the inland-most tidal reach. This trend is seen in both the nitrogen levels (highest inland), eelgrass distribution, infaunal community stress indicators and community properties, as well as summer dissolved oxygen and chlorophyll a records. The following is a brief synopsis of the present habitat quality within each of the sub-embayments. The underlying quantitative data is presented on nitrogen (Section VI.1.3), oxygen and chlorophyll *a* (Section VII.2), eelgrass (Section VII.3), and benthic infauna (Section VII.4).

Combining the dissolved oxygen and chlorophyll a data yields a clear pattern of nutrient related habitat quality (based on these parameters only). At present, the central basin of Popponesset Bay supports relatively healthy habitat conditions, with consistently high bottom water dissolved oxygen and only modest phytoplankton blooms during summer. In contrast, the other regions of the System have moderate to high levels of nitrogen related impairment. Shoestring Bay shows both periodic oxygen declines and significant phytoplankton blooms, while Ockway Bay has similar oxygen declines, but apparently less phytoplankton biomass. Farther along the gradient in nutrient enrichment is the estuarine region of the Mashpee River, which has extreme oxygen excursions and night-time oxygen depletion on a consistent basis and significant phytoplankton blooms. The major issue with the Mashpee River is the extent to

which its structure as a salt marsh system ameliorates the impact of these water quality features. However, even as a salt marsh these levels of chlorophyll a and oxygen excursion indicate a moderate level of impairment. Based upon the dissolved oxygen and chlorophyll data the ranking of the Popponesset Bay System components is as follows:

- Popponesset Bay Central Basin -- high quality
- Popponesset Bay upper/confluence, Shoestring & Ockway Bays
  --significantly impaired
- Mashpee River
  -- significantly impaired to degraded (relative to embayments)
  -- moderately to significantly impaired (relative to salt marshes)

At present, the Popponesset Bay System does not support eelgrass. In addition, to the DEP mapping, this has been confirmed during the various MEP surveys for infauna and sediment sampling and the moored instrument studies. The current lack of eelgrass is expected, given the high chlorophyll a and low dissolved oxygen levels and the watercolumn nitrogen concentrations within this system. However, it appears that a substantial area of the central basin did support an extensive eelgrass bed in 1951. In addition, there were smaller beds within the upper region of the main basin, at the mouth to Shoestring Bay. The spatial distribution of these beds is consistent with the pattern of nitrogen related habitat quality, which is currently observed within the System. However, the 1951 nitrogen levels would have been much lower than present levels given the difference in projected watershed nitrogen loading from 1951 versus 2003 population. It appears that as the Bay became nutrient enriched, that the Popponesset Bay basin could no longer support eelgrass. However, it is likely that if nitrogen loading were to decrease that eelgrass could first be restored in the lower portion of the main basin and with further reductions, be restored to the 1951 pattern.

It is significant that eelgrass was not detected Shoestring Bay and Ockway Bay in the 1951 data. It appears that these sub-embayments are not supportive of this type of habitat. Given the structure of these sub-embayments and their sediment types, it appears that they are natural depositional basins and may not be conducive to supporting rooted macrophytes. The lack of eelgrass in the Mashpee River is consistent with its role as a salt marsh system, which drains completely at low tide in some regions and which is “naturally” organic rich. For these reasons, salt marshes typically do not support eelgrass beds within their main channels.

The Infauna Study indicated that all areas but the lower station within the central basin of Popponesset Bay are presently moderately to severely degraded (Table VII-5). Upper Ockway Bay was found to support the poorest infaunal communities within the System. This is based upon the very low number of species and individuals observed in the sediments of Ockway Bay. Although the 2 species that were found (compared to 31 in the central basin) were indicative of healthy conditions, the low numbers (20’s compared to 400-500 typically) indicated that this system is not presently supporting a viable community. The Mashpee River sites supported a higher quality habitat related to its function as a riverine salt marsh. The stress indicator species present were dominated by *Cyathura polita,* which is tolerant of the natural salinity stress that helps to define to this marsh system. However, the total numbers of individuals and diversity was low, indicative of a significantly impaired resource, even as a salt marsh. Shoestring Bay and the uppermost portion of the Popponesset Bay central basin both showed a resource between moderate and significant impairment. The numbers of individuals was generally high (500-600 per 0.018 m^2) representing a moderate number of species. Diversity was also moderate to high and distributed between indicators of healthy and stressed conditions (Table VII-6), again indicative of moderate impairment. In contrast the Lower Popponesset Bay station

supports a relatively healthy infaunal community, with nearly double the species of other sites and high numbers of individuals (~500 per 0.018 m^2). The high diversity (H') and general eveness (E) are consistent with a healthy community. The indication of moderate impairment stems from the presence of stress indicator species. The overall results indicate a system capable of supporting diverse healthy communities in the region nearest the tidal inlet with most of the system having infaunal habitat that is significantly impaired under present nitrogen loading conditions.

3. Conclusions of the Analysis

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

Threshold nitrogen levels for each of the sub-embayment systems in this study were developed to restore or maintain SA waters or high habitat quality. In these systems, high habitat quality was defined as supportive of eelgrass and diverse benthic benthos animal communities. Dissolved oxygen and chlorophyll *a* were also considered in the assessment.

Watershed nitrogen loads (Tables ES-1 and ES-2) for the Towns of Mashpee and Barnstable Popponesset Bay embayment system was comprised primarily of wastewater nitrogen. Land-use and wastewater analysis found that generally about 75%-80% of the watershed nitrogen load to an embayment was from wastewater.

A major finding of the MEP is clearly not a single total nitrogen threshold that can be applied to Massachusetts' estuaries, based upon the results of the Popponesset Bay System and the Pleasant Bay and Nantucket Sound embayments associated with the Town of Chatham. This is almost certainly going to be true for the other embayments within the MEP area, as well.

The threshold nitrogen levels for the Popponesset Bay embayment system was determined as follows:

- The target nitrogen concentration for restoration of eelgrass in this system was determined to be 0.38 mg TN L^{-1}. The value stems from (1) the analysis of Stage Harbor, Chatham which also exchanges tidal water with Nantucket Sound and for which a MEP target has already been set), (2) analysis of nitrogen levels within the vestigial eelgrass bed in adjacent Waquoit Bay, near the inlet (measured TN of 0.395 mg N L^{-1}, tidally corrected <0.38 mg N L^{-1}), and (3) a similar analysis in West Falmouth Harbor. Threshold values relating to eelgrass restoration was based upon these other Cape Cod systems with similar nitrogen dynamics, since there are presently no remaining eelgrass beds within Popponesset Bay (or even adjacent Three Bays).

- The sentinel station was located within the upper region of the central basin to Popponesset Bay and the mouth of Shoestring Bay, at the uppermost eelgrass bed detected in the 1951 data. Under present loading conditions the sentinel station supports a measured nitrogen level at mid-ebb tide of 0.581 mg TN L^{-1} and a tidally corrected average concentration of 0.451 mg TN L^{-1}. This location was selected as a

sentinel station because: (1) it was the upper extent of the eelgrass coverage in 1951, (2) restoration of nitrogen conditions supportive of eelgrass at this location will necessarily result in even higher quality conditions throughout the whole of the central basin, and (3) restoration of nitrogen concentrations at this site should result in conditions similar to 1951 within Shoestring and Ockway Bays. Shoestring Bay and Ockway Bay should then be supportive of high quality habitat for benthic infaunal communities

- Based upon sequential reductions in watershed nitrogen loading in the analysis described in the Section VIII-3, the sentinel station achieved an average TN level of 0.371 mg L^{-1} , the mouth of Ockway Bay, 0.376 mg TN L^{-1} and the whole of the Popponesset Bay basin <0.331 mg TN L^{-1}.

The data suggest that there is likely a range of total nitrogen which can support healthy infauna within this system. Since Shoestring and Ockway Bays did not support eelgrass in the 1951 data, evaluation was based upon benthic animal habitat.

- Based upon current conditions, the infaunal analysis (Chapter VII) coupled with the nitrogen data (measured and modeled), indicated that nitrogen levels on the order of 0.4 to 0.5 mg TN L-1 are supportive of high quality infauna habitat within the Popponesset Bay System.

- The results of the Linked Watershed-Embayment modeling indicated that when the nitrogen threshold level is attained at the sentinel station (Section VIII-3), TN levels in Shoestring and Ockway Bays are consistent with high quality infauna habitat; upper to lower Shoestring Bay, 0.522 to 0.412 mg TN L^{-1}; upper Ockway Bay, 0.421 mg TN L^{-1}; and mid to lower Mashpee River, 0.525 to 0.422 mg TN L^{-1}.

- It appears that achieving the nitrogen target at the sentinel station will be restorative of eelgrass habitat throughout the Popponesset Bay central basin and restorative of infaunal habitat throughout Shoestring and Ockway Bays and the lower portion of the Mashpee River.

It is important to note that the analysis of future nitrogen loading to the Popponesset Bay Estuarine system focuses upon additional shifts in land-use from forest/grasslands to residential and commercial development. However, the MEP analysis indicates that significant increases in nitrogen loading can occur under present land-uses, due to shifts in occupancy, shifts from seasonal to year-round useage and increasing use of fertilizers (presently less than half of the parcels use lawn fertilizers). Therefore, watershed-estuarine nitrogen management must include management approaches to prevent increased nitrogen loading from both shifts in land-uses (new sources) and from loading increases of current land-uses. The overarching conclusion of the MEP analysis of the Popponesset Bay Estuarine System is that restoration will necessitate a reduction in the present (2002) nitrogen inputs and management options to negate additional future nitrogen inputs.

Table ES-1. Existing total and sub-embayment nitrogen loads to the estuarine waters of the Popponesset Bay System, observed nitrogen concentrations, and sentinel system threshold nitrogen concentrations. Loads to estuarine waters of Mashpee River and Shoestring Bay include both upper watershed regions contributing to the major rivers (Mashpee River, Santuit River, Quaker Run)and groundwater dominated lower regions.

Sub-embayments	Natural (unaltered) Watershed Load [1] (kg/day)	Present Land Use Load [2] (kg/day)	Present Septic System Load (kg/day)	Present WWTF Load [3] (kg/day)	Present Watershed Load [4] (kg/day)	Present Atmospheric Deposition [5] (kg/day)	Present Benthic Flux (kg/day)	**Present Total Load [6]** (kg/day)	Observed TN Conc. [7] (mg/L)	Threshold TN Conc. (mg/L)
POPPONESSET BAY SYSTEM										
Mashpee River [a]	5.30	8.01	19.51	0.15	27.67	0.66	11.47	39.80	0.958-0.627	--
Shoestring Bay [a]	1.85	7.54	23.00	0.23	30.77	2.23	-11.85	21.15	0.690-0.520	--
Ockway Bay	0.24	0.76	2.39	0	3.15	1.09	1.78	6.02	0.677-0.536	--
Pinquicket Cove	0.11	0.19	0.58	0	0.76	0.29	-0.33	0.72	0.527	--
Popponesset Bay	0.18	1.19	5.57	0	6.76	4.01	-5.04	5.73	0.485-0.422	--
System Total	7.68	17.68	51.05	0.38	69.11	8.28	-3.97	73.42	--	0.380[8]

[1] assumes entire watershed is forested (i.e., no anthropogenic sources)
[2] composed of non-wastewater loads, e.g. fertilizer, runoff, present-day natural surfaces and atmospheric deposition to lakes
[3] existing wastewater treatment facility discharges to groundwater
[4] composed of combined present-day natural surfaces, fertilizer, runoff, and septic system loadings
[5] atmospheric deposition to embayment surface only
[6] composed of natural background, fertilizer, runoff, septic system atmospheric deposition and benthic flux loadings
[7] average of 1997 – 2003 data, ranges show the upper to lower regions (highest-lowest) of an sub-embayment. Individual yearly means and standard deviations in Table
[8] Threshold for sentinel site located at the upper portion of Popponesset Bay and Mouth of Shoestring Bay (PBh), infaunal "targets" for Shoestring and Ockway Bays in the range of 0.400 – 0.500 were used to "check" the validity of the sentinel threshold value.
[a] Loads to Shoestring Bay and Mashpee River include loads from rivers.

Table ES-2. Present Watershed Loads, Thresholds Loads, and the percent reductions necessary to achieve the Thresholds Loads for the Popponesset Bay embayment system, Towns of Mashpee and Barnstable, Massachusetts.

Embayment Systems and Sub-Embayments	Present Watershed Load (1) (kg/day)	Target Threshold Watershed Load (2) (kg/day)	Atmospheric Deposition (kg/day)	Benthic Flux (3) (kg/day)	TMDL (4) (kg/day)	Percent watershed load reductions needed to achieve threshold loads
Popponesset Bay System						
Mashpee River	27.67	13.95	0.66	9.47	24.08	-49.5%
Shoestring Bay	30.77	19.71	2.23	-8.73	13.21	-35.9%
Ockway Bay	3.15	0.76	1.09	1.11	2.96	-75.9%
Pinquickset Cove	0.76	0.76	0.29	-0.33	0.72	0.0%
Popponesset Bay	6.76	2.77	4.01	-4.91	1.87	-59.0%

(1) Composed of combined present-day natural surfaces, fertilizer, runoff, and septic system

(2) Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentration identified in Table ES-1.

(3) Projected future flux (present rates reduced approximately proportional to watershed load reductions).

(4) Sum of target threshold watershed load, atmospheric deposition load, and benthic flux load.