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Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Quashnet River, Hamblin Pond, and Jehu Pond, in the Waquoit Bay System of the Town of Mashpee, 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 Quashnet River, Hamblin Pond, and Jehu Pond sub-embayments to the larger Waquoit Bay System. These three sub-systems to Waquoit Bay are coastal embayments within the Town of Mashpee, Massachusetts. Analyses of the Quashnet River, Hamblin Pond, and Jehu Pond Systems was performed to assist the Town of Mashpee with up-coming nitrogen management decisions associated with the Town's 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 assessments were conducted on the embayments 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 Town of Mashpee 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 Quashnet River, Hamblin Pond, and Jehu Pond systems, (2) identification of all nitrogen sources (and their respective N loads) to embayment 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 embayment 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 Quashnet River, Hamblin Pond, and Jehu Pond systems.

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 associated with wastewater disposal, with various other widely distributed non-point sources (e.g. fertilizers, runoff, atmospheric deposition) playing a lesser role. 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 Quashnet River, Hamblin Pond, and Jehu Pond systems within the Town of Mashpee are at risk of eutrophication (over enrichment) from enhanced nitrogen loads entering through groundwater and surface water from the 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 are currently developing Comprehensive Wastewater Management Plans, which they plan to rapidly implement. Both the Towns of Mashpee and Falmouth share the waters of the Waquoit Bay System and have nutrient management activities related to their tidal embayments. While the Town of Mashpee has focused primarily on the MEP effort in the Quashnet River, Hamblin Pond, and Jehu Pond systems, restoration of the Waquoit System will depend upon the efforts of both municipalities working in a coordinated fashion. These groups have recognized that a rigorous scientific approach yielding site-specific nitrogen loading targets was required for decision-making and alternatives analysis. At present, both municipalities are focused on nitrogen management to restore their embayments, with nitrogen thresholds being determined 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 the MEP 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 Quashnet River, Hamblin Pond, and Jehu Pond embayment systems using site-specific data collected by the MEP and water quality data from the Mashpee Nutrient Monitoring Program, which continued to collect data through summer 2004, since it is the only source of nitrogen baseline data for the whole of the Waquoit Bay System (see Chapter 2). The Town of Mashpee is currently conducting planning for the watersheds of the eastern three sub-embayments and for the adjacent Popponesset Bay System. As part of this effort, the Town of Mashpee supported MEP data collection efforts and also supported the collection of the only nitrogen related water quality data available for these sub-embayments (and for the main Bay). Evaluation of upland nitrogen loading was conducted by the MEP, data was provided by the Town of Mashpee Planning Department and watershed boundaries delineated by USGS, as part of the MEP. This land-use data was used to determine watershed nitrogen loads within the Quashnet River, Hamblin Pond, and Jehu Pond sub-embayment systems to Waquoit Bay (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 Quashnet River, Hamblin Pond, and Jehu Pond embayment systems. Once the hydrodynamic properties of the estuarine systems were 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 were 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 embayments was quantified by direct measurement of stream nutrient concentrations and freshwater flow in streams discharging directly to the embayment. These streams are predominantly groundwater fed. 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 the Quashnet River, Hamblin Pond, and Jehu Pond embayment systems 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 tidally averaged 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. This results, in part, from the differential response to a nitrogen load depending upon where it enters the estuarine system (e.g. near the inlet versus the headwaters). Therefore, the specific examples presented herein do not represent the only method for achieving nitrogen reductions to meet threshold levels. However, 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 Quashnet River, Hamblin Pond, and Jehu Pond embayment systems.

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 Quashnet River, Hamblin Pond, and Jehu Pond embayment systems in the Town of Mashpee. 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 72% of the controllable watershed load to Eastern Waquoit Bay (Quashnet River, Hamblin Pond, and Jehu Pond embayment systems) 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 East Waquoit Bay based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. The Quashnet River, Hamblin Pond, and Jehu Pond embayment systems showed variations in habitat quality, both between embayments and along the longitudinal axis of the systems such as Great River to Jehu Pond and Little River to Hamblin Pond. In general, 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 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 yield a clear pattern of nutrient related habitat quality. A further analysis incorporating eelgrass and infaunal indicators is included in Section VII. At present, the Quashnet River Estuary is showing poor oxygen status (based upon depletions, daily excursions, mooring in lower basin) and large phytoplankton blooms. While this system appears to be stressed throughout, there is a clear gradient from hypereutrophic in the upper regions to eutrophic in the lower basin. Jehu Pond is also showing nitrogen enriched conditions, with periodic hypoxia/anoxia in the basin and high phytoplankton biomass. Hamblin Pond is showing the best nutrient related habitat quality, based both upon its moderately good oxygen conditions and moderate phytoplankton biomass. Based upon the dissolved oxygen and chlorophyll data the nutrient related habitat quality of the three estuarine sub-embayments to eastern Waquoit Bay can be classified is as follows:

- Quashnet River estuary – Significantly Impaired
- Jehu Pond – Moderately/Significantly Impaired
- Hamblin Pond – Moderately Impaired

At present, eelgrass is not present within the Quashnet River Estuary, nor was there evidence of eelgrass beds in 1951. This is consistent with observations in the 1960's of nutrient enriched conditions and macroalgae within this sub-embayment (Curley et al. 1971). In contrast, Hamblin Pond/Little River and Jehu Pond/Great River were almost completely colonized by eelgrass in the period 1951-1987 (Figures VII-7 and VII-8). The data suggest that during the 1980's eelgrass in these tributary embayments to Waquoit Bay began to significantly decline in coverage. The decline continued and by 2001 only 5%-10% of the beds remained (Table VII-4). More recent observations indicate that the residual beds are still declining in area, with only marginal areas remaining. In addition, to the on-going DEP mapping, the more recent bed loss (since 2001) has been confirmed by the multiple MEP staff conducting sampling and the mooring studies. It appears that as these systems became nutrient enriched, that they could no longer support eelgrass beds. The proximate cause of loss is most likely related to nutrient related shifts in habitat quality, most significantly the high chlorophyll a (turbidity/shading) and low dissolved oxygen levels. However, it is likely that if nitrogen loading were to decrease, eelgrass could be restored in these basins to the 1951 pattern. This is supported by the fact that small areas still remain and that the decline from "full" coverage has been recent.

It is significant that eelgrass was not detected in the Quashnet River Estuary in the 1951 data. The upper reaches of this estuary are highly altered, but the lower basin with direct communication to the Bay also did not support beds. Part of the reason, as suggested above, may be related to higher historical nitrogen loading to this estuary, but other causes such as tidal restriction cannot be evaluated at this time. Overall the mapping data indicate that nitrogen management of the Hamblin Pond and Jehu Pond estuaries should target eelgrass restoration. Based upon the 1951-1987 coverage data, it appears that on the order of 200 acres of eelgrass might be potentially recoverable in these estuarine sub-embayments, if nitrogen management alternatives were implemented (Table VII-4).

Based on analysis of infauna in each of the three sub-embayments to Eastern Waquoit Bay, clearly the Quashnet River Estuary is significantly impaired with only a single species being found (e.g. diversity = 0). The severely degraded nature of this habitat is underscored by the virtual absence of an infaunal community with only 18, 4, and 0 individuals being found at the three sites, compared to 100's to 1000's being found at healthy sites. The Jehu Pond and Hamblin Pond systems showed infaunal community habitats ranging from healthy to significantly impaired. There appears to be a gradient in habitat quality within the Jehu Pond/Great River Estuary. The basin of Jehu Pond supported a low number of species (4-6) and total individuals <150 at two of three stations and low diversity at all stations (<1.8). However, the Great River showed markedly better habitat, with 9-10 species and >1000 individuals per sample at each station, and slightly higher diversity. Hamblin Pond/Little River showed a similar pattern, although with much better habitat quality. Only the mid basin of Hamblin Pond was significantly impaired with all of the other stations showing 10-19 species and 500-3200 individuals per sample. Diversity was also high, generally $\geq$2.4. Most likely deposition within the mid basin of Hamblin Pond and subsequent organic matter loading effects are responsible for the observations at this station. However, the other areas of this system appear to support healthy benthic animal habitat (Lower Hamblin Pond and Little River) or habitat that is only moderately impaired (Upper Hamblin Pond).

3. Conclusions of the Analysis

The threshold nitrogen level for an embayment represents the upper limit of water-column concentration of nitrogen (tidally averaged) 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 animal communities. Dissolved oxygen and chlorophyll *a* were also considered in the assessment.

Watershed nitrogen loads (Tables ES-1 and ES-2) for the Town of Mashpee Quashnet River, Hamblin Pond, and Jehu Pond embayment systems was comprised primarily of wastewater nitrogen. Land-use and wastewater analysis found that overall 72% of the controllable watershed nitrogen load to an embayment was from wastewater associated with on-site septic systems.

A major finding of the MEP is clearly that a single total nitrogen threshold can not 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 approach for determining nitrogen loading rates, which will maintain acceptable habitat quality throughout and embayment system, is to first identify a sentinel location within the embayment and second, to determine the nitrogen concentration within the water column which will restore that location to the desired habitat quality. The sentinel location is selected such that its restoration will necessarily produce the high quality habitat throughout the embayment system, to meet historical levels and water quality standards. The sentinel locations and associated threshold nitrogen levels for the Quashnet River, Hamblin Pond, and Jehu Pond embayment systems were determined as follows:

- The sentinel system within the Quashnet River Estuary was set within the upper/mid basin (region above the bridge). The target nitrogen concentration to restore infaunal habitat in the Quashnet River is based upon the high quality infaunal sites in lower Hamblin Pond and in Little River (Stations 176 and 170, Figure VII-9). The tidally averaged nitrogen levels at these sites are 0.498 and 0.524 mg N L^{-1}, respectively. These values are consistent with the infaunal guidance levels within the Popponesset Bay sub-embayments of 0.5 to 0.4 mg N L^{-1} (0.5 mg N L^{-1} being the upper threshold value). Based upon these data a conservative estimate for the infaunal threshold for the Quashnet River Estuary is 0.50 mg N L^{-1}, with 0.52 likely to represent a slight stress, but still high quality habitat. The value stems from (1) 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 (2) a similar analysis in West Falmouth Harbor.

- Within the Hamblin Pond/Little River and Jehu Pond/Great River Estuaries the sentinel locations were placed within the pond basins. The target nitrogen threshold focuses on eelgrass restoration of these systems. Based upon the modeling and ecological indicators, it appears that Jehu Pond could support eelgrass at a nitrogen threshold of 0.446 mg N L^{-1}. This is above the 0.38 mg N L^{-1} threshold likely for the main bay (and utilized for Stage Harbor and Popponesset Bay), but lower than the 0.527-0.552 found in the Bassing Harbor System. This level for Jehu Pond is also consistent with the pattern and timing of eelgrass loss throughout the Waquoit Bay System. Although Hamblin Pond is similar to Jehu Pond in gross structure, it has very different loading and attenuation characteristics. The result is that the structure of the system produces much lower nitrogen levels so a threshold of 0.38 mg N L-1 was selected for both systems to allow for uncertainties.

- Based upon sequential reductions in watershed nitrogen loading in the analysis described in the Section VIII-3, it will not be possible to achieve the target nitrogen levels for the Quashnet River, Hamblin Pond/Little River or Jehu Pond/Great River Estuary without lowering the nitrogen level within the main basin of Waquoit Bay. At present the flooding waters from Waquoit Bay are sufficiently nitrogen enriched that even modest nitrogen loads from the watersheds to these tributary estuaries result in nitrogen levels in excess of the nitrogen targets. In fact, the flood waters from the main basin currently exceed the 0.38 mg N L^{-1} target concentration.

The tidally averaged total nitrogen thresholds derived in Section VIII-2 were used to adjust the calibrated constituent transport model developed in Section VI. Watershed nitrogen loads were lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold level at the sentinel region for the Quashnet River, Hamblin Pond/Little River and Jehu Pond/Great River Estuaries. It is important to note that load reductions can be produced by reduction of any or all sources or by increasing the natural attenuation of nitrogen within the freshwater systems to the embayment.

- The only realistic mechanism for reaching 0.38 mg N L^{-1} within Jehu Pond requires nitrogen management relative to the Waquoit Bay basin in concert with nitrogen reductions within this sub-watershed. As such, the approach taken for determining the Threshold Load to Jehu Pond was to set the boundary condition in the main basin of Waquoit Bay at 0.35 mg N L^{-1}, a level unquestionably supportive of eelgrass. The second step was to reduce the watershed nitrogen load to Jehu Pond by about two-thirds of present day loading. Under these very conservative conditions, the nitrogen level attained in Jehu Pond is 0.446 mg N L^{-1}. The conclusion is that the nitrogen target restorative of eelgrass within this estuary is 0.446 mg N L^{-1}.

- Upon review of various modeling scenarios employed to determine threshold loading for Jehu Pond, it appears that the 0.38 mg N L-1 target is applicable to Hamblin Pond. Hamblin Pond watershed nitrogen management can achieve this nitrogen target when Jehu Pond nitrogen levels are reduced to 0.446 mg N L^{-1} and the Waquoit Bay main basin is lowered to 0.35 mg N L^{-1}. Therefore, it appears that nitrogen management to restore eelgrass in Jehu Pond and Hamblin Pond, and to lower nitrogen levels within the Waquoit Bay main basin, should be considered as part of an integrated nitrogen management plan.

- It appears that achieving the nitrogen target at the sentinel stations will be restorative of eelgrass habitat with the Hamblin Pond/Little River and Jehu Pond/Great River systems and restorative of infaunal habitat throughout Quashnet River.

It is important to note that the analysis of future nitrogen loading to the Quashnet River, Hamblin Pond/Little River and Jehu Pond/Great River Estuarine systems 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 Quashnet River, Hamblin Pond/Little River and Jehu Pond/Great River Estuarine Systems 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 Hamblin Pond /Jehu Pond and Quashnet River systems observed nitrogen concentrations, and sentinel system threshold nitrogen concentrations. Loads to estuarine waters of the systems include both upper watershed regions contributing to the major surface water inputs (Red Brook and Moonakiss River).

Sub-embayments	Natural Background Watershed Load [1] (kg/day)	Present Non-Septic System Land Use Load [2] (kg/day)	Present Septic System Load (kg/day)	Present WWTF Load [3] (kg/day)	Present Total Watershed Load [4] (kg/day)	Direct Atmospheric Deposition [5] (kg/day)	Present Net Benthic Flux (kg/day)	**Present Total Load [6]** (kg/day)	Observed TN Conc. [7] (mg/L)	Threshold TN Conc. (mg/L)
HAMBLIN POND/ JEHU POND SYSTEM										
Upper Hamlin Pond [a]	0.48	0.86	4.56	0.00	5.42	0.06	-4.98	0.50	0.65	--
Hamblin Pond	0.13	0.37	3.47	0.00	3.84	1.53	-3.48	1.89	0.54	**0.380**[8]
Little River	0.02	0.15	0.96	0.00	1.11	0.16	3.53	4.80		--
Lower Great River	0.07	0.47	2.48	0.00	2.95	0.75	10.06	13.76	0.57	--
Upper Great River	0.22	0.27	0.41	0.00	0.68	0.55	9.55	10.78	0.61	--
Jehu Pond	0.12	0.77	2.84	0.00	3.61	0.67	10.43	14.71	0.59	**0.446**[8]--
System Total [a]	**1.04**	**2.89**	**14.72**	**0.00**	**17.61**	**3.72**	**25.11**	**46.44**	**--**	**--**
QUASHNET SYSTEM										
Upper Quashnet [a]	4.29	10.34	14.39	0.43	25.16	0.33	10.05	35.54	0.83-0.77	**0.500**[8]
Lower Quashnet	0.02	0.22	0.57	0.00	0.79	0.25	4.78	5.82	0.55	--
System Total [a]	**4.31**	**10.56**	**14.96**	**0.43**	**25.95**	**0.58**	**14.83**	**41.36**	**--**	**--**

[1] assumes entire watershed is forested (i.e., no anthropogenic sources)
[2] composed of non-wastewater loads, e.g. fertilizer and runoff and natural surfaces and atmospheric deposition to lakes
[3] existing wastewater treatment facility discharges to groundwater
[4] composed of combined natural background, 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 2001 – 2003 data, ranges show the upper to lower regions (highest-lowest) of an sub-embayment. Individual yearly means and standard deviations in Table VI-6.
[8] Threshold nitrogen level for sentinel sites located at Jehiu Pond, and the lower basin of the Quashnet River.
[a] Nitrogen load to this sub-embayment includes inputs from surface water sources (e.g., rivers).

Table ES-2 Present Watershed Loads, Threshold Loads, and the percent reductions necessary to achieve the Target NitrogenThreshold level within the Hamblin Pond /Jehu Pond and Quashnet River estuaries (Town of Mashpee, Massachusetts).

Sub-embayments	Direct Atmospheric Deposition (kg/day)	Present Watershed Load [1] (kg/day)	Target Threshold Watershed Load [2] **Scen A** (kg/day)	Target Threshold Watershed Load [2] **Scen B** (kg/day)	Net Benthic Flux [3] **Scen A** (kg/day)	Net Benthic Flux [3] **Scen B** (kg/day)	TMDL [4] **Scen A** (kg/day)	TMDL [4] **Scen B** (kg/day)	Percent watershed reductions to achieve threshold load levels **Scen A**	Percent watershed reductions to achieve threshold load levels **Scen B**
HAMBLIN POND/ JEHU POND SYSTEM										
Upper Hamlin Pond [a]	0.06	5.42	0.92	2.06	-3.17	-3.63	-2.19	-1.51	-83.0%	-62.0%
Hamblin Pond	1.53	3.84	0.47	1.34	-2.23	-2.54	-0.23	0.33	-87.8%	-65.1%
Little River	0.16	1.11	0.19	0.43	2.45	2.73	2.80	3.32	-82.9%	-61.3%
Lower Great River	0.75	2.95	0.6	0.6	7.12	7.12	8.47	8.47	-79.7%	-79.7%
Upper Great River	0.55	0.68	0.32	0.32	6.75	6.75	7.62	7.62	-52.9%	-52.9%
Jehu Pond	0.67	3.61	0.96	0.96	7.64	7.64	9.27	9.27	-73.4%	-73.4%
System Total [a]	**3.72**	**17.61**	**3.46**	**5.71**	**12.94**	**18.07**	**25.74**	**27.5**	**-80.4%**	**-67.6%**
QUASHNET SYSTEM										
Upper Quashnet [a]	0.33	25.16	10.77	15.51	5.56	7.04	16.66	47.71	-57.2%	-38.4%
Lower Quashnet	0.25	0.79	0.22	0.41	2.99	3.58	3.46	4.78	-72.2%	-48.1%
System Total [a]	**0.58**	**25.95**	**10.99**	**15.92**	**8.55**	**10.62**	**20.12**	**52.49**	**-57.6%**	**-38.7%**

(1) Composed of combined natural background, fertilizer, runoff, and septic system loadings.
(2) Target threshold watershed load is the load from the watershed needed to meet the nitrogen threshold concentration within the estuary 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.