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Massachusetts Department of Environmental Protection

Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Slocum's and Little River Estuaries, Dartmouth, 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 Slocums River and Little River estuarine system, two adjacent coastal embayments residing within the Town of Dartmouth, Massachusetts. Analyses of these two embayment systems was performed to assist the Town 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 and open-space programs. As part of the MEP approach, habitat assessment was 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 Dartmouth 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 Slocum's and Little Rivers embayments, (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 Town) for the restoration of the Slocum's and Little Rivers embayment 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 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 Slocum's and Little Rivers embayment systems within the Town of Dartmouth are at risk of eutrophication (over enrichment) from enhanced nitrogen loads entering through groundwater and surface waters discharging from the increasingly developed watershed to this coastal system. 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 Dartmouth, relatively early on, recognized the severity of the problem of eutrophication and the need for watershed nutrient management and as such has over the years embarked on coordinated data gathering efforts. Regular documentation of a decline in ecological health of the Slocum's River began in 1993 with the start of the Baywatchers Program in Dartmouth and other Buzzards Bay community's coastal waters by the Coalition for Buzzards Bay. The Baywatchers data from 1993 to 2006 showed the upper Slocum's River to be among the poorest in nutrient related habitat quality (bottom 20%) of the more than 65 embayment segments surveyed throughout Buzzards Bay (Coalition for Buzzards Bay 2007). In 2000, the water quality of the Slocum's River and other Dartmouth estuaries was consistent with a land-use analyses performed by the Buzzards Bay Project National Estuary Program in 1994 and revised in 1999, based primarily upon land-use analysis and generic Buzzards Bay water quality standards. This survey study suggested that the Slocum's River was receiving nitrogen pollution inputs 3 fold higher than what it could tolerate without significant habitat decline (Buzzards Bay Project 1999). The measured water quality data, absence of eelgrass beds and low shellfish populations (even without harvest) were consistent with this preliminary analysis. However, nitrogen management required a more quantitative site-specific analysis and restoration threshold, which lead to the Town's support for and participation in the present application of the MEP Linked Assessment and Modeling Approach to the Slocum's River Estuarine System.

The present effort arose directly from the efforts of concerned citizens, municipal officials and staff and local advocates to restore the health of all of Dartmouth's estuaries (Slocum's River, Little River, Apponagansett Bay). That partnership effort became Turn the Tide: Restore Dartmouth's Estuaries, and includes active participation by the Town of Dartmouth, the Coalition for Buzzards Bay, the Lloyd Center for the Environment and the University of Massachusetts School for Marine Science and Technology (SMAST).

Nitrogen Loading Thresholds and Watershed Nitrogen Management: Realizing the need for scientifically defensible management tools has resulted in a focus on determining a given 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 within 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 Slocum's and Little Rivers embayment systems by using site-specific data collected by the MEP and water quality data from the Water Quality Monitoring Program conducted by the Town of Dartmouth and the Coalition for Buzzards Bay, with technical guidance from the Coastal Systems Program at SMAST (see Chapter II). Evaluation of upland nitrogen loading was conducted by the MEP, data was provided by the Town of Dartmouth and the Southeastern Regional Planni9ng and Economic Development District (SRPEDD), and watershed boundaries delineated by USGS, and the SMAST-MEP Technical Team. This land-use data was used to determine watershed nitrogen loads within the Slocum's and Little River embayment systems and each of the systems sub-embayments as appropriate (current and build-out loads are summarized in Chapter IV). Water quality within a 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 each of the estuarine systems as defined by water levels throughout the estuaries. 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 systems 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 Slocum's and Little River embayment systems. Once the hydrodynamic properties of each 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 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. Boundary nutrient concentrations in Buzzards Bay source waters were taken from water quality monitoring data. Measurements of current salinity distributions throughout the estuarine waters of the Slocum's and Little Rivers embayment systems was 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 embayments.

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 nitrogen thresholds developed in this report were used to determine the amount of total nitrogen mass loading reduction required for restoration of eelgrass and infaunal habitats in the Slocums River Estuary and to maintain the high quality of infaunal habitat, within the Little River Estuary. Tidally averaged total nitrogen thresholds derived in Section VIII.1 were used to adjust the calibrated constituent transport model developed in Section VI. Watershed nitrogen loads were sequentially lowered (Slocums River) or raised (Little River). Watershed nitrogen reduction was through lowering the total septic effluent discharges only (e.g. wastewater treatment), until the nitrogen levels reached the threshold level at the sentinel stations chosen for lower basin of the Slocums River and at the secondary station for the middle basin. 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 load reductions presented below for the Slocums River represent only one of a suite of potential reduction approaches that need to be evaluated by the community. The presentation is to establish the general degree and spatial pattern of reduction that will be required for restoration of this nitrogen impaired embayment. The Little River analysis focused on increases in watershed nitrogen at projected build-out of the watershed, which includes all nitrogen sources associated with changing land use (Section IV.1).

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 Slocum's and Little Rivers embayment systems in the Town of Dartmouth. Future water quality modeling scenarios should be run which incorporate the spectrum of strategies that result in nitrogen loading reduction to the embayments. 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 represented 37-57% of the controllable watershed load to each of these 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)

A habitat assessment was conducted throughout the Slocum's and Little Rivers systems based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. At present the Slocums River Estuary is supporting significantly impaired eelgrass habitat within its lower basin and significantly impaired infaunal habitat within its broad middle basin. These impairments result from watershed nitrogen inputs that exceed the nitrogen tolerance of these basins, resulting in the loss of historical eelgrass beds and stress to infaunal communities by organic enrichment through phytoplankton blooms, macroalgal accumulations and periodic oxygen depletion. In contrast, the Little River Estuary, which functions primarily as a salt marsh basin and therefore does not represent potential eelgrass habitat, is presently supporting high quality infaunal habitat typical of this type of estuary. This estuary is presently receiving watershed nitrogen inputs below its tolerance level with the result that some additional nitrogen loading can occur before habitat impairment occurs.

The present lack of eelgrass throughout the Slocums River System is consistent with the observed oxygen depletions in each basin and the chlorophyll levels and functional basin types comprising this estuary. This loss of eelgrass classifies the lower tidal reach as "significantly impaired", although it presently supports healthy to moderately healthy infaunal communities. The impairments to both the infaunal habitat (middle basin) and the eelgrass habitat (lower basin) are supported by a variety of other indicators: oxygen depletion, chlorophyll, and TN levels. Considered in combination, all the indicators support the conclusion that these impairments are the result of nitrogen enrichment, primarily from watershed nitrogen loading.

The target nitrogen concentration (tidally averaged TN) for restoration of eelgrass at the sentinel location, SRT-12 (Chapter VI) within the lower reach of the Slocums River, was determined to be 0.37 mg TN L^{-1}. As the present TN level at this site is 0.390 mg TN L^{-1}, watershed nitrogen management will be required for restoration of the estuarine habitats within this system

Although the nitrogen management target is restoration of eelgrass habitat (and associated water clarity, shellfish and fisheries resources), benthic infaunal habitat quality must also be supported as a secondary condition. Therefore, in addition to the primary nitrogen threshold at the sentinel station, the MEP establishes secondary criteria to ensure that all impaired regions are restored if the threshold at the sentinel station is achieved. These values merely provide a check on the acceptability of conditions within the up-gradient basins at the point that the threshold level is attained at the sentinel station. The secondary criteria for the Slocums River targeted infaunal habitat restoration within the presently significantly impaired middle basin. The infaunal "check" station is the long-term monitoring station, SRT-6, which has an average TN level of 0.594 mg N L^{-1}. The tidally averaged total nitrogen level required at this station (SRT-6) to restore the infaunal animal habitat throughout the Slocums River System is <0.5 mg N L^{-1}. Watershed nitrogen management to achieve this "check" nitrogen level will ensure restoration of infaunal habitats within the down-gradient reach as well.

Based upon the above analysis, eelgrass habitat should be the primary nitrogen management goal for the lower Slocums River System and infaunal habitat quality the management target for the upper reaches. These goals are the focus of the MEP management threshold loading analysis (Section VIII.3) and alternatives analysis. It must be stressed that the nitrogen threshold for the Slocums River Estuarine System is at the sentinel location. The secondary criteria (infaunal habitat) should be met when the threshold is met at the sentinel station. The secondary criteria were not used for setting the nitrogen threshold, but serve as a “check”. The nitrogen loads associated with the threshold concentration at the sentinel location and secondary infaunal check stations are discussed in Section VIII.3.

Little River is presently supporting a low level of nitrogen enrichment (TN levels ~0.4 mg N L^{-1}) with associated low to moderate levels of chlorophyll-a. Infaunal communities within Little River are consistent with a wetland dominated organic matter enriched estuarine sediment, with moderate to high numbers of individuals and species, with generally moderate to high diversity and Eveness. The lower-most reach of this system is a tidal channel supporting the highest number of species within the Slocums and Little River complex. The assessment of high quality infauna habitat is consistent with the generally low total nitrogen and chlorophyll-a levels, with oxygen depletion evident, but typical of salt marsh basins.

Since the Little River Estuary is presently supporting high quality habitat and low total nitrogen levels (ca. 0.4 mg TN L^{-1}) and is predominantly a salt marsh basin, its nitrogen threshold level is higher than the present conditions of watershed nitrogen loading (at present tidal flushing rates). A conservative estimate of the nitrogen threshold level of this system would follow the 0.5 mg TN L^{-1} developed above for the Slocums River System. However, as Little River is a wetland dominated system, it is capable of tolerating even higher levels of TN within its waters

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 this embayment system were developed to restore or maintain SA waters or high habitat quality. In this system, high habitat quality was defined as possibly supportive of eelgrass and supportive of 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 Dartmouth Slocum's and Little Rivers embayment systems were comprised primarily of wastewater nitrogen. Land-use and wastewater analysis found that generally about 37-57% of the controllable watershed nitrogen load to the embayment was from wastewater.

A major finding of the MEP clearly indicates that a single total nitrogen threshold can not be applied to Massachusetts' estuaries, based upon the results of the Great, Green and Bournes Pond Systems, Popponesset Bay System, the Lewis Bay system, the Hamblin / Jehu Pond / Quashnet River analysis in eastern Waquoit Bay, the analysis of the Sesachacha Pond and Nantucket Harbor systems as well as the Pleasant Bay and other 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, including those of Buzzards Bay.

It is important to note that the analysis of future nitrogen loading to the Slocum's and Little Rivers estuarine systems focuses upon changes in development in the watersheds to each system as well as additional shifts in land-use and associated nutrient loading to the estuaries. However, the MEP analysis indicates that increases in nitrogen loading can occur under present land-uses, due to shifts in occupancy, shifts from seasonal to year-round usage and increasing use of fertilizers (be it residential or agricultural use). 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 Slocums River Estuary is that habitat impairments result from watershed nitrogen inputs that exceed the nitrogen tolerance of the basins in this estuary. In contrast, the Little River Estuary, which functions primarily as a salt marsh basin, is presently supporting high quality infaunal habitat typical of this type of estuary. The Little River estuary is presently receiving watershed nitrogen inputs below its tolerance level with the result that some additional nitrogen loading can occur before habitat impairment occurs.

Table ES-1. Existing total and sub-embayment nitrogen loads to the estuarine waters of the Slocums and Little River estuary systems, observed nitrogen concentrations, and sentinel system threshold nitrogen concentrations.

Sub-embayments	Natural Background 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)	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)
SYSTEMS										
Slocums River	1.630	5.633	2.855	--	8.488	5.395	-4.874	9.009	0.26-1.52	0.37
Little River	0.732	2.906	1.784	--	4.690	1.186	8.898	14.774	0.33-0.51	--
Surface Water Sources										
Paskamansett River & Destruction Brook	10.622	94.791	24.299	--	118.863	--	--	118.863	--	--
Barneys Joy River North	0.208	3.019	0.241	--	3.260	--	--	3.260	--	--
Barneys Joy River South	0.436	4.677	0.808	--	5.485	--	--	5.485	--	--
System Total	**13.628**	**111.026**	**29.987**	**0.00**	**140.786**	**6.581**	**4.024**	**151.391**	**0.26-1.52**	**0.370**[8]

[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 2000 – 2006 data, ranges show the upper to lower regions (highest-lowest) of an sub-embayment. Individual yearly means and standard deviations in Table VI-1.
[8] Threshold for sentinel site located in Slocums River at water quality station STR-12.

Table ES-2. Present Watershed Loads, Thresholds Loads, and the percent reductions necessary to achieve the Thresholds Loads for the Slocums and Little River estuary systems, Town of Dartmouth, Massachusetts.

Sub-embayments	Present Watershed Load [1] (kg/day)	Target Threshold Watershed Load [2] (kg/day)	Direct Atmospheric Deposition (kg/day)	Benthic Flux Net [3] (kg/day)	TMDL [4] (kg/day)	Percent watershed reductions needed to achieve threshold load levels
SYSTEMS						
Slocums River	8.488	2.121	5.395	-3.867	3.649	-75.01%
Little River	4.690	4.690	1.186	8.898	14.774	0.00%
Surface Water Sources						
Paskamansett River & Destruction Brook	118.863	91.151	--	--	91.151	-23.31%
Barneys Joy River North	3.260	3.260	--	--	3.260	0.00%
Barneys Joy River South	5.485	5.485	--	--	5.485	0.00%
System Total	**140.786**	**106.707**	**6.581**	**5.031**	**118.319**	**-24.21%**

(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 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.