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Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Little Pond Falmouth, 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 Little Pond embayment system, a coastal embayment within the Town of Falmouth, Massachusetts. Analyses of the Little Pond embayment system 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, 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 Town of Falmouth 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 Little Pond embayment, (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 Little Pond embayment 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 Little Pond embayment system within the Town of Falmouth is at risk of eutrophication (over enrichment) from enhanced nitrogen loads entering through groundwater and surface water from the increasingly developed watersheds to these coastal salt ponds. 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 Falmouth 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 Falmouth has also completed and implemented wastewater planning in other regions of the Town not associated with the Little Pond embayment system. The Town has nutrient management activities related to their tidal embayments, which have been associated with the MEP effort in Great/Perch Pond, Green Pond and Bourne Pond embayment systems as well as other embayments in the Town of Falmouth such as Oyster Pond and West Falmouth Harbor. The Town of Falmouth and work 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 Town. 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 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 Little Pond embayment system by using site-specific data collected by the MEP and water quality data from the Falmouth PondWatch Program (see Chapter 2). Evaluation of upland nitrogen loading was conducted by the MEP, data was provided by the Town of Falmouth Planning Department, and watershed boundaries delineated by USGS. This land-use data was used to determine watershed nitrogen loads within the Little Pond embayment system and each systems sub-embayments as appropriate (current and build-out loads are summarized in Table IV-3). Water quality within a sub-embayment is the integration of nitrogen loads with the site-specific estuarine circulation. Therefore, water quality modeling of this tidally influenced estuary 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 Little Pond embayment system. Once the hydrodynamic properties of the estuarine system 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 while nitrogen entering Falmouth'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 Vineyard Sound source waters were taken from water quality monitoring data. Measurements of current salinity distributions throughout the estuarine waters of the Little Pond embayment system 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 Section VIII-2 of this report were used to determine the amount of total nitrogen mass loading reduction required for restoration of eelgrass and infaunal habitats in the Little Pond. 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, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold level at the sentinel stations chosen for Little Pond. 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 in the report represent only one of a suite of potential reduction approaches that need to be evaluated by the community. The presentation in this report of load reductions aims to establish the general degree and spatial pattern of reduction that will be required for restoration of this nitrogen impaired 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 Little Pond embayment system in the Town of Falmouth. 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%-85% of the watershed load to the Little Pond embayment 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)

A habitat assessment was conducted throughout Little Pond based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. Little Pond, both upper and lower reaches, is showing significantly impaired habitat quality. The lower reach is only moderately better habitat than the upper reach, in spite of its proximity to the tidal inlet and high quality waters of Vineyard Sound. All of the habitat indicators are consistent in the evaluation of the whole of Little Pond being classified as a significantly impaired estuarine habitat. The following is a brief synopsis of the present habitat quality within the salt pond. 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).

The effect of nitrogen enrichment is to cause oxygen depletion; however, with increased phytoplankton (or epibenthic algae) production, oxygen levels will rise in daylight to above atmospheric equilibration levels in shallow systems (generally $\sim 7\text{-}8 \text{ mg L}^{-1}$ at the mooring sites). The clear evidence of oxygen levels above atmospheric equilibration indicates that the upper tidal reach of the Little Pond System is eutrophic.

The dissolved oxygen records indicate that the upper region of Little Pond is currently under seasonal oxygen stress, consistent with nitrogen enrichment. That the cause is eutrophication is supported by the high levels of chlorophyll a, with blooms of $>20 \text{ }\mu\text{g/L}$ occurring at both sites and concentrations $>15 \text{ }\mu\text{g/L}$ occurring over $\sim 15\%$ of the deployment

period. Oxygen conditions and chlorophyll a levels were only slightly improved in the lower versus upper Little Pond locations. The upper and lower sites showed oxygen depletions below 3 mg/L on 5% and 2% of the 28 day sampling period and were below 6 mg/L 27% and 21% of time, respectively. The dissolved oxygen, chlorophyll a and total nitrogen data show a consistent pattern of a highly nitrogen enriched embayment with only a modest longitudinal gradient. The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate highly nutrient enriched waters and impaired habitat quality at all mooring sites within the estuary.

At present, eelgrass is present within the Little Pond System. Based on the 2001 eelgrass survey conducted by the DEP Eelgrass Mapping Program, the remaining eelgrass appears to be limited to an area within the lower basin (in the region of LP-3), just upgradient of the Little Pond inlet. In addition, to the DEP mapping, this has been confirmed by the multiple MEP staff conducting the infaunal and sediment sampling and the mooring studies. The eelgrass is not present as a “bed” or even significant patches, rather the plants are sparsely distributed. In essence, eelgrass is present, but does not represent a significant habitat feature at this time.

It is not possible to determine a general idea of short- and long-term rates of change in eelgrass coverage from the mapping data, since there is only one survey with eelgrass “beds”, the recent maps are only sparsely distributed plants. However, it is possible to utilize the 1951 coverage data to gauge the amount of eelgrass bed that might be recovered with nitrogen management. It appears that when nitrogen loading was at 1951 levels that on the order of 27 acres of eelgrass was present in Little Pond and that this eelgrass was sufficiently dense to allow detection on aerial photographs. Other factors which influence eelgrass bed loss in embayments may also be at play in the Little Pond system, though the loss seems completely in-line with nitrogen enrichment.

The relative pattern of these eelgrass data is consistent with the results of the benthic infauna analysis and the observed eelgrass loss is typical of nutrient enriched shallow embayments.

The Infauna Study was fully consistent with the nitrogen data and oxygen and chlorophyll a records and the loss of eelgrass from this system, showing nitrogen related habitat impairment and only a relatively modest gradient between the upper and lower reaches. The infaunal community data indicated that Little Pond is presently moderately to severely degraded throughout its estuarine reach. The Lower basin stations (LP-6, 7, 8) nearest the tidal inlet showed generally higher numbers of individuals, higher diversity and evenness than the upper estuarine reach stations (LP-2,3,4). While the trend is clear, it is important to note that the indicators from the lower basin are still much lower than indicative of higher quality systems. Equally important, the dominant species in both the upper and lower reaches are indicative of poor quality habitat.

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 Town of Falmouth Little Pond embayment system was comprised primarily of wastewater nitrogen. Land-use and wastewater analysis found that generally about 75%-85% of the 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 Bourne Pond Systems, Popponesset Bay System, the Hamblin / Jehu Pond / Quashnet River analysis in eastern Waquoit Bay 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 Little Pond embayment system in Falmouth were determined as follows:

Little Pond Threshold Nitrogen Concentrations

- The target nitrogen concentration for restoration of eelgrass in this system was determined to be 0.45 mg TN L⁻¹ for Station LP2 and TN <0.45 mg TN L⁻¹ in the lower basin. This threshold level is consistent with the findings that (1) eelgrass beds have been lost in the lower basin which currently supports a tidally averaged TN of 0.837 mg TN L⁻¹ at LP2 and 0.705 mg TN L⁻¹ in the lower basin (LP3), (2) sparse eelgrass can be still be found within the lower basin at tidally averaged TN of 0.61 mg TN L⁻¹, and (3) the eelgrass beds in Bourne Pond (threshold 0.45 mg TN L⁻¹) at water depths similar to those in the lower basin of Little Pond, which is important for light penetration. Based upon these data, the threshold TN level at the sentinel station was set at 0.45 mg TN L⁻¹ to achieve eelgrass habitat recovery throughout the lower basin and to re-establish the marginal beds seen in 1995 near LP-2. .
- The nitrogen load reductions within the system necessary to achieve the threshold nitrogen concentrations required 100% removal of septic load (associated with direct groundwater discharge to the embayment) for the systems' lower watersheds. In addition, a portion of the septic load entering the pond from the fresh water stream also must be removed to meet the threshold nitrogen concentrations. For the load reduction scenario evaluated, the Little Pond Stream sub-watershed required removal of approximately 60% of the septic load.

It is important to note that the analysis of future nitrogen loading to the Little Pond 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 usage 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 Little Pond 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 load to the estuarine waters of the Little Pond estuary system, observed nitrogen concentration, and sentinel system threshold nitrogen concentration.

Sub-embayment	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)
LITTLE POND SYSTEM										
Little Pond System Total^a	1.53	8.65	10.42	0.00	19.07	0.58	1.58	21.23	2.32-0.75	0.45⁸
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 1997 – 2004 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 for sentinel sites located at the mid point of Little Pond (LP2). ^a loads to Little Pond include loads from surface water sources (e.g., streams).										

Table ES-2. Present Watershed Load, Thresholds Load, and the percent reduction necessary to achieve the Thresholds Load for the Little Pond system, Town of Falmouth, Massachusetts.

Sub-embayment	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
<i>LITTLE POND SYSTEM</i>						
Little Pond System Total	19.07	5.36	0.58	0.67	6.61	-71.9%
<p>(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.</p>						