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Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Great/Perch Pond, Green Pond and Bourne 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 Great/Perch Pond, Green Pond and Bourne Pond embayment systems, three coastal embayments within the Town of Falmouth, Massachusetts. Analyses of the Great/Perch Pond, Green Pond and Bourne Pond 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, open-space, and harbor maintenance 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 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 Great/Perch Pond, Green Pond and Bourne Pond embayment 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 Town) for the restoration of the Great/Perch Pond, Green Pond and Bourne Pond 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 Great/Perch Pond, Green Pond and Bournes Pond embayment systems within the Town of Falmouth are 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 Great/Perch Pond, Green Pond and Bournes Pond embayment systems. 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 Bournes Pond embayment systems as well as other embayments in the Town of Falmouth. 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 Great/Perch Pond, Green Pond and Bourne Pond embayment systems 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 Great/Perch Pond, Green Pond and Bourne Pond embayment systems and each systems sub-embayments (current and build-out loads are summarized in Table IV-3). Water quality within each sub-embayment is the integration of nitrogen loads with the site-specific estuarine circulation. Therefore, water quality modeling of these tidally influenced estuaries included a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. Once the hydrodynamics of each 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 Great/Perch Pond, Green Pond and Bourne Pond embayment systems. Once the hydrodynamic properties of each estuarine system was computed, two-dimensional water quality model simulations were used to predict the dispersion of the nitrogen at current loading rates. Using standard dispersion relationships for estuarine systems of this type, the water quality model and the hydrodynamic model was then integrated in order to generate estimates regarding the spread of total nitrogen from the site-specific hydrodynamic properties. The distributions of nitrogen loads from watershed sources were determined from land-use analysis while nitrogen entering Falmouth's coastal embayments was quantified by direct measurement of stream nutrient concentrations and freshwater flow, predominantly groundwater, in streams discharging directly to each of the embayments. 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 Great/Perch Pond, Green Pond and Bourne 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 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 tidally averaged total nitrogen thresholds derived in Section VIII-2 of this report were used to adjust the calibrated constituent transport model developed in Section V of this report. Watershed nitrogen loads were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold levels in each sentinel system within the embayment of interest. Water quality modeling results help to analyze whether a nutrient reduction approach will be effective in meeting a nutrient threshold for a specific embayment. However, the approach for any specific embayment discussed in this report serves as only one manner of achieving the selected threshold level for the sentinel sub-embayment within the estuarine system. The specific examples presented herein do not represent the only method for achieving this goal. It is certain that a more targeted nitrogen reduction program that incorporates more localized wastewater treatment and use of natural attenuation processes will result in the most cost-effective plan for restoring the Great/Perch Pond, Green Pond and Bourne 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 Great/Perch Pond, Green Pond and Bourne Pond embayment systems 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%-80% of the watershed load to the Great/Perch Pond, Green Pond and Bourne 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 throughout Green Pond and on each sub-embayment to Great Pond and Bourne Pond based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. The Great Pond and Bourne Pond Systems and the respective sub-embayments (Perch Pond and Isreals Cove) showed variations in habitat quality between the sub-embayment and along the longitudinal axis of the larger main body of the Ponds. In general, sub-embayments show declining habitat quality moving from the inlet to the inland-most tidal reach. This trend is seen in both the nitrogen levels (highest inland), eelgrass distribution, infaunal community stress indicators and community properties, as well as summer dissolved oxygen and chlorophyll a records. The following is a brief synopsis of the present habitat quality within each of the sub-embayments as well as the main basins of each 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 ~7-8 mg L⁻¹ at the mooring sites). The clear evidence of oxygen levels above atmospheric equilibration indicates that the upper tidal reaches of the Great Pond, Green Pond, and Bournes Pond Systems are eutrophic.

The dissolved oxygen records indicate that the upper regions of Great Green and Bournes Ponds are currently under seasonal oxygen stress, consistent with nitrogen enrichment (Table VII-1). That the cause is eutrophication is supported by the high levels of chlorophyll a, >25 µg/L 44%, 65% and 22% of the time, respectively (Table VII-2). Oxygen conditions and chlorophyll a levels improved in each system with decreasing distance to the tidal inlet, although all systems showed oxygen depletions below 5 mg L⁻¹ and generally to <4 mg L⁻¹ at the most southern stations measured in 2002. In all systems there was a clear gradient in chlorophyll a, with highest levels in the uppermost reaches and lowest levels near the tidal inlet to Vineyard Sound. The embayment specific results are as follows:

Based upon the available dissolved oxygen and chlorophyll data the ranking of the more sensitive regions of the Great Pond, Green Pond and Bournes Pond Estuaries is as follows:

- Great Pond:
 - Upper Reach – significantly impaired to severely degraded
 - Perch Pond – significantly impaired to severely degraded
 - Upper Central region of main basin – moderately to significantly impaired
- Green Pond:
 - Upper Region -- significantly impaired to severely degraded
 - Middle Region – moderately to significantly impaired
- Bournes Pond:
 - Upper Region – significantly impaired to severely degraded

Currently, there are no eelgrass beds within the Great Pond and Green Pond systems, other than a few small sparse isolated patches within the lower basin of Great Pond and adjacent the tidal inlet in Green Pond, with these residual patches within the boundary of the 1951 beds. Bournes Pond currently supports eelgrass beds within its lower reach, primarily in the region at the mouth of Israel's Cove. However, the Bournes Pond beds appear to be diminishing rapidly.

It is not possible to determine a quantitative rate of change in eelgrass coverage from the mapping data for Great and Green Pond, since there is only one survey with eelgrass. However, in the case of Bournes Pond, the 1995 survey and the 2001 survey do show eelgrass with a reduction in bed acreage from 1995 to 2001 equal to approximately 19.5 acres. If bed loss in Bournes Pond was uniform from year to year this would translate to bed loss of approximately 3.9 acres per year from 1995 to 2001.

In all three estuaries, eelgrass habitat appears to be restricted to primarily the lower basins even in the 1951 coverage. This is likely the result of the sensitivity of the upper reaches of these systems to nitrogen inputs, primarily due to the poor tidal flushing resulting from the small driving tide in Vineyard Sound (see Section V). As a result, the upper reaches likely were unable to support eelgrass even at the 1951 nitrogen input levels. Other factors which influence eelgrass bed loss in embayments may also be at play in Great, Green and Bournes Pond, although the loss of beds in Great and Green Pond and the significantly reduced eelgrass

distribution in Bournes Pond is expected given the high chlorophyll a and low dissolved oxygen levels and watercolumn nitrogen concentrations within these estuarine areas (Tables VII-1, VII-2). However, a brief listing of non-nitrogen related factors is useful. Eelgrass bed loss does not seem to be directly related to mooring density, as only Great Pond supports significant moorings. Similarly, pier construction and boating pressure may be adding additional stress in nutrient enriched areas, but do not seem to be the overarching factor. It is not possible at this time to determine the potential effect of shellfishing on eelgrass bed distribution, although it must be small as there is little shellfishing on an areal basis in the Ponds.

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 Surveys conducted throughout the Great/Perch Pond, Green Pond and Bournes Pond Estuaries showed similar spatial patterns of nitrogen related impairment, although the magnitude of habitat decline varied significantly between systems. All systems showed significant nitrogen related habitat quality impairment within the uppermost reaches and within tributary deep basins (e.g. Perch Pond in Great Pond System). Mid and Lower reaches showed higher habitat health. However, only the lower basin of Bournes Pond exhibited moderately healthy benthic animal habitat. See Section VII.4 for details of evenness and diversity of benthic animals in Great, Green and Bournes Pond.

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 Great, Green and Bournes Pond embayment systems was comprised primarily of wastewater nitrogen. Land-use and wastewater analysis found that generally about 75%-80% of the watershed nitrogen load to an embayment was from wastewater.

A major finding of the MEP clearly indicates that a single total nitrogen threshold can not be applied to Massachusetts' estuaries, based upon the results of the Popponeset 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 Great, Green and Bournes Pond embayment systems in Falmouth were determined as follows:

Great Pond Threshold Nitrogen Concentrations

- Within the Great/Perch Pond Estuary the most appropriate sentinel station was the upper station within the large main basin (Station GT6 in Figure VIII-1). For embayment restoration, an additional requirement within Perch Pond and upper Great Pond was to ensure that TN in these sub-systems has been reduced to levels supportive of healthy infauna habitat when the eelgrass threshold was met for the main basin of Great Pond.
- The target nitrogen concentration for restoration of eelgrass in this system was determined to be 0.40 mg TN L⁻¹ within the large main basin (Station GT5). 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 0.591 mg TN L⁻¹ at GT5 (2) sparse eelgrass can still be found adjacent to the inlet at tidally averaged TN of 0.34 mg TN L⁻¹, and (3) eelgrass beds are not supported at similar depths within the lower basin of Great or Green Ponds at a tidally averaged TN of 0.409 mg TN L⁻¹ and (4) the eelgrass beds in Bournes Pond (threshold 0.45 mg TN L⁻¹, discussed below) are in much shallower water which is important for light penetration. The moderately impaired upper region of the basin currently supports a tidally corrected average concentration of 0.59 mg TN L⁻¹. The significantly impaired upper tributary and Perch Pond have much higher TN levels, >0.78 mg TN L⁻¹. Based upon sequential reductions in watershed nitrogen loading in the analysis described in the section below (VIII-3), the sentinel station achieved an average TN level of 0.40 mg L⁻¹ and the lower main basin <0.30 mg TN L⁻¹. This indicates that significant eelgrass habitat restoration would occur within the regions of the 1951 eelgrass coverage. Based upon these data and the deeper waters of Great Pond, the threshold TN level was set at 0.40 mg TN L⁻¹, lower than for Bournes Pond (0.42-0.45 mg TN L⁻¹).

Green Pond Threshold Nitrogen Concentrations

- Within the Green Pond Estuary the most appropriate sentinel station was about 2/3 of the distance from the headwaters to the tidal inlet (G4 in Figure VIII-2). For embayment restoration, an additional requirement within the upper 2/3 of the estuary was to ensure that TN in this region has been reduced to levels supportive of healthy infauna habitat when the eelgrass threshold was met for the lower 1/3 of the embayment.
- The target nitrogen concentration for restoration of eelgrass in this system was determined to be 0.42 mg TN L⁻¹ for Station G4 and 0.4 mg TN L⁻¹ in the lower basin (below the bridge). This threshold level is consistent with the findings that (1) eelgrass beds have been lost in the lower basin which currently supports at tidally averaged TN of 0.53 mg TN L⁻¹ at G4 and 0.41 mg TN L⁻¹ below the bridge (G5), (2) sparse eelgrass can be still be found adjacent to the inlet at tidally averaged TN of 0.41 mg TN L⁻¹, (3) the eelgrass beds in Bournes Pond (threshold 0.45 mg TN L⁻¹) at shallower water depths which is important for light penetration, and (4) the restriction of eelgrass beds to the margins in the region of the sentinel station (G4) in 1951 with more complete coverage in the lower basin. Based upon these data, the threshold TN level was set at 0.40 mg TN L⁻¹ for complete coverage of the lower basin and 0.42 mg TN L⁻¹ at the Sentinel Station to re-establish the marginal beds (both conditions are required in this system). Based on the results of the Linked Watershed – Embayment Model approach, it appears that achieving the nitrogen target at the sentinel location is restorative of eelgrass habitat throughout the lower Green Pond main basin and marginal beds above the bridge (1951 distribution) and restorative of infaunal habitat throughout the estuary.

Bournes Pond Threshold Nitrogen Concentrations

- Within the Bournes Pond Estuary the most appropriate sentinel station was 2/3 of the way down the upper tributary (Station B3 in Figure VIII-3). This location was selected because (1) it was the upper extent of the full channel eelgrass bed coverage in 1951 (and is slightly above the eelgrass record for 1979), (2) restoration of nitrogen conditions supportive of eelgrass at this location will necessarily result in even higher quality conditions throughout the entire lower basin and Israels Cove, and (3) restoration of nitrogen concentrations at this site should result in conditions similar to 1951 within the upper 2/3 of the upper tributary, which will be supportive of high quality habitat for benthic infaunal communities.
- The target nitrogen concentration for restoration of eelgrass in this system was determined to be 0.45 mg TN L⁻¹ within the lower 1/3 of the tributary (Station B3), 0.31 mg TN L⁻¹ within the lower basin adjacent to the inlet and 0.42 mg TN L⁻¹ within Israels Cove. Although there is only one sentinel station (B3), the thresholds analysis placed an additional requirement that the TN level in the upper region of the lower basin (Station B4) was supportive of healthy infauna habitat when the eelgrass threshold was met for the lower 1/3 of the embayment. The sentinel station (B3) under present loading conditions supports a tidally corrected average concentration of 0.643 mg TN L⁻¹. Based upon sequential reductions in watershed nitrogen loading in the analysis described in the section below (VIII-3), the sentinel station achieved an average TN level of 0.45 mg L⁻¹, the lower basin <0.355 mg TN L⁻¹, and Israels Cove 0.42 mg TN L⁻¹. This indicates that significant eelgrass habitat restoration would occur within the regions of the 1951 coverage. Based on the site-specific eelgrass and TN data for Bournes Pond, restoration of eelgrass beds within Israels Cove should occur when TN levels are lowered to 0.42 mg TN L⁻¹ and restoration of eelgrass beds within the lower 1/3 of the estuary (from B3 south) should occur when TN levels are lowered to 0.45 mg TN L⁻¹ at the sentinel station.

It is important to note that the analysis of future nitrogen loading to the Great, Green and Bournes 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 Great, Green and Bournes Pond 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 Ashumet Valley estuary systems (Great, Green and Bournes Ponds), observed nitrogen concentrations, and sentinel system threshold nitrogen concentrations. Loads to estuarine waters of the three ponds include both upper watershed regions contributing to the major surface water inputs (Coonamessett River, Backus Brook and Bournes Brook).

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)
<i>GREAT POND SYSTEM</i>										
Great Pond ^a	8.68	11.26	36.36	1.48	47.63	3.22	-0.27	50.58	0.88-0.54	--
Perch Pond	0.29	0.90	4.47	0.00	5.38	0.22	-1.39	4.21	0.90	--
Great Pond System Total	8.97	12.16	40.83	1.48	53.01	3.44	-1.66	54.79	0.90-0.54	0.400⁸
<i>GREEN POND SYSTEM</i>										
Green Pond System Total^a	2.20	3.65	18.70	1.37	22.36	1.61	55.60	79.57	0.99-0.44	0.450⁸
<i>BOURNES POND SYSTEM</i>										
Bournes Pond ^a	1.49	2.19	10.71	0.00	12.90	1.61	28.45	42.96	0.88-0.39	--
Israels Cove	0.21	0.27	1.78	0.00	2.05	0.26	-0.32	1.99	0.67	--
Bournes Pond System Total	1.70	2.46	12.49	0.00	14.95	1.87	28.13	44.95	0.88-0.39	0.450⁸

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 – 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 for sentinel sites located at the upper portions of Great Pond (GT5), Green Pond (G4), and Bournes Pond (B3).

^a Loads to Great, Green, and Bournes Ponds include loads from surface water sources (e.g., rivers).

Table ES-2. Present Watershed Loads, Thresholds Loads, and the percent reductions necessary to achieve the Thresholds Loads for the Ashumet Valley embayment systems (Great, Green and Bournes Ponds), Towns of Falmouth, 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
<i>GREAT POND SYSTEM</i>						
Great Pond	47.63	18.81	3.22	0.47	22.50	-60.5%
Perch Pond	5.38	0.90	0.22	-0.53	0.59	-83.3%
Great Pond System Total	53.01	19.71	3.44	-0.06	23.09	-62.8%
<i>GREEN POND SYSTEM</i>						
Green Pond System Total	22.36	10.16	1.61	34.49	46.26	-54.6%
<i>BOURNES POND SYSTEM</i>						
Bournes Pond	12.90	3.28	1.61	19.28	24.17	-74.6%
Israels Cove	2.05	0.27	0.26	-0.14	0.39	-86.8%
Bournes Pond System Total	14.95	3.55	1.87	19.14	24.56	-76.3%
<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>						