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Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for West Falmouth Harbor 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 West Falmouth Harbor embayment system, a coastal embayment within the Town of Falmouth, Massachusetts. Analyses of the West Falmouth Harbor 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 West Falmouth Harbor 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 West Falmouth Harbor 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 West Falmouth Harbor 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 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 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 West Falmouth Harbor 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 Bournes Pond embayment systems as well as other embayments in the Town of Falmouth such as Oyster Pond and Little Pond. 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 relative to the Town of Falmouth Wastewater Treatment Plant that operates within the West Falmouth Harbor watershed. 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 West Falmouth Harbor 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 West Falmouth Harbor embayment system and the 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 West Falmouth Harbor 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 Buzzards Bay source waters were taken from water quality monitoring data. Measurements of current salinity distributions throughout the estuarine waters of the West Falmouth Harbor 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 West Falmouth Harbor system. 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 station (Snug Harbor, PWF-5) chosen for West Falmouth Harbor. 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 West Falmouth Harbor 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. It should be noted that the recent upgrade to the WWTF allowed stream lining of the target nitrogen loads to West Falmouth Harbor as this upgrade significantly reduced the total nitrogen load entering this system.

2. Problem Assessment (Current Conditions)

A habitat assessment was conducted throughout West Falmouth Harbor based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. At present, West Falmouth Harbor, is showing a strong gradient in habitat quality from severely degraded (Oyster Pond) to significantly impaired (Snug Harbor, Harbor Head) transitioning to less impaired (South Basin) to moderately impaired (Outer/Mid Basin) to healthy (basin nearest inlet). The Snug Harbor shows significant impairment based upon all 3 parameters (eelgrass, infauna, D.O.), while the outer/mid basin was moderately impaired in spite of its proximity to the tidal inlet and high quality waters of Buzzards Bay. All of the habitat indicators show consistent patterns of habitat quality in each of the major subembayments and those habitat impairments are consistent with nitrogen enrichment (Chapter VII).

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 $\sim 7-8 \text{ mg L}^{-1}$ at the mooring sites). This was periodically seen in Snug Harbor and the mid/outer Harbor. The oxygen and chlorophyll data also shows a gradient of impairment with high levels in the inner sub-embayments (Oyster Pond, Snug Harbor) and better conditions in the lower basins (Outer Harbor). The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate nutrient enriched waters and impaired habitat quality, particularly in

Snug Harbor. The oxygen data throughout the estuary is consistent with elevated organic matter loads from phytoplankton production (chlorophyll a levels) indicative of nitrogen enrichment and eutrophication of these estuarine systems. The oxygen records further indicate that the upper tidal reaches of each estuary have the largest daily oxygen excursion, with daily excursions in excess of >4 mg L⁻¹ common. This further supports the assessment of a high degree of nutrient enrichment.

The West Falmouth Harbor Estuary is moderately deep compared to others along the south shore of Cape Cod from Falmouth to Barnstable (Chapter V). However, water depths are well within the range for eelgrass growth in Massachusetts, given suitable conditions of light penetration. There has been a clear and ecologically significant alteration of eelgrass distribution within West Falmouth Harbor within the past 15 years. Analysis of the mapping data is consistent with a real change in eelgrass coverage. Comparison of inner versus outer Harbor areas indicates only a small decline in eelgrass area in the outer Harbor region from 1979 to 1999 (and 1995, 2001 data). This indicates that although three different groups conducted sampling, consistent results could be achieved. In contrast, the inner areas appear to have lost their functional eelgrass habitat, with only sparse coverages remaining in a small fraction of the area that historically supported eelgrass (details provided in Chapter VII and VIII).

The surveys indicate that both the inner and outer Harbor basins are capable of supporting eelgrass when the watershed nitrogen loading rates are at the 1979-1985 levels. The current absence of functional eelgrass beds within the inner basins and the fact that these areas supported eelgrass in the recent past classifies the Snug Harbor and South Basin eelgrass habitat as “significantly impaired”. The presence of significant eelgrass beds within the mid/outer basin (Field Cove) coupled with recent declines in the uppermost portion classifies this basin’s eelgrass habitat as “moderately impaired”, while the outermost basin nearest the inlet still supports healthy eelgrass beds and garners a “healthy” classification. There is no evidence that the small tributaries to the main estuary (Mashapaquit Creek, Harbor Head and Oyster Pond) have supported eelgrass and therefore restoration of eelgrass habitat in these basins is not a management goal (although infaunal habitat should be).

The Infaunal study indicated that most of the Harbor basins have nutrient related impairment of benthic habitat, although it appears that near the inlet habitat quality remains high. However, the level of impairment varied greatly between sub-embayments. Within the main Harbor, Snug Harbor was found to support patchy habitat dominated by stress indicator (opportunistic) species such as *Capitella*. Harbor Head was very similar to Snug Harbor in numbers of individuals and species and dominance by stress indicator species. The infaunal habitat in these basins appears to be “significantly impaired” by organic matter enrichment stemming from nitrogen overloading. In contrast, South Basin was not dominated by opportunistic species but by species indicative of lower organic enrichment with deeper burrowers and mollusks, although the numbers of individuals and species were similar to Snug Harbor and Harbor Head. This indicates a less stressed habitat. However, South Basin’s moderate number of species indicates a “moderately impaired” community when compared to healthy embayments where >20 species is typical.

Overall, the pattern of infaunal community quality is consistent with the pattern of oxygen depletion and chlorophyll a during summer and eelgrass habitat quality. Almost all sites showed some level of degradation, either in number of individuals, diversity or the presence of stress indicator species. Lowering nitrogen inputs to this system should allow a relatively rapid recovery of communities in the mid/outer Harbor and South Basins, with higher levels of nitrogen management required to restore benthic habitat to Snug Harbor and Harbor Head

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 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 West Falmouth Harbor embayment system was comprised primarily of wastewater nitrogen. Land-use and wastewater analysis found that generally about 80%-90% 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 West Falmouth Harbor embayment system in Falmouth were determined as follows:

West Falmouth Harbor Threshold Nitrogen Concentrations

- The healthy eelgrass beds within the Outer Harbor are at tidally averaged total nitrogen levels of 0.33-0.31 mg N/L. Total nitrogen levels in the upper and lower reach of Snug Harbor where sparse eelgrass is still found are 0.46 (<5% cover) and 0.37 (5-15% cover and patches), respectively. South Basin does not currently have eelgrass and has a tidally averaged total nitrogen level of 0.38 mg N/L. Note that the background total nitrogen in the inflowing Buzzards Bay waters is 0.296 mg N L⁻¹. The average measured mid-ebb tide total nitrogen level in the outer harbor, which currently supports eelgrass beds is 0.345 mg N L⁻¹, which compares well with the 0.353-0.356 mg N L⁻¹ ebb tidal maximum from the MEP water quality module (Chapter VI). In addition, measured mid-ebb tide total nitrogen levels in the inner basins in 1992-93, when eelgrass habitat was still presumably relatively healthy (pre-WWTF plume discharge to Harbor) were 0.34-0.36 mgN/L⁻¹.
- The data argue for a tidally averaged total nitrogen level <0.37 N/L⁻¹ and mid-ebb concentration <0.36 mg N/L⁻¹ to support high quality eelgrass habitat. Given all of the data considered in the analysis, the tidally averaged total nitrogen threshold at the sentinel station in Snug Harbor was set at 0.35 mg N L⁻¹. This threshold is also consistent with previous analyses of this system (Eichner et al. 1998, Howes et al. 2000), targeted at restoration of high quality estuarine habitats throughout the West

Falmouth Harbor System. A nitrogen threshold greater than 0.35 mg N L^{-1} is likely to result in some loss of eelgrass habitat.

- Although a single sentinel station (Snug Harbor) was selected, secondary criteria relating to infaunal habitat must be achieved at other locations (e.g. Harbor Head). The secondary criteria serve only as checks to make sure that the targets are achieved when the nitrogen threshold at the sentinel station has been reached. The historical analysis did not indicate that Harbor Head is supportive of eelgrass habitat and therefore eelgrass was not used to evaluate habitat health. In these cases, as discussed previously, the MEP focuses on maintenance of a high quality infaunal habitat as the restoration objective. At present, the infaunal habitat within the Harbor Head basin is significantly impaired. The present tidally averaged total nitrogen level is 0.44 N/L^{-1} and the measured mid-ebb average is 0.48 N/L^{-1} . This contrasts with South Basin which shows only a modest level of impairment to infaunal habitat at 0.38 N/L^{-1} . The secondary criteria relating to Harbor Head infaunal habitat would then require tidally averaged total nitrogen level between 0.35 and 0.38 N/L^{-1} when the nitrogen level at the sentinel station is achieved

It is important to note that the analysis of future nitrogen loading to the West Falmouth Harbor estuarine system focuses upon additional shifts in land-use from forest/grasslands to residential and commercial development. However, the MEP analysis indicates that significant increases in nitrogen loading can occur under present land-uses, due to shifts in occupancy, shifts from seasonal to year-round 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 West Falmouth Harbor estuarine system is that restoration will necessitate a reduction in the present (2003) 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 West Falmouth Harbor system, observed nitrogen concentrations, and sentinel system threshold nitrogen concentrations. Loads to estuarine waters of the West Falmouth Harbor system include both upper watershed regions contributing to the major surface water inputs.

| 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) |
|---|--|--|--|--|---|--|--------------------------------------|---|--|------------------------------|
| WEST FALMOUTH HARBOR SYSTEM | | | | | | | | | | |
| Outer West Falmouth Hbr. | 0.271 | 0.416 | 1.274 | 0.000 | 1.690 | 0.921 | -3.086 | -0.475 | 0.34-0.35 | -- |
| Inner West Falmouth Hbr. | 1.027 | 8.301 | 2.085 | 7.118 | 10.386 | 0.866 | -6.091 | 5.161 | 0.39 | -- |
| Harbor Head | 0.197 | 0.274 | 0.811 | 0.000 | 1.085 | 0.153 | -0.478 | 0.760 | 0.48 | -- |
| Oyster Pond | 0.290 | 0.375 | 0.984 | 0.000 | 1.359 | 0.079 | 0.000 | 1.438 | 0.51 | -- |
| Snug Harbor | 0.901 | 7.658 | 1.912 | 6.584 | 9.570 | 0.455 | -3.699 | 6.326 | 0.44 | -- |
| Mashapaquit Creek ^a | 0.822 | 14.674 | 2.975 | 22.737 | 17.649 | 0.019 | 0.000 | 17.668 | 0.74 | -- |
| West Falmouth Harbor System Total | 3.510 | 31.699 | 10.041 | 36.438 | 41.740 | 2.493 | -13.354 | 30.879 | 0.34-0.74 | 0.35 |
| 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 unattenuated 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 1995 – 2004 data, ranges show the upper to lower regions (highest-lowest) of a sub-embayment. ⁸ Eel grass threshold for sentinel site located at Snug Harbor (WF 5). ^a Include loads from surface water sources. | | | | | | | | | | |

Table ES-2. Present Watershed Loads, Thresholds Loads, and the percent reductions necessary to achieve the Thresholds Loads for the West Falmouth Harbor system.

| 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 |
|--|---|--|---|---|-------------------------------|--|
| WEST FALMOUTH HARBOR SYSTEM | | | | | | |
| Outer West Falmouth Hbr. | 1.690 | 1.359 | 0.921 | -2.895 | -0.616 | -19.6% |
| Inner West Falmouth Hbr. | 10.386 | 5.301 | 0.866 | -4.949 | 1.219 | -49.0% |
| Harbor Head | 1.085 | 0.592 | 0.153 | -0.372 | 0.373 | -45.5% |
| Oyster Pond | 1.359 | 0.718 | 0.079 | 0.000 | 0.797 | -47.2% |
| Snug Harbor | 9.570 | 3.715 | 0.455 | -2.892 | 1.278 | -61.2% |
| Mashapaquit Creek | 17.649 | 6.844 | 0.019 | 0.000 | 6.863 | -61.2% |
| West Falmouth Harbor System Total | 41.740 | 18.529 | 2.493 | -11.108 | 9.914 | -55.6% |

(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.