SMAST University of Massachusetts Dartmouth
The School for Marine Science and Technology

Massachusetts Department of Environmental Protection

Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Namskaket Marsh Embayment System Town of Orleans, 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 Namskaket Marsh embayment system, a coastal embayment situated within the Town of Orleans, Massachusetts. Analyses of the Namskaket Marsh embayment system was performed to assist the Town with up-coming nitrogen management decisions associated with current and future wastewater planning efforts, as well as wetland restoration, anadromous fish runs, shell fishery, and open-space programs. As part of the MEP approach, habitat assessment was conducted on the 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 Orleans 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 Namskaket Marsh 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 / protection of the Namskaket 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 Namskaket embayment system within the Town of Orleans (though primarily a large salt marsh environment) is at risk of eutrophication (over enrichment) in its upper reaches if enhanced nitrogen loads entering through groundwater and surface water from the increasingly developed watersheds to this complicated estuarine system eventually exceed the salt marshes ability to uptake the nutrient loads. 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 Orleans has recognized the severity of the problem of eutrophication and the need for watershed nutrient management. Concern over declining resource quality of the estuarine systems of Orleans (inclusive of Namskaket Marsh) prompted the Town of Orleans to initiate the town-wide Orleans Water Quality Monitoring Program in 2001, which continues in a reduced form through present (2008). The 2001 Program was an expansion of a previous effort targeting Pleasant Bay, begun in 1997 by the Orleans Water Quality Task Force. The town-wide monitoring program is focused on restoring and protecting the estuarine habitats associated with the Town of Orleans and is being undertaken in concert with the DEP/SMAST Massachusetts Estuaries Project. This is a collaborative effort whereby the Town of Orleans provides the support, coordination and oversight of the program through its Planning Office and through its Wastewater Management Steering Committee and SMAST provides the technical and analytical aspects needed for the project through the MEP Technical Team.

The investigations undertaken prior to the Massachusetts Estuaries Project analysis summarized in this report provided significant information related directly to the implementation of the MEP Linked Management Modeling Approach and helped yield insight into the interpretation of the results. In addition, the Town of Orleans' comprehensive Water Quality Monitoring Program was of sufficient rigor to be used as the water quality baseline required for the MEP threshold analysis presented in this MEP Technical Report.

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 Namskaket Marsh embayment system by using site-specific data collected by the MEP and water quality data from the Orleans Water Quality Task Force Water Quality Monitoring Programs (see Chapter 2). Evaluation of upland nitrogen loading was conducted by the MEP, data was provided by the Planning Department in the Town of Orleans and watershed boundaries were delineated by USGS. This land-use data was used to determine watershed nitrogen loads within the Namskaket Marsh embayment system and associated sub-embayments (current and build-out loads are summarized in Chapter IV). Water quality within a sub-embayment is the integration of nitrogen loads with the site-specific estuarine circulation. Therefore, water quality modeling of 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 Namskaket Marsh embayment system. Once the hydrodynamic properties of the 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 bio-available and 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 the 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 the Cape Cod Bay source waters were taken from water quality monitoring data. Measurements of current salinity distributions throughout the estuarine waters of the Namskaket Marsh 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 approach for determining nitrogen loading rates, which will maintain acceptable habitat quality throughout and embayment system, is to first identify a sentinel location within the embayment and second to determine the nitrogen concentration within the water column which will restore that location to the desired habitat quality (threshold nitrogen level). The sentinel location is selected such that the restoration of that one site will necessarily bring the other regions of the system to acceptable habitat quality levels. Once the sentinel site and its target nitrogen level are determined, the Linked Watershed-Embayment Model is used to adjust nitrogen loads sequentially until the targeted nitrogen concentration is achieved. For the Namskaket Marsh system, the restoration target should reflect both pre-degradation habitat quality and be reasonably achievable. The presentation in this report of nitrogen loading limits aims to establish the general degree and spatial pattern of loading that will be required for protection of this healthy salt marsh dominated embayment system.

The Massachusetts Estuaries Project's thresholds analysis, as presented in this technical report, provides the site-specific nitrogen loading guidelines for future nitrogen management in the watershed to the Namskaket Marsh embayment system. Future water quality modeling scenarios should be run which incorporate the spectrum of strategies that result in changes to nitrogen loading (increase or decrease) to the embayment. These scenarios should be developed in coordination with the Town of Orleans in the Namskaket Marsh watershed in order to effectively examine the effect of load increases/reductions on water column nutrient concentrations.

It is important to note that contrary to most other estuarine systems evaluated as part MEP, the threshold concentration for Namskaket Marsh (similar to the adjacent Little Namskaket Marsh) was set higher than present conditions, meaning that the system would be allowed to have a higher load than present while still being able to meet the threshold. Therefore, watershed nitrogen loads were sequentially raised in the model until the nitrogen levels reached the threshold level at the sentinel station (WMO-23) chosen for Namskaket Creek. It is important to note that load increases could be produced by increasing of any or all sources of nitrogen to the system. The load increases presented in this report represent only one of a suite of potential approaches that need to be evaluated by the community. The current presentation is to establish the general degree and spatial pattern of loading that will be allowable for this system.

2. Problem Assessment (Current Conditions)

A habitat assessment was conducted throughout Namskaket Marsh system based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. The Namskaket Estuary is showing high habitat quality throughout its salt marsh reach. The upper reach appears to be a fully functional tidal salt marsh with deeply incised narrow creeks surrounded by

extensive emergent marsh. This reach is typical of New England "pocket" marshes, with smaller tidal creeks and a marsh plain dominated by low marsh and high marsh plant communities with patches of fringing brackish marsh vegetation. The lower reach of the marsh supports a large wetland area to the west along with larger tidal creeks. The lower portion of the system is also heavily influenced by sand transport via nearshore coastal processes associated with adjacent Cape Cod Bay. Plant communities in the lower reach are similar to the upper reach except that there is less fringing brackish water species and the marsh grades to barrier beach/dune vegetation near the tidal inlet. All of the key habitat indicators are consistent within Namskaket Marsh, and particularly its tidal creeks, supporting high quality habitat in line with the system's salt marsh structure and function (Chapter VII).

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 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 Namskaket Marsh embayment system were comprised primarily of wastewater nitrogen. Land-use and wastewater analysis found that generally about 85% of the controllable watershed nitrogen load to the embayment was from wastewater.

As a salt marsh dominated estuary, Namskaket Marsh does not support eelgrass habitat. As a result, threshold development for protection/restoration of this system focuses on infaunal habitat quality. The primary mechanism for infaunal habitat quality decline in salt marsh creeks of this type is through stimulation of macroalgal production and accumulation.

Determination of the critical nitrogen threshold for maintaining high quality habitat within the Namskaket estuarine system is based primarily upon: 1) the systems structure and function as a salt marsh, 2) macroalgal distribution, 3) current benthic community indicators and 4) nitrogen levels. Given the database it is possible to develop a site-specific threshold, which is a refinement upon general threshold analysis frequently employed.

The Namskaket Estuary is presently supportive of high quality salt marsh infaunal habitat throughout its tidal reach. While there is periodic summertime oxygen depletion of creek waters, the levels are consistent with unimpaired New England salt marsh systems. At present, significant macroalgal accumulations do not occur within this macro-tidal estuary at tidally averaged total nitrogen levels of 0.662 mg N L-1 (headwaters) to 0.421 mg N L-1 (tidal inlet).

The threshold nitrogen levels for the Namskaket embayment system in the Towns of Orleans and Eastham were determined as follows:

Namskaket Marsh Threshold Nitrogen Concentrations

- Namskaket Marsh is presently below the level of nitrogen loading that would cause impairment to its infaunal habitats (i.e. below its nitrogen threshold level), therefore, a conservative estimate of the threshold was established. The threshold was based upon site-specific data and comparison to other similar systems on Cape Cod where detailed nitrogen threshold studies have been completed. The inter-estuarine comparison focused upon similar salt marshes which are presently experiencing higher nitrogen levels, with and without impairment.

- A principal component of the high tolerance of salt marsh systems to nitrogen inputs from groundwater and surface water inflows is that unlike embayments, creek waters cannot accumulate nutrients over multiple tidal cycles as embayments do. In addition, increasing the nitrogen concentration in the tidal waters that flood the marsh plain will have a negligible or possibly a stimulatory effect on marsh primary and likely secondary production (i.e. an enhancement of habitat). In addition, since the inflowing fresh waters flow down gradient through the marsh creek and out to the adjacent offshore waters, the nitrogen level will never exceed the inflowing freshwater nitrogen level.

- A detailed nitrogen threshold analysis of Cockle Cove Creek (Chatham), a similarly configured salt marsh to Namskaket Creek, has recently been completed (SMAST 2006). In addition to having similar structures, Cockle Cove Creek and Namskaket Creek both support similar benthic communities, macroalgal accumulations are sparse to absent in both systems and tidal velocities within the central creek are similar. In addition, the infaunal habitats within Namskaket and Cockle Cove Marsh are similar in composition and diversity (dominated by polychaetes and crustaceans, with some mollusks). The dominant species (*Leptocheirus, Paranais*) was also observed in a study of a healthy salt marsh, Great Sippewisset Marsh on Cape Cod.

- Putting all the assessment elements together, it appears that for Namskaket Creek, the critical values are a total nitrogen level of 2 mg N L^{-1} in the headwaters and a level of 1 mg N L^{-1} at the border of the upper and lower reach (Station WMO-23). As this upper/lower boundary station is the uppermost long-term marine water quality sampling site and integrates all of the watershed and upper marsh nitrogen inputs and removals, it was selected as the sentinel station for this system (WMO-23). The threshold (tidally averaged) total nitrogen level of 1 mg N L^{-1}.was determined to be appropriate for the sentinel station (WMO-23). It should be noted that the tidally averaged total nitrogen level at the middle marsh station in Cockle Cove Creek is currently 1.378 mg N L^{-1} and the tidal inlet station shows concentrations of 0.472 mg N L^{-1}, consistent with the 1 mg N L^{-1} at the sentinel station in Namskaket Marsh. This threshold applies as long as the tidal creek maintains its present hydrodynamic characteristics (flushing and velocity). The nitrogen threshold for Namskaket Marsh is intentionally conservative based upon all available data from comparable systems. However, it indicates that additional nitrogen may enter this system without impairment of its habitat quality throughout the estuary.

- As presented in Chapter VIII, the threshold set for this system would allow up to 3.6 times (261% increase) the present watershed loading. The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-1.

The overarching conclusion of the MEP analysis of the Namskaket Marsh estuarine system is that protection of this currently healthy salt marsh system will allow for increased nitrogen loading from a variety of watershed sources, however, limits to nitrogen loading have been determined as detailed further in the report. This requires careful long term monitoring of conditions in the marsh system and watershed based management of present and future nitrogen inputs such that nitrogen concentration thresholds specified as supportive of health marsh habitat are not exceeded in the future.

Table ES-1. Existing total and sub-embayment nitrogen loads to the estuarine waters of the Namskaket Marsh system, observed nitrogen concentrations, and sentinel system threshold nitrogen concentrations. Loads to estuarine waters of the Namskaket 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. [8] (mg/L)
NAMSKATET MARSH SYSTEM										
Namskaket marsh	5.334	3.346	5.944	3.245	9.29	0.118	-0.409	8.999	0.52-0.84	--
Namskaket Creek (freshwater)	0.8	1.306	2.088	-	3.395	-	-	3.395	1.21	--
Namskatet Marsh System Total	6.134	4.652	8.032	-	12.685	0.118	-0.409	12.394	**0.52-1.21**	**1.000**

[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 data collected between 2001 and 2006, ranges show the upper to lower regions (highest-lowest) of the indicated sub-embayment.
[8] threshold for sentinel site located at mid-point WQ monitoring station of the system.

Table ES-2. Present Watershed Loads, Thresholds Loads, and the percent reductions necessary to achieve the Thresholds Loads for the Namskaket 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 change in watershed load to achieve allowed threshold load levels
NAMSKATET MARSH SYSTEM						
Namskaket marsh	9.29	31.510	0.118	-0.317	31.628	+239.2%
Namskaket Creek (freshwater)	3.395	14.381	-	-	14.381	+323.6%
Namskatet Marsh System Total	12.685	45.890	0.118	-0.317	46.008	+261.8%

(1) Composed of combined natural background, fertilizer, runoff, and septic system loadings.
(2) Target threshold watershed load is the load from the watershed that meets 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.