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Massachusetts Estuaries Project

Linked Watershed-Embayment Modeling to Determine Critical Nitrogen Loading Thresholds for Stage Harbor, Sulphur Springs, Taylors Pond, Bassing Harbor and Muddy Creek, Chatham, MA

Executive Summary

1. Background

This report presents the results generated from the implementation of the Massachusetts Estuaries Project's Linked Watershed-Embayment Approach to five coastal embayments within the Town of Chatham, Massachusetts: Stage Harbor, Sulphur Springs, Taylors Pond, Bassing Harbor, and Muddy Creek. Analyses of these five coastal embayments were performed to assist the Town with up-coming nitrogen management decisions associated with the Town's 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 assessments were conducted on each 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 Chatham's resource planning and decision-making process.

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 embayments within the Town of Chatham are at risk of eutrophication from enhanced nitrogen loads entering through groundwater and surface water from their increasingly developed watersheds. 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 Chatham has recognized the severity of the problem of eutrophication and the need for watershed nutrient management and is currently refining its Comprehensive Wastewater Management Plan, which it plans to rapidly implement. Based on the results of the initial version of the Town of Chatham CWMP, it became clear that a more rigorous scientific approach yielding site-specific nitrogen loading targets was required. Therefore, the Town of Chatham agreed to the use of a multi-phase, multi-disciplinary approach to address its estuarine water quality issues within the context of its wastewater planning effort. 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 CWMP Team 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 with 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 each of the five Chatham embayments using site-specific data collected by the MEP and water quality data from the Chatham WaterWatchers and Pleasant Bay Alliance. Evaluation of upland nitrogen loading was conducted by the MEP but incorporated land-use coverage data from the CWMP (Stearns & Wheler, 1999), data provided by the Town of Chatham Planning Department, and watershed boundaries delineated by USGS. This land-use data was used to determine watershed nitrogen loads within the five Chatham embayments (current and build-out loads are summarized in Table IV-3). Water quality with in each 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 each of the Chatham embayment systems. Once the hydrodynamic properties of each 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 models were 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 Chatham's coastal embayments 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 Nantucket Sound and Pleasant Bay source waters were taken from water quality monitoring data. Measurements of current nitrogen distributions throughout estuarine waters were used to calibrate the water quality model (under existing loading conditions).

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 each of the five-embayment systems in this study were developed to restore or maintain SA waters or high habitat quality. In these five systems, 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(s) within each 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 process will result in the most cost-effective plan for restoring Chatham's embayments.

The Massachusetts Estuaries Project's thresholds analysis, as presented in this technical report, provides the site-specific nitrogen reduction guidelines for nitrogen management of each embayment in the Town of Chatham. Future water quality modeling scenarios should be run which incorporate the spectrum of strategies that result in nitrogen loading reduction to each 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 ~85% of the watershed load 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 on each embayment based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. The five-embayment systems in this study displayed a range of habitat quality, both between systems and along the longitudinal axis of the larger systems. In general, sub-embayments show declining in 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 five-embayment systems. 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).

Stage Harbor System – Little Mill Pond, Mill Pond, and Oyster Pond have elevated nitrogen levels and have lost historic eelgrass beds that once covered most of their respective basins. Oxygen depletion is observed during summer in each system with Mill Pond (and presumably Little Mill Pond) having ecologically significant declines (<3 mg L^{-1}), as indicated in Table VII-1. Oyster Pond had less oxygen depletion possibly due to its greater fetch for ventilation with the atmosphere. Chlorophyll a levels were consistent with the observed oxygen depletion (Table VII-2). The lower reaches of the Oyster River and Upper Stage Harbor show good habitat quality as evidenced by their persistent eelgrass beds, infaunal community structure and oxygen and chlorophyll a levels. The innermost high quality habitat is found in the lower Mitchell River/upper Stage Harbor.

Sulphur Springs System – Cockle Cove consists primarily of a salt marsh and central tidal creek. This system contains little water at low tide and has a high assimilative capacity for nitrogen as do other New England salt marshes. Sulphur Springs is a shallow basin containing significant macroalgal accumulations, no eelgrass, and appears to be transitioning to salt marsh. However, Sulphur Springs basin is still functioning as an embayment, but a eutrophic one. Nitrogen levels are high (Table VI-1), oxygen levels become significantly depleted (6% of time <3 mg L^{-1}) and phytoplankton blooms are common and large (chlorophyll a levels >20 ug L^{-1}). Eelgrass has not been observed for over a decade.

Taylors Pond System – Taylors Pond represents the inland-most sub-embayment and is a drowned kettle pond. The lower portion of this system is comprised of a tidal salt marsh, Mill Creek. Like the Sulphur Springs System, the inner basin functions as an embayment and the tidal creek as a salt marsh with low sensitivity to nitrogen inputs. Taylors Pond is currently showing poor habitat quality. There is currently no eelgrass community and no record of eelgrass for over a decade. Watercolumn nitrogen levels are enriched over incoming tidal waters (Section VI) and dissolved oxygen depletion to ~4 mg L^{-1} is common. Chlorophyll a levels of 10-15 ug L^{-1} are common during summer. The benthic infaunal community is impoverished, with only a mean of 43 individuals collected in the grab samples, compared to several hundred in the high quality sub-embayments.

Bassing Harbor System – The innermost sub-embayments to this system contain high quality habitat that is currently becoming impaired by nitrogen enrichment. Ryder Cove receives the greatest watershed nitrogen load of the Bassing Harbor sub-systems. This sub-embayment has been losing its eelgrass over at least the last decade. In 1951 the full basin appears to have supported eelgrass beds, many of which do not exist today. Infaunal communities indicate a moderate quality system with relatively low diversity and evenness. This is consistent with a system whose habitat is in transition from high to moderate level of quality. Upper Ryder Cove is currently showing bottom water oxygen depletion, frequently to <4 mg L^{-1} and occasionally to < 3 mg L^{-1}. The periodic oxygen declines, loss of eelgrass, and watershed nitrogen loading is consistent with the observed phytoplankton blooms, which generally (>40% of time) are >15 ug L^{-1} and frequently >20 ug L^{-1}. In contrast, the outer reach of Ryder Cove still supports relatively high habitat quality with dissolved oxygen levels almost always above 5 mg L^{-1} (99%) and moderate chlorophyll a levels (<15 ug L^{-1}). These watercolumn parameters are consistent with the high eelgrass coverage. Crows Pond is the other inland-most sub-embayment in this bifurcated estuary. However, Crows Pond has a significantly lower watershed nitrogen load than that to Ryder Cove. Crows Pond currently supports a high level of habitat quality, with eelgrass beds surrounding the central basin and sparse coverage throughout. Infaunal diversity and evenness is consistent with a high quality habitat. Oxygen levels are consistently above 5 mg L^{-1} and chlorophyll a levels also are moderate (generally 10-15 ug L^{-1}). However, it appears that habitat quality is currently declining. Present eelgrass coverage is less than in the 1951 and 1995 records. At present it appears the Crows Pond is slightly beyond its threshold nitrogen level and is beginning to decline in habitat quality. In addition, Frost Fish Creek is a tributary system to outer Ryder Cove that functions primarily as a salt marsh with a central basin (Section IV, Section VI). The outer-most basin in this system is Bassing Harbor, which receives tidal exchanges with Pleasant Bay. Bassing Harbor currently supports high habitat quality and based upon the eelgrass records has been relatively constant since 1951. The infaunal community is consistent with high habitat quality as is the maintenance of oxygen levels and moderate to low chlorophyll a levels (typically 5-10 ug L^{-1}. The Bassing Harbor sub-embayment appears to be a relatively stable high habitat quality system, with demonstrated good eelgrass and infaunal communities.

Muddy Creek – Muddy Creek, like Bassing Harbor, exchanges tidal waters with the greater Pleasant Bay System. However, unlike Bassing Harbor, Muddy Creek is a highly eutrophic embayment. Muddy Creek does not support significant eelgrass beds; however, a small sparse bed has persisted adjacent to the inlet. Muddy Creek is divided into an upper and lower portion by a dike whose weir has been removed or washed away. Both portions are highly eutrophic with frequent bottom water anoxia and large algal blooms (chlorophyll a frequently >50 ug L^{-1}). The upper portion has a lower habitat quality than the lower portion, most likely as a result of access to the higher quality waters entering from Pleasant Bay. An infaunal community persists but it is dominated by species tolerant of organic enrichment. Species diversity and evenness are low. The whole of Muddy Creek currently supports nitrogen-impaired habitat of poor quality.

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 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 and by direct atmospheric deposition.

Threshold nitrogen levels for each of the five-embayment systems in this study were developed to restore or maintain SA waters or high habitat quality. In these five systems, high habitat quality was defined as supportive of eelgrass and benthic infaunal communities. Dissolved oxygen and chlorophyll *a* were considered in the assessment.

Watershed nitrogen loads for each of the five Town of Chatham embayments were comprised primarily of wastewater nitrogen. Land-use and wastewater analysis found that generally about 85% (81%-89%) of the watershed nitrogen load to an embayment was from wastewater and in four embayments this resulted entirely from on-site septic disposal (Figures IV-7a-e).

A major finding for Chatham (and almost certainly other embayments within the MEP area) was that there is clearly not a single total nitrogen threshold that can be applied to Massachusetts' estuaries. The total nitrogen level, which was supportive of high habitat quality, was almost 50% higher in the Pleasant Bay sub-systems (e.g. Bassing Harbor) than in the Nantucket Sound estuaries (e.g. Stage Harbor).

The threshold nitrogen levels for the each embayment system was determined as follows:

Stage Harbor System – This embayment system has two upper reaches. Therefore, two sentinel sub-embayments were selected, mid-Oyster Pond and Mill Pond. Little Mill Pond could not be used as it is small and has steep horizontal nitrogen gradients (see Section VI). Within the Stage Harbor System, the upper most sub-embayment supportive of high quality habitat was upper Stage Harbor (Section VII, VIII-1). Water column total nitrogen levels within this embayment region vary with the tidal stage due to high nitrogen out flowing waters and low nitrogen inflowing waters (Section VI). Therefore, the total nitrogen level determined from the water quality model (that corrected for tidally driven variation in nitrogen concentration at each site) was used in the threshold development. The calibrated water quality model for this system indicates an average total nitrogen level in the upper Stage Harbor of about 0.40 mg N L^{-1} is most representative of the conditions within this sub-embayment. However, upper Stage Harbor does not appear to be stable based upon changes in eelgrass distribution. Therefore, a nitrogen level reflective of conditions closer to the inlet should achieve the stability required. The lower nitrogen level is equivalent to the tidally averaged total nitrogen concentration mid-way between upper Stage Harbor and Stage Harbor or 0.38 mg N L^{-1}. This threshold selection is supported by the fact that the high quality and stable habitat near the mouth of the Oyster River (to the Stage Harbor basin) is also at a tidally averaged total nitrogen concentration of 0.37 mg N L^{-1}. The 0.38 mg N L^{-1} was used to develop watershed nitrogen loads required to reduce the average nitrogen concentrations in each sentinel system to this level. Tidal waters inflowing from Nantucket Sound have an average concentration of total nitrogen of 0.285 mg N L^{-1}.

Sulphur Springs System – The Sulphur Springs basin is both the inland-most sub-embayment and also represents the largest component of this system. Since this system exchanges tidal waters with the Nantucket Sound (0.285 mg N L^{-1}), as does Stage Harbor and since there is currently no high quality habitat within this system. The tidally averaged nitrogen threshold concentration for this system was determined to be the same as for the sentinel sub-embayments to the Stage Harbor System or 0.38 mg N L^{-1}. The 0.38 mg N L^{-1} was used to develop watershed nitrogen loads required to reduce the average nitrogen concentrations in the Sulphur Springs sentinel system to this level.

Taylors Pond System – This system was approached in a similar manner to the Sulphur Springs System and for the same reasons. Taylors Pond represents the innermost and functional embayment within this system. This system also exchanges tidal waters with Nantucket Sound (0.285 mg N L^{-1}), as does the Stage Harbor System and there is no high quality stable embayment habitat within this system. Therefore, the tidally averaged nitrogen threshold concentration for this system was determined to be the same as for the sentinel sub-embayments to the Stage Harbor System or 0.38 mg N L^{-1}. The 0.38 mg N L^{-1} was used to develop watershed nitrogen loads required to reduce the average nitrogen concentrations in Taylors Pond to this level.

Bassing Harbor System – Although this system has two inland-most sub-embayments, Ryder Cove and Crows Pond, only Ryder Cove was selected as the sentinel system. This resulted from the fact that Crows Pond has a relatively low nitrogen load from its watershed and appears to currently support higher quality habitat than Ryder Cove. Ryder Cove currently shows a gradient in habitat quality with lower quality habitat in the upper reach and higher quality in the lower reach. Ryder Cove represents a system capable of fully supporting eelgrass beds and stable high quality habitat. At present, this basin is transitioning from high to low habitat quality in response to increased nitrogen loading. Restoration of nitrogen levels in upper Ryder Cove to levels supportive of high quality habitat should also result in the restoration and protection of the whole of the Bassing Harbor System.

Following the approach used for the Stage Harbor System, a region of stable high quality habitat was selected within the Bassing Harbor System. The region selected was Bassing Harbor that has both high quality eelgrass and benthic animal communities, which appear to be stable. Unfortunately, total nitrogen within this system appears to be very high. In fact, the whole of lower Pleasant Bay appears to contain very high levels of total nitrogen. Analysis of the composition of the water column nitrogen pool within these embayments revealed that the concentrations of dissolved inorganic nitrogen (DIN) and particulate organic nitrogen (PON) were the same as for the Stage Harbor System. In fact, the level of these combined pools (DIN+PON) was lower in Bassing Harbor (0.135 mg N L^{-1}) than in the Stage Harbor (0.158 mg N L^{-1}) and the mouth of Oyster River (0.160 mg N L^{-1}). It appears that the reason for the higher total nitrogen levels in the Pleasant Bay waters results from the accumulation of dissolved organic nitrogen. The bulk of dissolved organic nitrogen is relatively non-supportive of phytoplankton production in shallow estuaries, although some fraction is actively cycling. Based upon these site-specific observations, an adjusted nitrogen threshold could be developed for the Bassing Harbor System. The approach was to determine the baseline dissolved organic nitrogen level for the region (average of inner and outer Ryder Cove, Bassing Harbor, Frost Fish Creek, Tern Island, and Pleasant Bay), which was determined to be 0.394 mg N L^{-1}. A threshold range was then developed using a conservative DIN+PON level from the Bassing Harbor sub-embayment plus the dissolved organic nitrogen background and an upper threshold based upon the Stage Harbor DIN and PON values discussed above. The threshold range for this system was set as 0.527 mg N L^{-1} to 0.552 mg N L^{-1} and the higher threshold was used to develop watershed nitrogen loads required to reduce the average nitrogen concentrations in upper Ryder Cove to this level. The nitrogen boundary condition (the concentration of nitrogen in inflowing tidal waters from Pleasant Bay) for the Bassing Harbor System is 0.48 mg N L^{-1}.

Muddy Creek System – This system is highly eutrophic. Given the long narrow basin and the hydrodynamic evaluation (Section V), it was decided to make lower Muddy Creek the sentinel system. This is also based upon the fact that the upper portion was historically a freshwater system. Following the approach for the Bassing Harbor System, the MEP Team considered the Ryder Cove Threshold appropriate for application to Muddy Creek. Note that lower Muddy Creek recently support a sparse eelgrass bed. The threshold was used to develop watershed nitrogen loads required to reduce the average nitrogen concentrations in lower Muddy Creek to this level. Attainment of this threshold in Upper Muddy Creek required a nearly complete load reduction. The nitrogen boundary condition (the concentration of nitrogen in inflowing tidal waters from Pleasant Bay) for the Muddy Creek System is 0.50 mg N L^{-1}.

Based on the technical report, the MEP has the following recommendations for the five Chatham embayments:

- The nitrogen load reductions within the Stage Harbor system necessary to achieve the threshold nitrogen concentrations were relatively high, with more than 90% removal of septic load required within three sub-embayments (Oyster Pond, Oyster River, and Stage Harbor) and more modest reductions of ~50% within the Mitchell River to Little Mill Pond tributary.

- For the other south coastal embayment systems, Sulphur Springs and Taylors Pond, between 50% and 60% of the septic load would need to be removed to achieve the nitrogen concentration targets.

- The nitrogen load reductions within the Bassing Harbor system necessary to achieve the threshold nitrogen concentrations were relatively low, with between 30% and 50% removal of septic load required within the sub-embayments. The total nitrogen threshold value of 0.53 for Bassing Harbor is a preliminary value because the total nitrogen threshold value for Pleasant Bay has not yet been established. Following completion of the modeling work for the Pleasant Bay system, the Bassing Harbor threshold value will need to be revisited to ensure accuracy using the Pleasant Bay information. Accordingly, the preliminary nature of these Bassing Harbor values should be taken into account during completion of the Town's CWMP.

- For Muddy Creek, between 50% and 60% of the septic load would need to be removed to achieve the nitrogen concentration targets. Based on the results of nitrogen loading alternatives analysis, several load reducing alternatives for Muddy Creek show promise. These include Alternative E (3,000 kg/year reduction in upper watershed) and Alternative N (50% reduction in watershed load) as described in Section IX of the Report.

It appears from this initial nitrogen reduction modeling that the restoration of nutrient related habitat quality is both feasible and achievable within the Town of Chatham's major embayments, Stage Harbor and Bassing Harbor Systems, as well as Taylors Pond. However, restoration approaches and targets need to be further addressed for the Muddy Creek and Sulphur Springs Systems, due to their unique characteristics.

The next technical step towards the restoration of Chatham's embayments will be the development of a series of nitrogen management scenarios, based upon multiple nitrogen reduction strategies, for evaluation by the MEP Linked Watershed-Embayment Model to determine their restoration efficacy. This information will then form the basis of a cost/benefit alternatives analysis for use by the Town's Wastewater Planning Committee and ultimately the citizens of Chatham. The MEP Technical Team looks forward to the continued partnership with the Town of Chatham and the restoration and protection of these important natural resources.