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Massachusetts Department of Environmental Protection

Massachusetts Estuaries Project

Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Pleasant Bay System, Towns of Orleans, Chatham, Brewster and Harwich, 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 Pleasant Bay embayment system, a coastal embayment situated within the Towns of Chatham, Harwich and Orleans, Massachusetts. Analyses of the Pleasant Bay embayment system was performed to assist the Towns with up-coming nitrogen management decisions associated with 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 Towns of Chatham, Harwich and 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 Pleasant Bay 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 Towns) for the restoration of the Pleasant Bay 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 Pleasant Bay embayment system within the Towns of Chatham, Harwich and Orleans is at risk of eutrophication (over enrichment) in its upper reaches due to enhanced nitrogen loads entering through groundwater and surface water from the increasingly developed watersheds to this large estuarine 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 Towns that exist in the Pleasant Bay watershed (including the Town of Brewster that does not share Pleasant Bay shoreline) have recognized the severity of the problem of eutrophication and the need for watershed nutrient management. By example, the Town of Chatham is currently developing Comprehensive Wastewater Management Plans, which it plans to rapidly implement. The Town of Chatham and Orleans have also completed and implemented wastewater planning in other regions of those Towns that are not associated with the Pleasant Bay embayment system and as such look to integrate restoration of Pleasant Bay with wastewater planning efforts already underway. All of the Towns currently have nutrient management activities related to their tidal embayments, which have been associated with the MEP effort in Pleasant Bay as well as other embayments such as Namskaket marsh, Little Namskaket Marsh, Rock Harbor, Nauset and Nantucket Sound systems such as Saquatucket and Allens Harbors. The Towns and specific work groups have recognized that a rigorous scientific approach yielding site-specific nitrogen loading targets was required for decision-making and alternatives analysis. The completion of this multi-step process has taken place under the programmatic umbrella of the Massachusetts Estuaries Project, which is a partnership effort between all MEP collaborators, the Pleasant Bay Alliance and the Towns. 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 Pleasant Bay embayment system by using site-specific data collected by the MEP and water quality data from the Chatham WaterWatchers, the Orleans and the Pleasant Bay Alliance Water Quality Monitoring Programs (see Chapter 2). Evaluation of upland nitrogen loading was conducted by the MEP, data was provided by the Planning Departments in each of the Towns, and watershed boundaries delineated by USGS. This land-use data was used to determine watershed nitrogen loads within the Pleasant Bay embayment system and each systems 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 Pleasant Bay 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 Atlantic Ocean source waters were taken from water quality monitoring data. Measurements of current salinity distributions throughout the estuarine waters of the Pleasant Bay 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 Pleasant Bay System, the restoration target should reflect both recent pre-degradation habitat quality and be reasonably achievable. 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 Pleasant Bay embayment system. Future water quality modeling scenarios should be run which incorporate the spectrum of strategies that result in nitrogen loading reduction to the embayment. These scenarios should be developed in coordination with all the Towns in the Pleasant Bay watershed in order to effectively examine the effect of load reductions on water column nutrient concentrations. 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 70%-80% of the controllable watershed load to the Pleasant Bay embayment system and are more manageable than other of the nitrogen sources, the ability to achieve needed reductions through this source is a good gauge of the feasibility for restoration of these systems.

2. Problem Assessment (Current Conditions)

A habitat assessment was conducted throughout Pleasant Bay based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. The Pleasant Bay System is comprised of a variety of basins showing a range of habitat health form "Healthy" (supportive of eelgrass, infaunal communities and with little oxygen stress) to "Degraded" (absence of eelgrass and benthic animals and periodic hypoxia/anoxia). There appears to be a clear relationship between habitat quality and the level of nitrogen enrichment. The less well flushed enclosed basins tend to be focal points for watershed nitrogen inputs and have relatively lower tidal flushing rates and greater habitat impairment. In contrast, the larger basins and areas near the tidal inlet have a range in habitat quality, Moderately Impaired to Healthy, related to their flushing rate and depth.

The spatial distribution of habitat quality among the Pleasant Bay sub-embayments shows significant spatial variation, typical of other embayments within the MEP region. Although there are a large number of sub-embayments to the Pleasant Bay System, the habitat health or impairment associated with each of the key indicators (oxygen/chlorophyll a, eelgrass, infauna communities) tends to follow the 4 classifications listed below based upon the basin type:

(A) small enclosed basin (Meetinghouse Pond, Lonnies Pond, Areys Pond, Round Cove, Quanset Pond, Paw Wah Pond, Upper Muddy Creek),
(B) moderate sized tributary sub-embayment (The River, Muddy Creek),
(C) salt marsh dominated tidal sub-estuary (Pochet),
(D) large lagoonal estuarine basin (Little Pleasant Bay, Pleasant Bay, Chatham Harbor).

The underlying quantitative data is presented on nitrogen (Section VI.1.3), oxygen and chlorophyll *a* (Section VII.2), eelgrass (Section VII.3), and benthic infauna (Section VII.4).

The effect of nitrogen enrichment is to cause oxygen depletion; however, with increased phytoplankton (or epibenthic algae) production, oxygen levels will rise in daylight to above atmospheric equilibration levels in shallow systems (generally ~7-8 mg L^{-1} at the mooring sites). The clear evidence of oxygen levels above atmospheric equilibration indicates that the upper tidal reaches of the Pleasant Bay System (particularly in the terminal sub-embayments are eutrophic.

The extent of oxygen related stress among the Pleasant Bay sub-embayments showed significant spatial variation, typical of other embayments within the MEP region. Although there are a large number of sub-embayments to the Pleasant Bay System, the habitat impairment associated with oxygen depletion tended to follow the 4 groups mentioned above.

The general pattern is for a high level of oxygen stress (frequent hypoxia or anoxia) in the bottomwaters of the small enclosed basins (group A) which tend to have higher nitrogen levels and high rates of sediment metabolism, associated with their circulation and focus of watershed nitrogen loads. The Meetinghouse Pond basin and outlet channel, Lonnies Pond and its outlet channel, the Areys Pond outlet channel (Namequoit River), Quanset Pond all showed significant levels of oxygen depletion were routinely hypoxic and except for Quanset Pond levels were frequently <2 mg/L. In the same group of enclosed basins, Areys Pond, Paw Wah Pond and upper Muddy Creek showed frequent anoxia (absence of oxygen). Among the enclosed basins only Round Cove showed only mild hypoxia with levels above 4 mg/L and generally above 5 mg/L during the full deployment.

In contrast, the salt marsh dominated tidal creek of Pochet (group C) showed frequent oxygen depletions to 3-4 mg/L, but was generally above 4 mg/L. The oxygen conditions in Pochet creek are consistent with the biogeochemistry of salt marshes. Salt marsh creeks (that do not empty at low tide) frequently become hypoxic in summer as a result of the high organic matter loading associated with marshes. Even pristine salt marshes can exhibit this behavior.

The large main basins of the lagoonal estuarine component (group D) showed oxygen conditions consistent with their rates of sediment metabolism associated with their deep waters and depositional nature (Little Pleasant Bay, Pleasant Bay) or their high tidal velocities (Chatham Harbor and eastern channel form Chatham Harbor to Little Pleasant Bay, channel between Strong Island and Bassing Harbor). The Upper Pleasant Bay at Namequoit Point showed oxygen levels frequently declining to 4-5 mg/L and the western most basin of Pleasant Bay (between Round Cove and Muddy Creek) had a single event to 2-4 mg/L, although was generally >5 mg/L. Approaching Chatham Harbor oxygen conditions improved (see Strong Island results), with oxygen conditions generally >6 mg/L with short declines to 5 mg/L associated with the outflow of lower oxygen waters from Pleasant Bay.

At present, eelgrass is present within large portions of the Pleasant Bay System, indicative of a system with high habitat quality areas. These eelgrass beds are generally restricted to the larger lagoonal basins, Little Pleasant Bay, Pleasant Bay and Chatham Harbor. There are also smaller eelgrass areas in Pochet and fringing shallow areas in The River and Meetinghouse Pond. The only tributary embayment to Pleasant Bay with significant eelgrass habitat is Bassing Harbor. The basins presently supporting eelgrass habitat also supported habitat in the 1951 historical analysis. However, it is clear from the 1951, 1995 and 2001 temporal sequence that the eelgrass areas in each basin, except Chatham Harbor, are declining in coverage. In The River and Pochet the eelgrass areas were always patchy and in the shallows. By the 2001 survey this pattern continues, but the beds appear to be declining, although they persist.

Virtually all of the small enclosed basins (group A) did not appear to support eelgrass historically and do not support it today, with the exception of the small patch in the shallows of Meetinghouse Pond and in lower Muddy Creek. The general pattern is consistent with the deeper waters of these basins and their location and structure which tends to result in nitrogen enrichment.

The overall pattern of eelgrass distribution and temporal decline in coverage fully consistent with the spatial pattern of nitrogen enrichment (Chapter VI) and oxygen and chlorophyll levels in the various basins (see above). The pattern of decline is typical of environmental changes wrought by nutrient enrichment. It is possible to determine a general idea of short- and long-term rates of change in eelgrass coverage from the mapping data, although there are only 3 surveys. Over the 50 year period1951-2001 the Pleasant Bay System has lost ~583 acres of eelgrass habitat. Interestingly, the rate of loss has been relatively constant at ~11 acres per year. This loss has occurred as watershed nitrogen loading rates gradually increased several fold due to changes in land use within the Pleasant Bay watershed

The Infauna Study indicated that as for the oxygen and chlorophyll indicators and the distribution of sediment metabolism, the enclosed basins (group A, above) are generally significantly to severely impaired relative to benthic infaunal habitat quality. Among the enclosed basins, all were at least significantly impaired. Paw Wah Pond is virtually devoid of benthic animals (only 1-4 individuals per sample) as would be expected from its high level of oxygen stress. Similarly, Areys Pond, Quanset Pond, Upper Muddy Creek supported significantly depleted benthic animal populations, consistent with their nitrogen related oxygen stress. The other enclosed basins were able to support benthic infauna, but the community was dominated by opportunistic species indicative of very high organic matter loading (Lonnies Pond, Meetinghouse Pond outlet channel) or by intermediate stress indicators. The dominance of these intermediate indicators in The River, Round Cove, Meetinghouse Pond suggests that these systems, which also showed only moderate oxygen stress, are only moderately beyond their nitrogen loading limits (Chapter VII).

The larger lagoonal basins of Little Pleasant Bay generally supported infaunal communities indicative of a moderate level of stress from organic matter loading and oxygen depletion. However, the pattern was for a decrease in habitat quality moving from the marginal to depths. This pattern is typical of a system near, but beyond its nitrogen loading limit, where organic matter deposition in the deep basin areas is the proximate cause of the impairment of benthic habitat quality. Chatham Harbor habitat supported only moderate numbers of individuals and species, but this appeared to result from the dynamic nature of the bottom sediments (unstable bottom), due to the high tidal velocities, rather than nutrient related impairment.

3. Conclusions of the Analysis

The threshold nitrogen level for an embayment represents the average watercolumn concentration of nitrogen that will support the habitat quality being sought. The watercolumn nitrogen level is ultimately controlled by the integration of the watershed nitrogen load, the nitrogen concentration in the inflowing tidal waters (boundary condition) and dilution and flushing via tidal flows. The water column nitrogen concentration is modified by the extent of sediment regeneration and by direct atmospheric deposition.

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

Watershed nitrogen loads (Tables ES-1 and ES-2) for the Pleasant Bay embayment system was comprised primarily of wastewater nitrogen. Land-use and wastewater analysis found that generally about 70%-80% of the controllable watershed nitrogen load to the embayment was from wastewater.

Based upon the significant historical and present eelgrass habitat within the Pleasant Bay System, 2400 acres and 1800 acres respectively (Chapter VII), eelgrass was selected as the target for the development of the site-specific nitrogen threshold. In addition, a secondary threshold supportive of benthic animal communities (infauna) was developed in areas that do not have documented eelgrass habitat. The eelgrass threshold applies to the sentinel station (and secondary eelgrass station in Ryders Cove) and the secondary "check" thresholds for infauna habitat is for the smaller sub-basins not naturally supportive of eelgrass based on historical records.

The MEP's previous analysis of Bassing Harbor found very high levels of dissolved organic nitrogen within the embayment's waters (based upon data from the Chatham and Pleasant Bay Alliance Water Quality Monitoring Programs). While some portion of the dissolved organic nitrogen is actively cycling, the vast majority is refractory (non-biologically active) within the timeframe of the flushing of the Pleasant Bay System. The result is that the dissolved organic nitrogen presents a large non-active pool generally separate from the nitrogen fractions active in eutrophication (i.e. ammonium and nitrate+nitrite, particulate organic nitrogen). The biologically active nitrogen pools are represented by the species directly available to phytoplankton and algae (plant available nitrogen), ammonium and nitrate+nitrite, and the particulate organic nitrogen comprised primarily of phytoplankton (live and dead). Together this nitrogen group is termed bioactive nitrogen. Given the large dissolved organic nitrogen pool within Pleasant Bay the MEP Technical Team adopted the same approach used previously for the TMDL analysis of Bassing Harbor. The threshold was developed based upon the bioactive nitrogen pool, which appears to be relatively consistent between embayments both within and outside of Pleasant Bay, and then the bioactive threshold was transformed to the total nitrogen level by adding back in the dissolved organic nitrogen concentration derived for the site from direct measurements.

The threshold nitrogen levels for the Pleasant Bay embayment system in the Towns of Brewster, Chatham, Harwich and Orleans were determined as follows:

Pleasant Bay Threshold Nitrogen Concentrations

- While there is significant variation in the dissolved organic nitrogen levels, hence total nitrogen levels supportive of healthy eelgrass habitat, the level of bioactive nitrogen supportive of this habitat appears to be relatively constant. Therefore, the MEP Technical Team set a single eelgrass threshold based upon stable eelgrass beds, tidally averaged bioactive N levels and the stability of eelgrass as depicted in coverages from 1951-2001. The eelgrass threshold was set at 0.16 mg bioactive N/L based upon the Chatham (Dec 2003 MEP report) analysis for Bassing Harbor. That report for Bassing Harbor indicated a bioactive level for high quality eelgrass habitat of 0.160 mg bioactive N/L based upon Healthy eelgrass community in both Bassing Harbor at 0.135 bioactive N/L and in Stage Harbor at 0.160 bioactive N/L (Oyster River Mouth). The higher value was used as the eelgrass habitat in Bassing Harbor was below its nitrogen loading limit at that time. Taking into consideration the analysis of the Pleasant Bay System, the bioactive nitrogen threshold of 0.160 mg N/L yields an equivalent Total Nitrogen Threshold for the Bassing Harbor Sub-embayment (average upper and lower Ryders Cove stations) of 0.523 mg N L^{-1}. This value is very close to the previous Bassing Harbor specific threshold range of 0.527-0.552 mg N L^{-1}. The slight shift in threshold level results from the greatly expanded water quality database for the present versus previous analysis. The nitrogen boundary condition (concentration of N in inflowing tidal waters from Pleasant Bay) for the Bassing Harbor System is 0.45 mg N L^{-1}.

- The sentinel station for the Pleasant Bay System based on a nitrogen threshold targeting restoration of eelgrass was placed within the uppermost reach of Little Pleasant Bay (PBA-12) near the inlets to The River and Pochet. The threshold bioactive nitrogen level at this site (as for Ryders Cove) is 0.160 mg bioactive N L^{-1}. Based upon the background dissolved organic nitrogen average of upper Little Pleasant Bay and Lower Pochet 0.563 mg N L^{-1} and the bioactive threshold value, the total nitrogen level at the sentinel station (PBA-12) is 0.723 mg N L^{-1}. The restoration goal is to improve the eelgrass habitat throughout Little Pleasant Bay and the historic distribution in Pleasant Bay, which will see lower nitrogen levels when the threshold is reached. In addition, the fringing eelgrass beds within The River and within Pochet should also be restored, as they are in shallower water than the nearby sentinel site and therefore are able to tolerate slightly higher watercolumn nitrogen levels. Moreover, the same threshold bioactive nitrogen level should be met for the previous sentinel station (upper Ryders Cove) in Bassing Harbor System when levels are achieved at the sentinel station in upper Little Pleasant Bay. However, given the partial independence of the Bassing Harbor sub-embayment system relative to the greater Pleasant Bay System (i.e. its own local watershed nitrogen load plays a critical role in its health), the upper Ryders Cove sentinel station should be maintained as the guide for this sub-embayment to Pleasant Bay. It should also be noted that while the bioactive threshold is the same at both sites, the Total Nitrogen level in Ryders Cove is 0.523 mg N L^{-1}, due to the lower dissolved organic nitrogen levels in the lower Bay.

- While eelgrass restoration is primary nitrogen management goal within the Pleasant Bay System, there are small basins which do not appear to have historically (1951) supported eelgrass habitat. For these sub-embayments, restoration and maintenance of healthy animal communities is the management goal. At present, moderately impaired infaunal communities are present in Ryders Cove (PBA-03) at tidally averaged bioactive nitrogen levels of 0.244 mg N L^{-1}. Similarly, there are moderately impaired infaunal communities, designated primarily by the dominance of amphipods (amphipod mats) in most of the 8 sub-embayments of focus. These communities are present adjacent the inlet to Lonnies Pond (in The River Upper) at bioactive nitrogen levels of 0.217 mg N L^{-1}, in the Namequoit River at 0.216-0.239 mg N L^{-1} and in Round Cove at mg N L^{-1} at 0.239 mg N L^{-1}. These communities can be found at even higher levels in the fringing shallow areas of deep basins like Areys Pond (0.299 mg N L^{-1}) and Meetinghouse Pond (0.411 mg N L^{-1}). Very shallow waters tend to minimize oxygen depletion that severely stress infaunal communities in deeper basins. Paw Wah Pond is periodically hypoxic and as a result does not presently support infaunal habitat. These data are at higher bioactive nitrogen levels than the healthy infaunal habitat in the lower Pochet Basin (WMO-03) at 0.178 mg N L^{-1}. It appears that the infaunal threshold lies between 0.18 and 0.22 mg N L^{-1} tidally averaged bioactive nitrogen. Based upon the animal community and nitrogen analysis discussed in Chapter VIII, the restoration goal for the 8 small tributary sub-basin systems to Pleasant Bay is to restore a healthy habitat to the full basin in the shallower or more open waters and to the margins in the deep drowned kettles that periodically stratify. This would argue for a bioactive nitrogen threshold of 0.21 mg N L-1, lower than the lowest station with significant amphipod presence. Translation to Total Nitrogen is presented in detail in Chapter VIII.

- Development of nitrogen load reductions needed to meet the threshold concentration of 0.16 mg/l bioactive nitrogen (DIN+PON) in Ryders Cove (the average of PBA-03 and CM-13) and Upper Little Pleasant Bay (PBA-13) focused primarily on septic load removal within the River and Bassing Harbor systems. Due to the relatively large size of the Pleasant Bay system, achieving the primary threshold concentration for the restoration of eelgrass at the sentinel stations alone did not achieve the secondary threshold at the series of small embayments surrounding Pleasant and Little Pleasant Bays. The secondary threshold concentration of 0.21 mg/l bioactive nitrogen (DIN+PON) in Meetinghouse Pond (Outer), Lonnies Pond, Upper Namequoit River, Upper Pochet, Paw Wah Pond, Little Quanset Pound, Round Cove and Lower Muddy Creek required site-specific removal of septic nitrogen from the watersheds directly impacting these sub-embayments. Chapter VIII presents the percent of septic load removed from the various watersheds to achieve both the primary and secondary threshold concentrations of bioactive nitrogen at the sentinel stations

It is important to note that the analysis of future nitrogen loading to the Pleasant Bay 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 useage 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 Pleasant Bay estuarine system is that restoration will necessitate a reduction in the present nitrogen inputs and management options to negate additional future nitrogen inputs.

Table ES-1a. Existing total and sub-embayment nitrogen loads to the estuarine waters of the Pleasant Bay system, observed nitrogen concentrations, and sentinel system threshold nitrogen concentrations. Loads to estuarine waters of Pleasant Bay include both upper watershed regions contributing to 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 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)	Observed Bioactive N Conc. [7] (mg/L)	Threshold Bioactive N Conc. (mg/L)
PLEASANT BAY SYSTEM										
Meetinghouse Pond	0.693	1.058	5.140	6.197	0.584	14.365	21.146	0.72-0.98	0.28-0.41	
The River – upper	0.526	0.701	2.071	2.773	0.288	6.263	9.324	0.85-0.86	0.22-0.25	0.200[8]
The River – lower	0.756	1.008	2.871	3.879	2.241	10.480	16.600	0.56	0.18	0.160[8]
Lonnies Pond	0.682	0.811	1.630	2.441	0.225	1.591	4.257	0.78	0.28	0.200[8]
Areys Pond	0.468	0.526	0.778	1.304	0.181	5.996	7.480	0.73	0.30	
Namequoit River	0.562	0.726	2.011	2.737	0.523	14.570	17.830	0.73-0.83	0.24-0.30	0.200[8]
Paw Wah Pond	0.233	0.351	1.510	1.860	0.082	3.630	5.572	0.71	0.27	0.200[8]
Pochet Neck	1.233	1.808	6.614	8.422	1.767	-0.791	9.398	0.72-0.78	0.24-0.28	0.200[8]
Little Pleasant Bay	1.660	3.148	4.986	8.134	24.086	37.226	69.446	0.57-0.77	0.14-0.18	
Quanset Pond	0.296	0.378	1.403	1.781	0.170	5.988	7.939	0.56-0.60	0.19-0.21	0.200[8]

[1] assumes entire watershed is forested (i.e., no anthropogenic sources)
[2] composed of non-wastewater loads, e.g. fertilizer and runoff and natural surfaces and atmospheric deposition to lakes
[3] existing wastewater treatment facility discharges to groundwater
[4] composed of combined natural background, fertilizer, runoff, and septic system loadings
[5] atmospheric deposition to embayment surface only
[6] composed of natural background, fertilizer, runoff, septic system atmospheric deposition and benthic flux loadings
[7] average of 2000 – 2005 data, ranges show the upper to lower regions (highest-lowest) of an sub-embayment.
[8] Threshold for sentinel sites correspond to monitoring station locations: The River (upper) WMO-10, The River (mouth) PBA-13, Lonnies Pond PBA-15, Namequoit River WMO-06, Paw Wah Pond PBA-11, Pochet Neck WMO-05, Quanset Pond WMO-12, Round Cove PBA-09, Muddy Creek PBA-05, Ryder Cove PBA-13 and CM-13.

Table ES-1b. Existing total and sub-embayment nitrogen loads to the estuarine waters of the Pleasant Bay system, observed nitrogen concentrations, and sentinel system threshold nitrogen concentrations. Loads to estuarine waters of Pleasant Bay include both upper watershed regions contributing to 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 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)	Observed Bioactive N Conc. [7] (mg/L)	Threshold Bioactive N Conc. (mg/L)
PLEASANT BAY SYSTEM										
Round Cove	0.603	1.063	3.162	4.225	0.170	8.416	12.811	0.71	0.25	0.200[8]
Muddy Creek - upper	1.951	2.825	7.156	9.981	0.162	4.560	14.702	1.26	0.70	
Muddy Creek - lower	1.471	2.137	6.340	8.477	0.205	-1.226	7.457	0.57	0.24	0.200[8]
Pleasant Bay	3.808	14.408	14.874	29.282	37.005	108.821	175.108	0.44-0.73	0.14-0.19	
Bassing Harbor - Ryder Cove	2.003	2.682	7.137	9.819	1.296	9.356	20.471	0.42-0.72	0.16-0.25	0.160[8]
Bassing Harbor - Frost Fish Creek	0.400	0.704	2.200	2.904	0.096	-0.154	2.846	1.16	0.35	
Bassing Harbor - Crows Pond	0.534	0.893	3.326	4.219	1.389	0.612	6.220	0.84	0.21	
Bassing Harbor	0.233	0.268	1.400	1.668	1.071	-4.976	-2.237	0.49	0.12	
Chatham Harbor	1.838	2.904	14.195	17.099	14.153	-40.208	-8.956	0.35-0.43	0.10-0.11	
Pleasant Bay System Total	**19.951**	**38.400**	**88.803**	**127.203**	**85.693**	**184.519**	**397.415**	**0.35-1.26**	**0.10-0.70**	**0.160[8]**

[1] assumes entire watershed is forested (i.e., no anthropogenic sources)
[2] composed of non-wastewater loads, e.g. fertilizer and runoff and natural surfaces and atmospheric deposition to lakes
[3] existing wastewater treatment facility discharges to groundwater
[4] composed of combined natural background, fertilizer, runoff, and septic system loadings
[5] atmospheric deposition to embayment surface only
[6] composed of natural background, fertilizer, runoff, septic system atmospheric deposition and benthic flux loadings
[7] average of 2000 – 2005 data, ranges show the upper to lower regions (highest-lowest) of an sub-embayment.
[8] Threshold for sentinel sites correspond to monitoring station locations: The River (upper) WMO-10, The River (mouth) PBA-13, Lonnies Pond PBA-15, Namequoit River WMO-06, Paw Wah Pond PBA-11, Pochet Neck WMO-05, Quanset Pond WMO-12, Round Cove PBA-09, Muddy Creek PBA-05, Ryder Cove PBA-13 and CM-13.

Table ES-2a. Present Watershed Loads, Thresholds Loads, and the percent reductions necessary to achieve the threshold concentrations identified for the Pleasant Bay 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)	Percent watershed reductions needed to achieve threshold load levels
PLEASANT BAY SYSTEM					
Meetinghouse Pond	6.197	1.058	0.584	7.857	-82.9%
The River - upper	2.773	1.737	0.288	4.102	-37.4%
The River - lower	3.879	2.444	2.241	8.517	-37.0%
Lonnies Pond	2.441	1.626	0.225	1.304	-33.4%
Areys Pond	1.304	0.915	0.181	4.929	-29.8%
Namequoit River	2.737	1.732	0.523	12.232	-36.7%
Paw Wah Pond	1.860	0.728	0.082	2.665	-60.9%
Pochet Neck	8.422	4.123	1.767	-0.622	-51.0%
Little Pleasant Bay	8.134	5.878	24.086	35.222	-27.7%
Quanset Pond	1.781	1.079	0.170	4.787	-39.4%

(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).

Table ES-2b. Present Watershed Loads, Thresholds Loads, and the percent reductions necessary to achieve the threshold concentrations identified for the Pleasant Bay 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)	Percent watershed reductions needed to achieve threshold load levels
PLEASANT BAY SYSTEM					
Round Cove	4.225	2.960	0.170	6.739	-29.9%
Muddy Creek - upper	9.981	4.614	0.162	2.700	-53.8%
Muddy Creek - lower	8.477	2.137	0.205	-0.710	-74.8%
Pleasant Bay	29.282	21.845	37.005	96.170	-25.4%
Bassing Harbor - Ryder Cove	9.819	4.466	1.296	6.705	-54.5%
Bassing Harbor - Frost Fish Creek	2.904	0.704	0.096	-0.087	-75.8%
Bassing Harbor - Crows Pond	4.219	4.219	1.389	0.612	0.0%
Bassing Harbor	1.668	1.668	1.071	-4.460	0.0%
Chatham Harbor	17.099	17.099	14.153	-38.398	0.0%
Pleasant Bay System Total	**127.203**	**81.032**	**85.693**	**150.264**	**-36.3%**

(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.