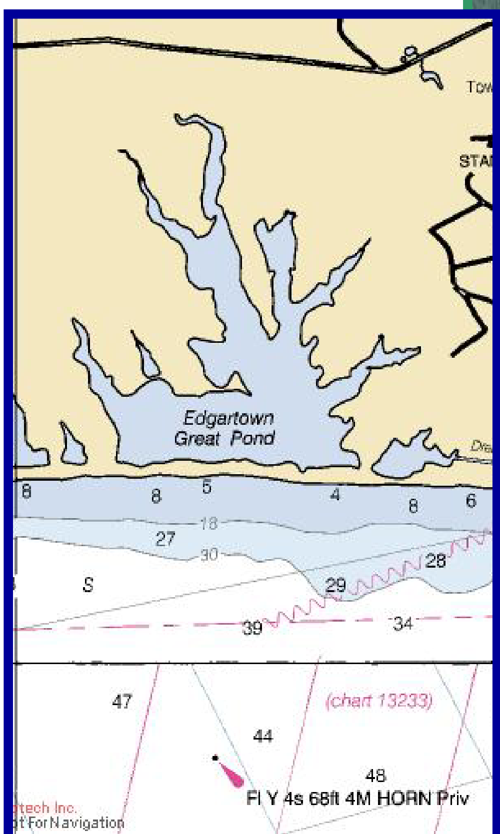
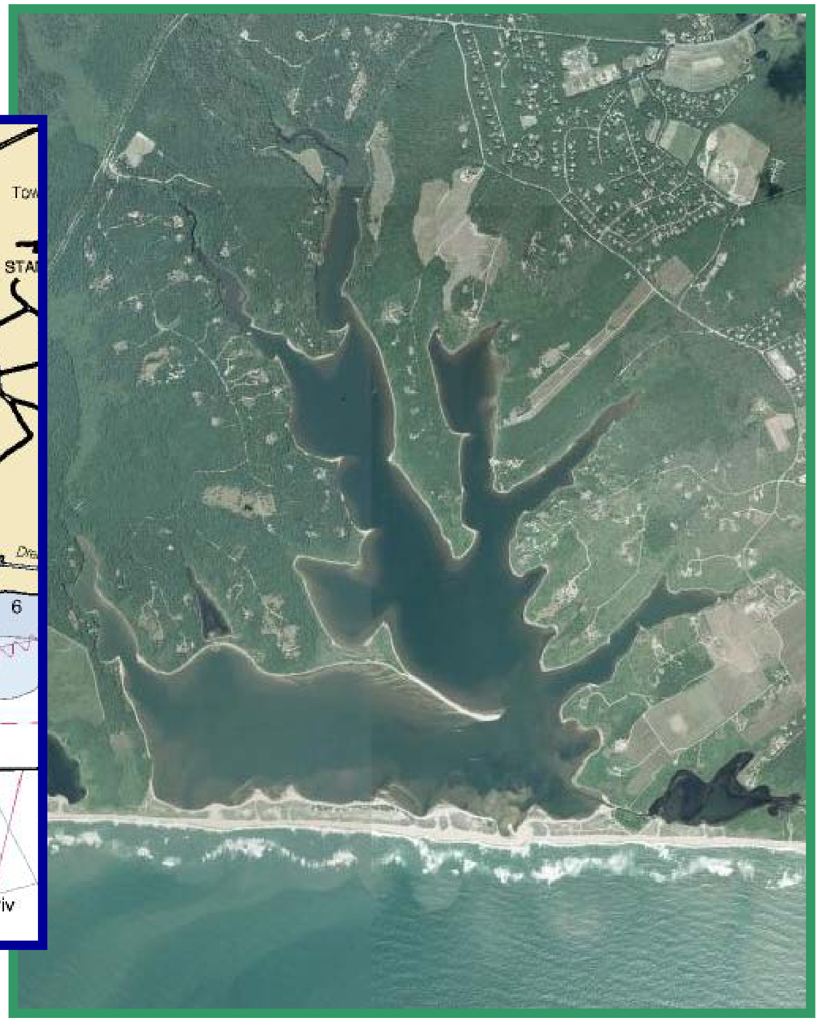
# Massachusetts Estuaries Project

## Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Threshold for the Edgartown Great Pond System, Edgartown, MA



University of Massachusetts Dartmouth
School of Marine Science and Technology

Massachusetts Department of
Environmental Protection

*FINAL REPORT – December 2008*

# Massachusetts Estuaries Project

## Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Threshold for the Edgartown Great Pond System, Edgartown, MA

**FINAL REPORT – December 2008**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# Massachusetts Estuaries Project

# Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Edgartown Great Pond System, Edgartown, 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 Edgartown Great Pond embayment system, a coastal embayment within the Town of Edgartown, Massachusetts on the Island of Martha's Vineyard. Analyses of the Edgartown Great Pond embayment system was performed to assist the Town with up-coming nitrogen management decisions associated with the Towns' current and future wastewater planning efforts, as well as wetland restoration, anadromous fish runs, shell fishery, open-space, and Pond maintenance programs. As part of the MEP approach, habitat assessment was conducted on the embayment based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. Nitrogen loading thresholds for use as goals for watershed nitrogen management are the major product of the MEP effort. In this way, the MEP offers a science-based management approach to support the Town of Edgartown 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 Edgartown Great Pond 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 and Pond opening alternatives (to be developed by the Town) for the restoration of the Edgartown Great Pond 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 Edgartown Great Pond embayment system within the Town of Edgartown is at risk of eutrophication (over enrichment) from enhanced nitrogen loads entering through groundwater from the increasingly developed watershed to this coastal system. Eutrophication is a process that occurs naturally and gradually over a period of tens or hundreds of years. However, human-related (anthropogenic) sources of nitrogen may be introduced into ecosystems at an accelerated rate that cannot be easily absorbed, resulting in a phenomenon known as cultural eutrophication. In both marine and freshwater systems, cultural eutrophication results in degraded water quality, adverse impacts to ecosystems, and limits on the use of water resources.

The Town of Edgartown, relatively early on, recognized the severity of the problem of eutrophication and the need for watershed nutrient management and as such has over the years embarked on coordinated data gathering efforts with the Martha's Vineyard Commission and SMAST scientists. This local concern has led to the conduct of several studies of nitrogen loading to the system. Key in these efforts has been the Edgartown Great Pond Water Quality Monitoring Program, spearheaded by the MVC and supported by private, municipal, county and state funds (most recently Massachusetts 604(b) grant program) with technical assistance by the Coastal Systems Program at SMAST-UMD. This effort provided the quantitative watercolumn nitrogen data (1996-2006) required for the implementation of the MEP's Linked Watershed-Embayment Approach used in the present study.

Since the initial results of the Water Quality Monitoring Program and the land-use studies indicated that parts of the Edgartown Great Pond system were presently impaired by land-derived nitrogen inputs, the Town of Edgartown and Martha's Vineyard Commission (MVC) undertook additional site-specific data collection that has served to support MEP's ecological assessment and modeling project. The effort was associated with the Town's Wastewater Treatment Facility upgrade effort. The common focus of the Town of Edgartown - MVC efforts in the Edgartown Great Pond system has been to gather site-specific data on the current nitrogen related water quality throughout the pond system and determine its relationship to watershed nitrogen loads. All the historic efforts to begin to understand the nutrient over-enrichment threat to the Edgartown Great Pond system serve as a foundation to the current MEP Nutrient Threshold Analysis that incorporates pertinent elements of previous work with high level hydrodynamic and water quality modeling in order to determine appropriate restoration targets for this coastal system.

The Town of Edgartown, the Martha's Vineyard Commission and other working groups have recognized that a rigorous scientific approach yielding site-specific nitrogen loading targets was required for decision-making and alternatives analysis. The completion of this multi-step process has taken place under the programmatic umbrella of the Massachusetts Estuaries Project, which is a partnership effort between all MEP collaborators and the Town. The modeling tools developed as part of this program provide the quantitative information necessary for the Towns' nutrient management groups to predict the impacts on water quality from a variety of proposed management scenarios.

***Nitrogen Loading Thresholds and Watershed Nitrogen Management:*** Realizing the need for scientifically defensible management tools has resulted in a focus on determining the aquatic system's assimilative capacity for nitrogen. The highest-level approach is to directly link the watershed nitrogen inputs with embayment hydrodynamics to produce water quality results that can be validated by water quality monitoring programs. This approach when linked to state-of-the-art habitat assessments yields accurate determination of the "allowable N concentration increase" or "threshold nitrogen concentration". These determined nitrogen concentrations are then directly relatable to the watershed nitrogen loading, which also accounts for the spatial distribution of the nitrogen sources, not just the total load. As such, changes in nitrogen load from differing parts of the embayment watershed can be evaluated relative to the degree to which those load changes drive embayment water column nitrogen concentrations toward the "threshold" for the embayment system. To increase certainty, the "Linked" Model is independently calibrated and validated for each embayment.

***Massachusetts Estuaries Project Approach:*** The Massachusetts Department of Environmental Protection (DEP), the University of Massachusetts – Dartmouth School of Marine Science and Technology (SMAST), and others including the Cape Cod Commission (CCC) have undertaken the task of providing a quantitative tool to communities throughout southeastern Massachusetts (the Linked Watershed-Embayment Management Model) for nutrient management in their coastal embayment systems. Ultimately, use of the Linked Watershed-Embayment Management Model tool by municipalities in the region results in effective screening of nitrogen reduction approaches and eventual restoration and protection of valuable coastal resources. The MEP provides technical guidance in support of policies on nitrogen loading to embayments, wastewater management decisions, and establishment of nitrogen Total Maximum Daily Loads (TMDLs). A TMDL represents the greatest amount of a pollutant that a waterbody can accept and still meet water quality standards for protecting public health and maintaining the designated beneficial uses of those waters for drinking, swimming, recreation and fishing. The MEP modeling approach assesses available options for meeting selected nitrogen goals that are protective of embayment health and achieve water quality standards.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach, which links watershed inputs with embayment circulation and nitrogen characteristics.

The Linked Model builds on well-accepted basic watershed nitrogen loading approaches such as those used in the Buzzards Bay Project, the CCC models, and other relevant models. However, the Linked Model differs from other nitrogen management models in that it:

- requires site-specific measurements within each watershed and embayment;
- uses realistic "best-estimates" of nitrogen loads from each land-use (as opposed to loads with built-in "safety factors" like Title 5 design loads);
- spatially distributes the watershed nitrogen loading to the embayment;
- accounts for nitrogen attenuation during transport to the embayment;
- includes a 2D or 3D embayment circulation model depending on embayment structure;
- accounts for basin structure, tidal variations, and dispersion within the embayment;

- includes nitrogen regenerated within the embayment;
- is validated by both independent hydrodynamic, nitrogen concentration, and ecological data;
- is calibrated and validated with field data prior to generation of “what if” scenarios.

The Linked Model Approach’s greatest assets are its ability to be clearly calibrated and validated, and its utility as a management tool for testing “what if” scenarios for evaluating watershed nitrogen management options.

For a comprehensive description of the Linked Model, please refer to the *Full Report: Nitrogen Modeling to Support Watershed Management: Comparison of Approaches and Sensitivity Analysis*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm. A more basic discussion of the Linked Model is also provided in Appendix F of the *Massachusetts Estuaries Project Embayment Restoration Guidance for Implementation Strategies*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm. The Linked Model suggests which management solutions will adequately protect or restore embayment water quality by enabling towns to test specific management scenarios and weigh the resulting water quality impact against the cost of that approach. In addition to the management scenarios modeled for this report, the Linked Model can be used to evaluate additional management scenarios and may be updated to reflect future changes in land-use within an embayment watershed or changing embayment characteristics. In addition, since the Model uses a holistic approach (the entire watershed, embayment and tidal source waters), it can be used to evaluate all projects as they relate directly or indirectly to water quality conditions within its geographic boundaries. Unlike many approaches, the Linked Model accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics and accommodates the spatial distribution of these processes. For an overview of several management scenarios that may be employed to restore embayment water quality, see *Massachusetts Estuaries Project Embayment Restoration Guidance for Implementation Strategies*, available for download at http://www.state.ma.us/dep/smerp/smerp.htm.

***Application of MEP Approach:*** The Linked Model was applied to the Edgartown Great Pond embayment system by using site-specific data collected by the MEP and water quality data from the Water Quality Monitoring Program conducted by the Town of Edgartown and the Martha’s Vineyard Commission, with technical guidance from the Coastal Systems Program at SMAST (see Chapter II). Evaluation of upland nitrogen loading was conducted by the MEP, data was provided by the Town of Edgartown and the Martha’s Vineyard Commission, and watershed boundaries delineated by USGS, the SMAST-MEP Technical Team and the Martha’s Vineyard Commission. This land-use data was used to determine watershed nitrogen loads within the Edgartown Great Pond embayment system and each of the systems sub-embayments as appropriate (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 as defined by the pond breaching regime. 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 and changes is groundwater levels once breaches were closed.

A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents, water elevations and pond openings was employed for the Edgartown Great Pond embayment system. Once the hydrodynamic properties of the estuarine system were computed, two-dimensional water quality model simulations were used to predict the dispersion of the nitrogen at current loading rates. Using standard dispersion relationships for estuarine systems of this type, the water quality model and the hydrodynamic model was then integrated in order to generate estimates regarding the spread of total nitrogen from the site-specific hydrodynamic properties. The distributions of nitrogen loads from watershed sources were determined from land-use analysis. Boundary nutrient concentrations in Atlantic Ocean source waters were taken from water quality monitoring data. Measurements of current salinity distributions throughout the estuarine waters of the Edgartown Great Pond embayment system was used to calibrate the water quality model, with validation using measured nitrogen concentrations (under existing loading conditions). The underlying hydrodynamic model was calibrated and validated independently using water elevations measured in time series throughout the embayments.

***MEP Nitrogen Thresholds Analysis:*** The threshold nitrogen level for an embayment represents the average water column concentration of nitrogen that will support the habitat quality being sought. The water column nitrogen level is ultimately controlled by the watershed nitrogen load and the nitrogen concentration in the inflowing tidal waters (boundary condition). The water column nitrogen concentration is modified by the extent of sediment regeneration. Threshold nitrogen levels for the embayment systems in this study were developed to restore or maintain SA waters or high habitat quality. High habitat quality was defined as supportive of eelgrass and infaunal communities. Dissolved oxygen and chlorophyll a were also considered in the assessment.

The nitrogen thresholds developed in Section VIII-2 were used to determine the amount of total nitrogen mass loading reduction required for restoration of eelgrass and infaunal habitats in the Edgartown Great Pond system. Total nitrogen thresholds derived in Section VIII.1 were used to adjust the calibrated constituent transport model developed in Section VI. Watershed nitrogen loads were sequentially lowered using: 1) reductions in septic effluent discharges, 2) reduction in nitrogen loading from the WWTP due to recent plant upgrades and 3) modified breaching schedules, until the nitrogen levels reached the threshold level at the sentinel stations chosen for the Edgartown Great Pond system. It is important to note that load reductions can be produced by reduction of any or all sources or by increasing the natural attenuation of nitrogen within the freshwater systems to the embayment. The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the community. The presentation is 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 Edgartown Great Pond embayment system in the Town of Edgartown. Future water quality modeling scenarios should be run which incorporate the spectrum of strategies that result in nitrogen loading reduction to the embayment. The MEP analysis has initially focused upon nitrogen loads from on-site septic systems and the WWTP 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 and WWTP nitrogen loads generally represent 80% of the controllable watershed load to the Edgartown Great Pond 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 the Edgartown Great Pond system based upon available water quality monitoring data, historical changes in eelgrass distribution, time-series water column oxygen measurements, and benthic community structure. At present, the Edgartown Great Pond System is generally showing moderately to significantly impaired habitat for infauna with the lower basin also supporting moderately impaired eelgrass habitat. There is a slight gradient in the infaunal habitat quality with the upper basin and its tributary coves showing greater impairment than he large lagoonal basin running parallel to the barrier beach. All of the habitat indicators are consistent with this evaluation of the whole of system as presented in Chapter VII.

The effect of nitrogen enrichment is to cause oxygen depletion; however, with increased phytoplankton (or epibenthic algae) production, oxygen levels will rise in daylight to above atmospheric equilibration levels in shallow systems (generally ~7-8 mg $L^{-1}$ at the mooring sites). Overall, Edgartown Great Pond is showing a moderate level of habitat impairment (eelgrass and infaunal animals) from summer oxygen depletion and organic enrichment primarily from phytoplankton production, parameters directly related to nutrient inputs. The level of oxygen depletion and the magnitude of daily oxygen excursions and chlorophyll-a levels indicate moderately nutrient enriched waters and impaired habitat quality within the upper and lower basins of the system. The oxygen data is consistent with organic matter enrichment, primarily from phytoplankton production as seen from the parallel measurements of chlorophyll-a. The periodic elevated oxygen levels observed in Edgartown Great Pond provides additional evidence that this system is presently receiving nitrogen inputs above the threshold required to maintain high quality estuarine habitat.

The measured levels of oxygen depletion in the bottom waters of Wintucket Cove and the lower main basin to Edgartown Great Pond indicate that this Great Salt Pond is currently organic matter enriched, primarily through in situ production by phytoplankton. Moreover, the system periodically experiences moderate levels of oxygen stress, consistent with nitrogen enrichment.

At present, eelgrass beds are not present in the Edgartown Great Pond System, although sparse patches of eelgrass can still be observed within the lower basin. The current lack of eelgrass beds and the remaining sparse patches are consistent with the elevated chlorophyll-a concentrations, the low dissolved oxygen levels and water column nitrogen concentrations within this system. That the remaining patches are found within the shallow margins versus within the "deeper" regions of the lower basin (1951 versus 1997-2002) also supports the contention that the mechanism of loss is nitrogen enrichment.

While water quality parameters, primarily related to nitrogen, chlorophyll and oxygen are the major factors causing shifts in eelgrass habitat quality within this system, water depth is also important in determining potential habitat locations for restoration. All of the locations with eelgrass (1951-2006) are <1.5 meter depth. The more recent field observations suggest eelgrass at depths of 0.5 - 1.0 meters, with the shallower depth potentially related to low water stand when the inlet is opened and the deeper depth being determined by light penetration when the inlet is closed. The depth of the upper main basin (above Swan Neck) appears to have historically limited eelgrass colonization of this basin. The absence of eelgrass within the Coves, most likely relates to their shallow depth, organic rich sediments and periodic salinity declines.

The overall results of the MEP analysis indicate that eelgrass habitat within Edgartown Great Pond is presently impaired and the eelgrass coverage has declined. While it is not possible to determine the density of the eelgrass beds in 1951 (historic benchmark used in all MEP analyses), it does appear the coverage has declined and that recent eelgrass areas support only sparse colonization by eelgrass plants. The decline of eelgrass beds relative to historical distributions is expected given the elevated nitrogen levels and resulting chlorophyll a and dissolved oxygen depletions within this embayment system.

Overall, the infauna survey indicated that most areas within Edgartown Great Pond are supporting moderate nutrient related infaunal habitat quality. It appears that the upper main basin (above Swan Neck) supports the poorest habitat, moderately to significantly impaired, with similar impairment in the major tributary coves (Janes Cove, Wintucket Cove, Mashacket Cove). The lower large lagoonal basin and one of the small associated tributary coves (Jobs Neck Cove) supported slightly higher quality habitat, although moderate impairment by nitrogen and organic enrichment was clearly observed in these basins as well. Both of the lower eastern coves (Turkeyland Cove and Slough Cove) support infaunal animal habitats of intermediate quality between upper and lower basin conditions.

The underlying structure of Edgartown Great Pond and its watershed supports the observed spatial variation in infaunal habitat quality. Moreover, the infaunal habitat quality was consistent with the gradients in dissolved oxygen, chlorophyll, nutrients and organic matter enrichment in this system. The results of the MEP analysis indicate that the nitrogen management threshold analysis (Chapter 8) needs to include a lowering of the level of nitrogen enrichment throughout this salt pond for restoration of nitrogen impaired benthic habitats. However, it is important to note that the non-tidal nature of this embayment and the depositional nature of the upper main basin (deep) make benthic habitat within that region of the system particularly sensitive to nitrogen enrichment.

## <u>3. Conclusions of the Analysis</u>

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 this embayment system were developed to restore or maintain SA waters or high habitat quality. In this system, high habitat quality was defined as possibly supportive of eelgrass and supportive of diverse benthic animal communities. Dissolved oxygen and chlorophyll *a* were also considered in the assessment.

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

A major finding of the MEP clearly indicates that a single total nitrogen threshold can not be applied to Massachusetts' estuaries, based upon the results of the Great, Green and Bournes Pond Systems, Popponesset Bay System, the Lewis Bay system, the Hamblin / Jehu

Pond / Quashnet River analysis in eastern Waquoit Bay, the analysis of the Sesachacha Pond and Nantucket Harbor systems as well as the Pleasant Bay and other Nantucket Sound embayments associated with the Town of Chatham. This is almost certainly going to be true for the other embayments within the MEP area, including those on Martha's Vineyard.

The threshold nitrogen levels for the Edgartown Great Pond embayment system in Edgartown were determined as follows:

***Edgartown Great Pond Threshold Nitrogen Concentrations***

- Following the MEP protocol, the restoration target for the Edgartown Great Pond system should reflect both pre-degradation habitat quality and be reasonably achievable. Based upon the assessment data provided in Chapter VII and since the Edgartown Great Pond System does not support strong horizontal gradients (range in total nitrogen levels from 0.58 mg N $L^{-1}$ in the lower basin to <0.63 mg N $L^{-1}$ in the coves, with 0.65 mg N $L^{-1}$ in upper Mashacket Cove), the MEP Technical Team decided to use the average of the five long-term water quality stations to determine a pond-wide threshold (EGP 2,3,5,6,9). This distributed "location" for the threshold stems from the variability at individual sites and the non-tidal nature of this system. These stations are presently showing an average TN level of 0.596 mg N $L^{-1}$ (range = 0.587-0.613 mg N $L^{-1}$).

- While it is certain that historic eelgrass habitat (1951 or earlier) was of a higher quality than at present, it was likely not a high quality habitat due to the systems periodic tidal exchange and "naturally" nitrogen enriched condition. Routine opening of this salt pond was initiated in the 1940's and would have been required for habitat maintenance at that time as well as today. Therefore, habitat restoration in this nutrient enriched system should focus on improving eelgrass habitat within the lower main basin and on full restoration of infaunal habitat quality pond-wide.

- Since the infaunal community at all sites with the Pond are either dominated by organic matter enrichment species or are depleted, comparisons to the muddy basins of other estuarine systems in the MEP study region were relied upon. This type of comparative analysis suggests that a healthy infaunal habitat would clearly be achieved at an average nitrogen level of TN <0.5 mg TN $L^{-1}$. This level was found for Popponesset Bay, where based upon the infaunal analysis coupled with the nitrogen data (measured and modeled), nitrogen levels on the order of 0.4 to 0.5 mg TN $L^{-1}$ were found to be supportive of high infaunal habitat quality in that system. Similarly, in the deeper basins of Three Bays System, healthy infaunal areas are found at nitrogen levels of TN <0.42 mg TN $L^{-1}$ (Cotuit Bay and West Bay) and in Eel Pond (Bourne) at a TN level of 0.45 mg TN $L^{-1}$. Conversely, moderate impairment of infaunal habitat has routinely been documented by the MEP in areas where nitrogen levels of TN >0.5 mg TN $L^{-1}$ were observed

- The MEP Technical Team determined that infaunal habitat quality within Edgartown Great Pond is responding to nitrogen levels in a manner consistent with other embayments within the MEP study region, as seen by the present TN level of ~0.6 mg TN $L^{-1}$ translating to a moderately impaired infaunal community. The integration of all information available clearly supports a nitrogen threshold for restoration of healthy infaunal habitat within Edgartown Great Pond of 0.5 mg N $L^{-1}$ (time averaged). The modeling simulations in Section VIII-3 targeted the 0.5 mg TN $L^{-1}$ for healthy habitat.

This significant lowering of average TN levels within the lower basin of Edgartown Great Pond will also improve eelgrass habitat within the historic 1951 coverage area and likely in the western portion of the lower basin as well.

It is important to note that the analysis of future nitrogen loading to the Edgartown Great Pond estuarine system focuses upon modification of pond breaching practices as well as additional shifts in land-use and associated nutrient loading to the pond. However, the MEP analysis indicates that significant increases in nitrogen loading can occur under present land-uses, due to shifts in occupancy, shifts from seasonal to year-round usage and increasing use of fertilizers (presently less than half of the parcels use lawn fertilizers). This is besides the fact that based on the MEP analysis, overall, buildout additions within the entire Edgartown Great Pond System watershed will increase the unattenuated nitrogen loading rate to the pond by 44%. 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 Edgartown Great Pond estuarine system is that restoration will necessitate a reduction in the present nitrogen inputs, modifying breach schedule and management options to negate additional future nitrogen inputs.

Table ES-1. Existing total and sub-embayment nitrogen loads to the estuarine waters of the Edgartown Great Pond system, observed nitrogen concentrations, and sentinel system threshold nitrogen concentrations. Loads to estuarine waters of the Great Pond system include both upper watershed regions contributing to the major surface water inputs.

| | 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) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Edgartown Great Pond System Total** | 2.759 | 8.537 | 15.167 | 6.586 | 30.282 | 11.445 | 20.445 | 62.172 | **0.58-0.71** | **0.500** |

[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 discharge to groundwater (Mashacket Cove)
[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 2003 and 2006, ranges show the upper to lower regions (highest-lowest) of the system.
[8] average TN concentration of whole system through summer months.

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

| | Present Watershed Load [1] (kg/day) | Target Threshold Watershed Load [2] (kg/day) | Direct Atmospheric Deposition (kg/day) | Benthic Flux Net [3] (kg/day) | TMDL [4] (kg/day) | Percent watershed reductions needed to achieve threshold load levels |
|---|---|---|---|---|---|---|
| **Edgartown Great Pond System Total** | 30.282 | 21.058 | 11.445 | 13.559 | 46.062 | -17.8% |

(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.

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The Massachusetts Estuaries Project Technical Team would like to acknowledge the contributions of the many individuals who have worked tirelessly for the restoration and protection of the critical coastal resources of the Edgartown Great Pond Embayment and supported the application of the Linked Watershed-Embayment Model to Determine the Critical Nitrogen Loading Threshold for this estuarine system. Without these stewards and their efforts, this project would not have been possible.

First and foremost we would like to recognize and applaud the significant time and effort in data collection and discussion spent by members of the Martha's Vineyard Commission/Edgartown Shellfish Department's Water Quality Monitoring Program. These individuals gave of their time to develop a consistent and sound nutrient related water quality from this system for over almost a decade, without which the present analysis would not have been possible. Of particular note has been the efforts of the Monitoring Coordinator, Bill Wilcox, who has spent countless hours ensuring a scientifically defensible monitoring program and reviewing data and information with MEP Technical Team members.

Staff from the Martha's Vineyard Commission and the Town of Edgartown and volunteers from the Martha's Vineyard Ponds Committee have provided essential insights toward this effort. Of particular note has been the efforts of Paul Bagnall (Edgartown Shellfish Constable/Marine Biologist) and Bill Wilcox (MVC Environmental Scientist) as well as Chris Seidel (GIS Specialist) of the MVC who provided critical GIS and land-use data and analysis.

In addition to local contributions, technical, policy and regulatory support has been freely and graciously provided by MaryJo Feurbach and Art Clark of the USEPA; and our MassDEP colleagues: Arleen O'Donnell, Art Screpetis, Rick Dunn, Steve Halterman, and Russ Issacs. We are also thankful for the long hours in the field and laboratory spent by the technical staff, interns and students within the Coastal Systems Program at SMAST-UMD.

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# I. INTRODUCTION

The Edgartown Great Pond Embayment System is a complex estuary located entirely within the Town of Edgartown on the island of Martha's Vineyard, Massachusetts with a southern shore bounded by water from the Atlantic Ocean (Figure I -1). The Edgartown Great Pond watershed is distributed entirely in the Town of Edgartown, with a large region of the upper watershed comprised primarily of "protected" forest land (Martha's Vineyard State Forest. Though it is true that land-uses closest to an embayment generally have greater impact than those in the upper portions of the watershed, which are subject to nitrogen attenuation during transport through natural aquatic systems (e.g. ponds, rivers, wetlands etc.) prior to discharge to the embayment, effective restoration of the Edgartown Great Pond System, will require consideration of all sources of nitrogen load. In the case of the Edgartown Great Pond system quantification of load must also include sources from outside the watershed as discharged from the Wastewater Treatment Facility. That the entire watershed to the Edgartown Great Pond system is contained entirely within the Town of Edgartown makes development and implementation of a comprehensive nutrient management and restoration plan for the pond more tractable as the challenges are not complicated by the municipal constraints of other towns.


Figure I-1. Location of the Edgartown Great Pond system, Island of Martha's Vineyard, Town of Edgartown, Massachusetts. Edgartown Great Pond is a great salt pond, maintained by periodic breaching of the barrier beach to allow exchange with Atlantic Ocean waters.

The nature of enclosed embayments in populous regions brings two opposing elements to bear: as protected marine shoreline they are popular regions for boating, recreation, and land development; as enclosed bodies of water, they may not be readily flushed of the pollutants that they receive due to the proximity and density of development near and along their shores. The large number of sub-embayments (i.e. coves) to the Edgartown Great Pond System greatly increases the shoreline and decreases the travel time of groundwater (and its pollutants) from the watershed recharge areas to bay regions of discharge. As such, the Edgartown Great Pond system is particularly vulnerable to the effects of nutrient enrichment from the watershed, especially considering that circulation is mainly through wind driven mixing in the small tributary sub-embayments, the long shoreline of the pond and the only periodic flushing with "clean" Atlantic Ocean water. In particular, the Edgartown Great Pond system and its sub-embayments along the south shore of Martha's Vineyard are at risk of eutrophication (over enrichment) from high nitrogen loads in the groundwater and runoff from the watershed and numerous sub-watersheds.

The Edgartown Great Pond Embayment System is a complex coastal salt pond estuary, with a single temporary inlet multiple sub-embayments (Jobs Neck Cove, Janes Cove, Wintucket Cove, Mashacket Cove, Turkeyland Cove, Slough Cove). The estuary only occasionally receives tidal waters from the Atlantic Ocean into its large lower main basin based on a breaching schedule set by the Town. Floodwater from the Atlantic Ocean enters the large lower basin of the Pond and circulates through channels and across flats making its way up the pond past the sand spit known as Swan Neck Point, separating Lyles Bay from the main lower basin of Edgartown Great Pond (Figure I-2). Outflow from the pond is through a small herring ladder to Crackatuxet Cove, as recharged "groundwater" through the barrier beach and during the periodic openings to the Atlantic Ocean.

The present Edgartown Great Pond system results from a complex geologic history dominated by glacial processes occurring during the last glaciation of the southeastern Massachusetts region. The late Wisconsinan Laurentide ice sheet reached its maximum extent and southernmost position about 20,000 years before present (BP), as indicated by the presence of terminal moraines on Martha's Vineyard and Nantucket and the southern limit of abundant gravel on the sea floor of Nantucket Sound and Vineyard Sound (Schlee and Pratt, 1970; Oldale, 1992; Uchupi et al., 1996). The lobate ice front was comprised of the Buzzards Bay lobe that deposited the moraine along the western part of Martha's Vineyard, the Cape Cod Bay lobe that deposited the moraines across eastern Martha's Vineyard and Nantucket, and the South Channel lobe that extended east toward Georges Bank (Oldale and Barlow, 1986; Oldale, 1992). During the retreat of the ice sheet, approximately 18,000 years BP, the main part of Cape Cod was deposited as the Barnstable outwash plain and a glacial lake occupied Nantucket Sound. The glacial meltwater lake occupying what is now considered Nantucket Sound is likely to have had a profound effect on the geomorphology of Edgartown Great Pond. The pond basin was probably formed by headward erosion by groundwater seepage fed from the glacial meltwater lake upgradient of present day Edgartown Great Pond. The process driving the formative headward erosion of the finger tributaries of Edgartown Great Pond is called spring sapping. This occurs when the water discharging from a spring to a wetland environment carries away loose sand and gravel and causes the spring and associated wetland to erode (and migrate) headward carving a long straight valley which then filled with seawater with rising sea levels post-glaciation. The terrestrial eroded "valleys" that represent the finger like tributary coves of the Edgartown Great Pond system are relict, because most (as is the case in Edgartown Great Pond) do not presently contain rivers or streams. They remain dry, except where their lower reaches have been drowned by the rise in sea level.

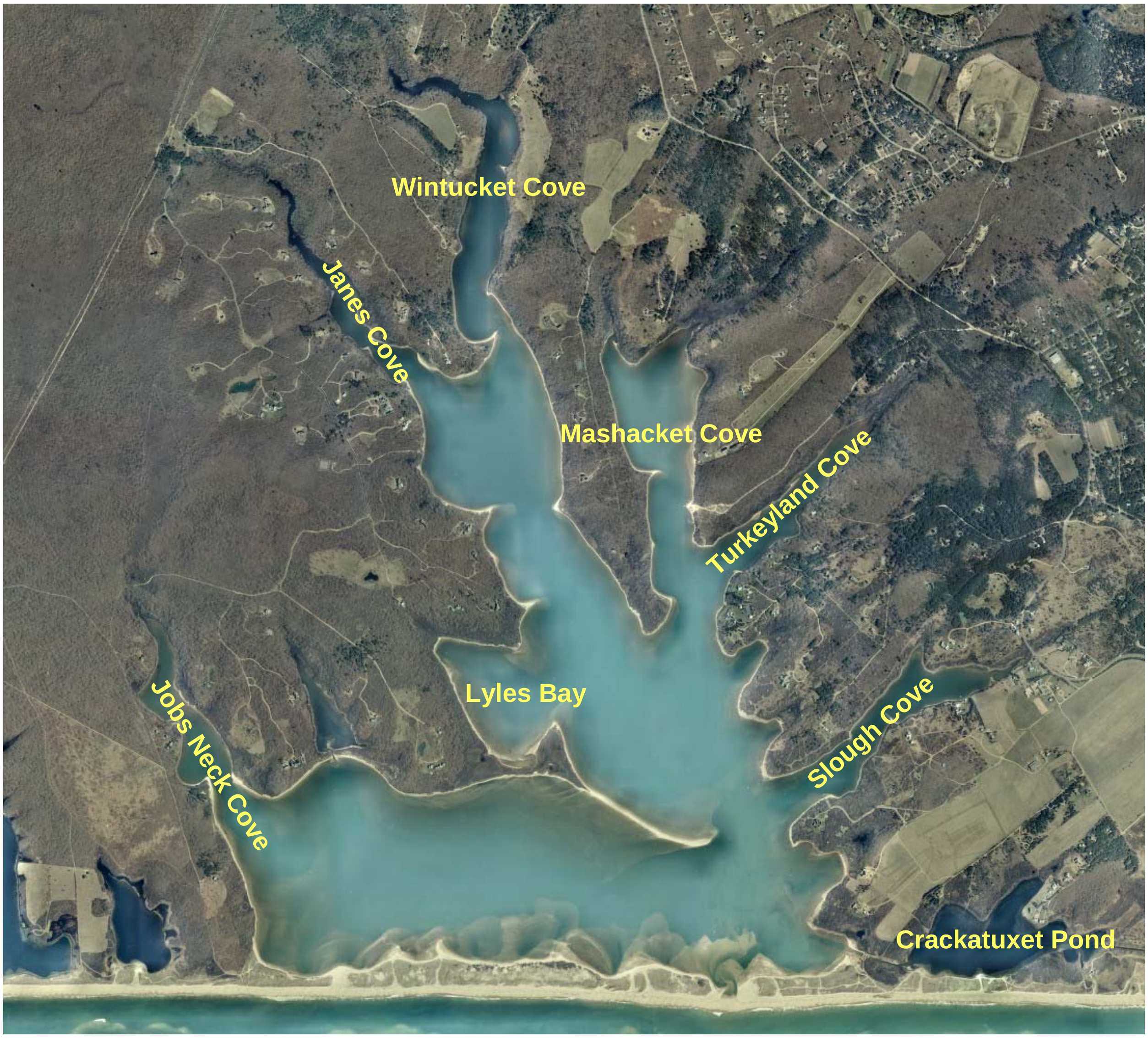



Figure I-2. Study region for the Massachusetts Estuaries Project analysis of the Edgartown Great Pond Embayment System. Tidal waters enter the Pond through periodic breaching of the barrier beach and flow in from the Atlantic Ocean. Freshwaters enter from the watershed primarily through direct groundwater discharge.

The formation of the Edgartown Great Pond System has and continues to be greatly affected by coastal processes, specifically the role that the barrier beach plays in separating the pond from Atlantic Ocean source waters. The ecological and biogeochemical structure of the pond is likely to have changed over time as the barrier beach naturally breached and closed in as a function of storm frequency and intensity. It is almost certain that its closed basin is geologically a recent phenomenon, and that the pond was more generally open during lower stands of sea level.

The primary ecological threat to the Edgartown Great Pond embayment system as a coastal resource is degradation resulting from nutrient enrichment. Although the watershed and the Pond have some issues relative to bacterial contamination, this does not appear to be having large ecosystem-wide impacts. Bacterial contamination causes closures of shellfish harvest areas, however and in contrast, loading of the critical eutrophying nutrient (nitrogen) to the Edgartown Great Pond System greatly increased over 1950 levels The upgrade of the WWTF discharging to the groundwater system of this great salt pond, has resulted in a brief period of decline in nitrogen loading, but the nitrogen loading will again increase due to land-use changes unless nitrogen management is implemented. The nitrogen loading to this system, like almost all embayments in southeastern Massachusetts, results primarily from on-site disposal of wastewater and WWTF discharges.

The Towns of Martha's Vineyard have been among the fastest growing towns in the Commonwealth over the past two decades and the Town of Edgartown does have a centralized wastewater treatment system with the site of discharge of its tertiary treated effluent located in the Edgartown Great Pond watershed. However, virtually all of the Edgartown Great Pond watershed is not connected to any municipal sewerage system. Rather, these unsewered areas rely on privately maintained septic systems for on-site treatment and disposal of wastewater. As existing and probable increasing levels of nutrients impact the coastal embayments of the Town of Edgartown, water quality degradation will accelerate, with further harm to invaluable environmental resources of the Town and the Island on the whole.

As the primary stakeholder to the Edgartown Great Pond system, the Town of Edgartown in collaboration with the Martha's Vineyard Commission (MVC) was among the first communities to become concerned over perceived degradation of their coastal embayments. Over the years, this local concern has led to the conduct of several studies (see Chapter II) of nitrogen loading to the system such as the Edgartown Great Pond: Nutrient Loading and Recommended Management Program 1996-1998. Key in this effort has been the Edgartown Great Pond Water Quality Monitoring Program, spearheaded by the MVC and supported by private, municipal, county and state funds (most recently Massachusetts 604(b) grant program) with technical assistance by the Coastal Systems Program at SMAST-UMD. This effort provides the quantitative watercolumn nitrogen data (1996-2006) required for the implementation of the MEP's Linked Watershed-Embayment Approach used in the present study.

Since the initial results of the Water Quality Monitoring Program and the land-use studies indicated that parts of the Edgartown Great Pond system were presently impaired by land-derived nitrogen inputs, the Town of Edgartown and Martha's Vineyard Commission (MVC) undertook additional site-specific data collection that has served to support MEP's ecological assessment and modeling project. The effort was associated with the Town's Wastewater Treatment Facility upgrade effort.

The common focus of the Town of Edgartown - MVC efforts in the Edgartown Great Pond system has been to gather site-specific data on the current nitrogen related water quality throughout the pond system and determine its relationship to watershed nitrogen loads. This multi-year effort has provided the baseline information required for determining the link between upland loading, tidal flushing, and estuarine water quality. The MEP effort builds upon the Water Quality Monitoring Program, and previous hydrodynamic and water quality analyses, and includes high order biogeochemical analyses and water quality modeling necessary to develop critical nitrogen targets for each major sub-embayment. These critical nitrogen targets and the link to specific ecological criteria form the basis for the nitrogen threshold limits necessary to complete wastewater planning and nitrogen management alternatives development needed by the Town of Edgartown.

While the completion of this complex multi-step process of rigorous scientific investigation to support watershed based nitrogen management has taken place under the programmatic umbrella of the Massachusetts Estuaries Project, the results stem directly from the efforts of large number of Town staff and volunteers over many years, most notably from members of the Martha's Vineyard Commission. The modeling tools developed as part of this program provide the quantitative information necessary for the Town of Edgartown to develop and evaluate the most cost effective nitrogen management alternatives to restore this valuable coastal resource which is currently being degraded by nitrogen overloading. It is important to note that the Edgartown Great Pond System and its associated watershed has been significantly altered by human activities over the past ~100 years. As a result, the present nitrogen "overloading" appears to result partly from alterations to its ecological systems. These alterations subsequently affect nitrogen loading within the watershed and influence the degree to which nitrogen loads impact the estuary. Therefore, restoration of this system should focus on managing nitrogen through both management of nitrogen loading within the watershed and restoration/management of processes which serve to lessen the amount or impact of nitrogen entering the estuary.

## I.1 THE MASSACHUSETTS ESTUARIES PROJECT APPROACH

Coastal embayments throughout the Commonwealth of Massachusetts (and along the U.S. eastern seaboard) are becoming nutrient enriched. The nutrients are primarily related to changes in watershed land-use associated with increasing population within the coastal zone over the past half century. Many of Massachusetts' embayments have nutrient levels that are approaching or are currently over this assimilative capacity, which begins to cause declines in their ecological health. The result is the loss of fisheries habitat, eelgrass beds, and a general disruption of benthic communities and the food chain which they support. At higher levels, nitrogen loading from surrounding watersheds causes aesthetic degradation and inhibits even recreational uses of coastal waters. In addition to nutrient related ecological declines, an increasing number of embayments are being closed to swimming, shellfishing and other activities as a result of bacterial contamination. While bacterial contamination does not generally degrade the habitat, it restricts human uses. However like nutrients, bacterial contamination is frequently related to changes in land-use as watersheds become more developed. 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 the Commonwealth's coastal embayments is nitrogen and the primary sources of this nitrogen are wastewater disposal, fertilizers, and changes in the freshwater hydrology associated with development. At present there is a critical need for state-of-the-art approaches for evaluating and restoring nitrogen sensitive and impaired embayments. Within Southeastern Massachusetts alone, almost all of the municipalities (as is the case with the Town of Edgartown) are grappling with Comprehensive Wastewater Planning and/or environmental management issues related to the declining health of their estuaries.

Municipalities are seeking guidance on the assessment of nitrogen sensitive embayments, as well as available options for meeting nitrogen goals and approaches for restoring impaired systems. Many of the communities have encountered problems with "first generation" watershed based approaches, which do not incorporate estuarine processes. The appropriate method must be quantitative and directly link watershed and embayment nitrogen conditions. This "Linked" Modeling approach must also be readily calibrated, validated, and implemented to support planning. Although it may be technically complex to implement, results must be understandable to the regulatory community, town officials, and the general public.

The Massachusetts Estuaries Project represents the next generation of watershed based nitrogen management approaches. The Massachusetts Department of Environmental Protection (MASSDEP), the University of Massachusetts – Dartmouth School of Marine Science and Technology (SMAST), and others including the Martha's Vineyard Commission (MVC) and the Cape Cod Commission (CCC) have undertaken the task of providing a quantitative tool for watershed-embayment management for communities throughout Southeastern Massachusetts and the Islands.

The Massachusetts Estuary Project is founded upon science-based management. The Project is using a consistent, state-of-the-art approach throughout the region's coastal waters and providing technical expertise and guidance to the municipalities and regulatory agencies tasked with their management, protection, and restoration. The overall goal of the Massachusetts Estuaries Project is to provide the MASSDEP and municipalities with technical guidance to support policies on nitrogen loading to embayments. In addition, the technical reports prepared for each embayment system will serve as the basis for the development of Total Maximum Daily Loads (TMDLs). Development of TMDLs is required pursuant to Section 303(d) of the Federal Clean Water Act. TMDLs must identify sources of the pollutant of concern (in this case nitrogen) from both point and non-point sources, the allowable load to meet the state water quality standards and then allocate that load to all sources taking into consideration a margin of safety, seasonal variations, and several other factors. In addition, each TMDL must contain an outline of an implementation plan. For this project, the MASSDEP recognizes that there are likely to be multiple ways to achieve the desired goals, some of which are more cost effective than others and therefore, it is extremely important for each Town to further evaluate potential options suitable to their community. As such, MASSDEP will likely be recommending that specific activities and timelines be further evaluated and developed by the Towns (sometimes jointly) through the Comprehensive Wastewater Management Planning process.

The MEP nitrogen threshold analysis includes site-specific habitat assessments and watershed/embayment modeling approaches to develop and assess various nitrogen management alternatives for meeting selected nitrogen goals supportive of restoration/protection of embayment health.

The major MEP nitrogen management goals are to:

- provide technical analysis and supporting documentation to Towns as a basis for sound nutrient management decision making towards embayment restoration
- develop a coastal TMDL working group for coordination and rapid transfer of results,
- determine the nutrient sensitivity of each of the 89 embayments in Southeastern MA
- provide necessary data collection and analysis required for quantitative modeling,
- conduct quantitative TMDL analysis, outreach, and planning,
- keep each embayment's model "alive" to address future municipal needs.

The core of the Massachusetts Estuaries Project analytical method is the Linked Watershed-Embayment Management Modeling Approach. This approach represents the "next generation" of nitrogen management strategies. It fully links watershed inputs with embayment circulation and nitrogen characteristics. The Linked Model builds on and refines 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 has been applied for watershed nitrogen management in approximately 32 embayments throughout Southeastern Massachusetts. In these applications it has become clear that 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.

The Linked Watershed-Embayment Model when properly parameterized, calibrated and validated for a given embayment becomes a nitrogen management planning tool, which fully supports TMDL analysis. The Model facilitates the evaluation of nitrogen management alternatives relative to meeting water quality targets within a specific embayment. The Linked Watershed-Embayment Model also enables Towns to evaluate improvements in water quality relative to the associated cost. In addition, once a model is fully functional it can be "kept alive" and updated for continuing changes in land-use or embayment characteristics (at minimal cost). 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.

***Linked Watershed-Embayment Model Overview:*** The Model provides a quantitative approach for determining an embayment's: (1) nitrogen sensitivity, (2) nitrogen threshold loading levels (TMDL) and (3) response to changes in loading rate. The approach is both calibrated and fully field validated and unlike many approaches, accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics (Figure I-3). This methodology integrates a variety of field data and models, specifically:

- Watercolumn Monitoring - multi-year embayment nutrient sampling
- Hydrodynamics -
    - embayment bathymetry
    - site specific tidal record
    - current records (in complex systems only)
    - hydrodynamic model
- Watershed Nitrogen Loading
    - watershed delineation
    - stream flow (Q) and nitrogen load
    - land-use analysis (GIS)
    - watershed N model

- Embayment TMDL - Synthesis
  - linked Watershed-Embayment N Model
  - salinity surveys (for linked model validation)
  - rate of N recycling within embayment
  - D.O record
  - Macrophyte survey
  - Infaunal survey

## I.2 SITE DESCRIPTION

The Edgartown Great Pond embayment system periodically exchanges tidal water with the Atlantic Ocean through managed "breaching" of the barrier beach (South Beach). This Great Salt Pond is opened to tidal exchange by excavating a trench through the barrier beach about every 3 months if the water levels in the pond have risen sufficiently to provide sufficient head to erode the desired channel to the sea. In addition, to insufficient pond level, openings can be delayed due to poor hydrodynamic conditions in the near shore ocean (wave height and direction can result in rapid in filling of the temporary inlet). Typically, pond water levels of one meters or greater above mean sea level are required, before a breach is attempted. Breaching of the pond is undertaken mainly as a means of controlling salinity levels in the pond and as a flood control measure to keep groundwater table levels low enough to keep the basements of houses bordering the pond from flooding during pond level and high water table periods of the year. The opening of the pond has historically resulted in the discharge of approximately 3 million cubic meters of water (Gaines, 1993) and prior to the opening, given groundwater infiltration into the pond, the salinity is typically in the 10 to 13 ppt. range. Post opening of the pond, the salinity ranges between 15 and 18 ppt. in the coves and 21 to 25 ppt. in the main basin of the pond nearest the opening (Gaines, 1993). Recently, a herring ladder was installed to Crackatuxet Cove which provides for an outflowing of pond waters between inlet openings, although pond water is continuously discharging to the ocean by pond water seepage through the barrier beach.

Edgartown Great Pond is an 890 acre coastal salt pond at high water. The pond is characterized by numerous tributary sub-embayments that are elongated and finger-like and extend into the coastal outwash plain built up during the last glacial period approximately 18,000 BP. The coves terminate in dry valleys, most likely created through spring sapping, that extend even further up into the outwash plain deposits creating unique habitat characterized by dry, sandy soils that are exposed to salt spray and frequent frosts in the winter time. For the MEP analysis, the Edgartown Great Pond estuarine system was partitioned into two general sub-embayment groups: the 1) the main basin, which is composed of an upper basin (Lyles Bay to Swan Neck Point) and lower basin (parallel to the barrier beach) and 2) the tributary sub-embayments of Janes Cove, Wintucket Cove, Mashacket Cove and Turkeyland Cove (associated with the upper basin) and Jobs Neck Cove and Slough Cove (associated with the lower basin)(see Figure I-1).

The present drainway that connects Edgartown Great Pond to Crackatuxet Pond which in turn is connected to Katama Bay via the Mattakesett Herring Creek is a reconfiguration of a natural outlet, until the 1938 hurricane interrupted the flow. This condition persisted until the 1970’s when a sluiceway was constructed to resume the flow of water out of Edgartown Great Pond. By the early 1990’s flow through the sluiceway once again ceased due to lack of maintenance. As reported in 1999 by the Martha’s Vineyard Commission, the sluiceway from Edgartown Great Pond to Crackatuxet Pond remained blocked due to sand overwash between the two ponds and as such the historic hydraulic connection was no longer a part of the function of the Edgartown Great Pond system. In 2002, the Herring Creek Restoration Project was initiated under the guidance of the Community Restoration Program Committee to restore the hydraulic connection between Edgartown Great Pond and Crackatuxet Pond and by 2003 a sluiceway was once again operational. Control of Pond levels by manipulation of the boards in the sluiceway as well as the timing of breaches of the barrier beach is the responsibility of the Town of Edgartown Shellfish Department. The operation of the sluiceway is important to managing Salt Pond water levels between openings, and as pond levels affect both the aquatic habitats and success of managed breaching of the barrier, operation is critical to the coordinated management of the pond system as a whole.

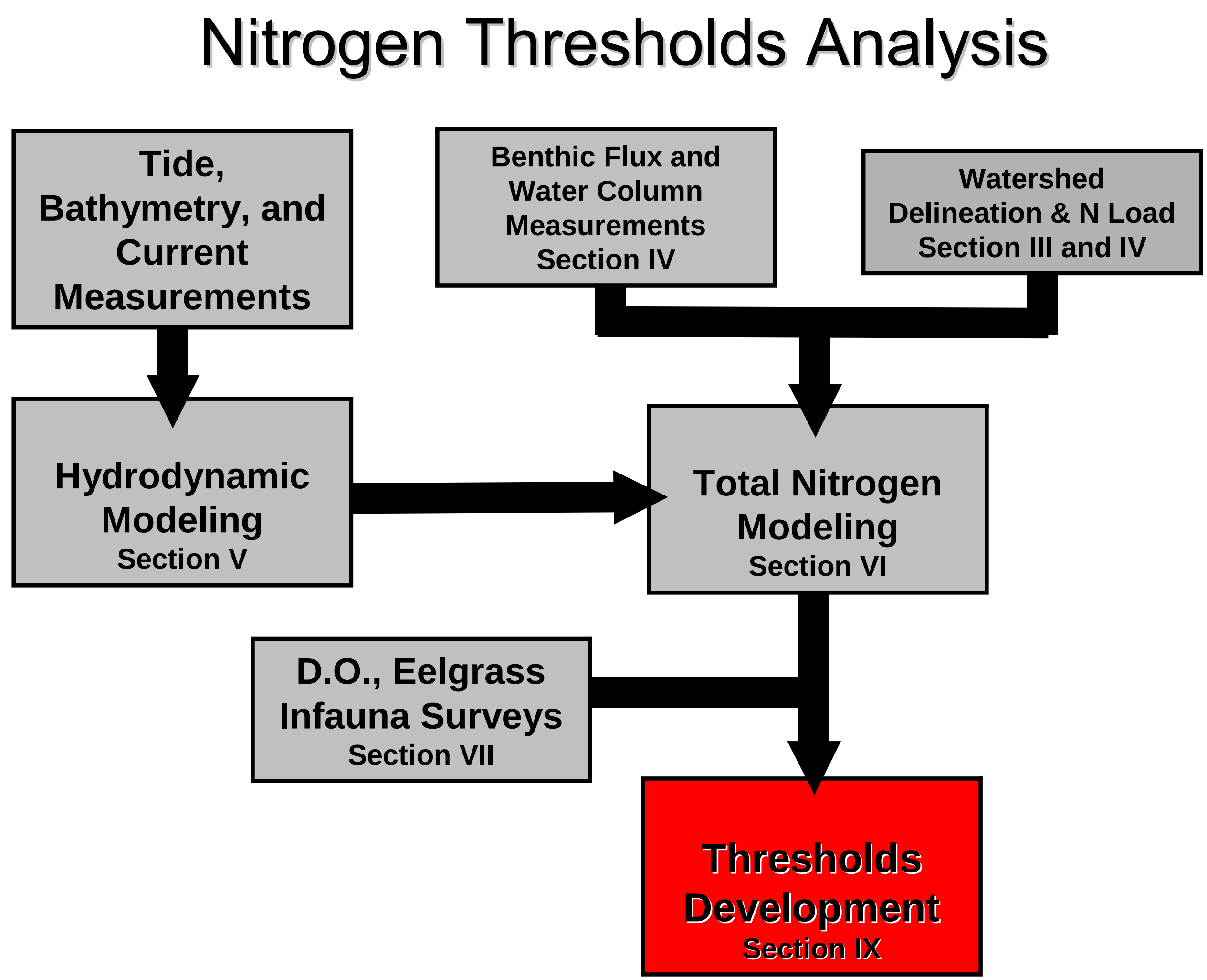



Figure I-3. Massachusetts Estuaries Project Critical Nutrient Threshold Analytical Approach

## I.3 NUTRIENT LOADING

Surface and groundwater flows are pathways for the transfer of land-sourced nutrients to coastal waters. Fluxes of primary ecosystem structuring nutrients, nitrogen and phosphorus, differ significantly as a result of their hydrologic transport pathway (i.e. streams versus groundwater). In sandy glacial outwash aquifers, such as in the watershed to the Edgartown Great Pond System, phosphorus is highly retained during groundwater transport as a result of sorption to aquifer minerals (Weiskel and Howes 1992). Since even Martha's Vineyard and Cape Cod "rivers" are primarily groundwater fed, watersheds tend to release little phosphorus to coastal waters. In contrast, nitrogen, primarily as plant available nitrate, is readily transported through oxygenated groundwater systems on Cape Cod (DeSimone and Howes 1998, Weiskel and Howes 1992, Smith *et al.* 1991) and Martha's Vineyard. The result is that terrestrial inputs to coastal waters tend to be higher in plant available nitrogen than phosphorus (relative to plant growth requirements). However, coastal estuaries tend to have algal growth limited by nitrogen availability, due to their flooding with low nitrogen coastal waters (Ryther and Dunstan 1971). The estuarine reaches within the Edgartown Great Pond System follow this general pattern, where the primary nutrient of eutrophication in these systems is nitrogen.

Nutrient 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 enclosed basins, shallow waters and large shoreline area, are generally the first indicators of nutrient pollution from terrestrial sources. By nature, these systems are highly productive environments, but nutrient over-enrichment of these systems worldwide is resulting in the loss of their aesthetic, economic and commercially valuable attributes.

Each embayment system maintains a capacity to assimilate watershed nitrogen inputs without degradation. However, as loading increases a point is reached at which the capacity (termed assimilative capacity) is exceeded and nutrient related water quality degradation occurs. This point can be termed the "nutrient threshold" and in estuarine management this threshold sets the target nutrient level for restoration or protection. Because nearshore coastal salt ponds and embayments are the primary recipients of nutrients carried via surface and groundwater transport from terrestrial sources, it is clear that activities within the watershed, often miles from the water body itself, can have chronic and long lasting impacts on these fragile coastal environments.

Protection and restoration of coastal embayments from nitrogen overloading has resulted in a focus on determining the assimilative capacity of these aquatic systems for nitrogen. While this effort is ongoing (e.g. USEPA TMDL studies), southeastern Massachusetts and the Islands has been the site of intensive efforts in this area (Eichner et al., 1998, Costa et al., 1992 and in press, Ramsey et al., 1995, Howes and Taylor, 1990, and the Falmouth Coastal Overlay Bylaw, MVC Water Quality Policy). While each approach may be different, they all focus on changes in nitrogen loading from watershed to embayment, and aim at projecting the level of increase in nitrogen concentration within the receiving waters. Each approach depends upon estimates of circulation within the embayment; however, few directly link the watershed and hydrodynamic models, and virtually none include internal recycling of nitrogen (as was done in the present effort). However, determination of the "allowable N concentration increase" or "threshold nitrogen concentration" used in previous studies had a significant uncertainty due to the need for direct linkage of watershed and embayment models and site-specific data. In the present effort we have integrated site-specific data on nitrogen levels and the gradient in N concentration throughout the Edgartown Great Pond System monitored by the Martha's

Vineyard Commission and the Town of Edgartown. The Water Quality Monitoring Program with site-specific habitat quality data (D.O., eelgrass, phytoplankton blooms, benthic animals) was utilized to “tune” general nitrogen thresholds typically used by the Cape Cod Commission, Buzzards Bay Project, and Massachusetts State Regulatory Agencies.

Unfortunately, almost all of the estuarine reaches within the Edgartown Great Pond System are near or beyond their ability to assimilate additional nutrients without impacting their ecological health. Nitrogen levels are elevated throughout this Great Salt Pond and eelgrass beds have declined over the past century to a few residual patches, observed by the MEP Technical Team during the summer of 2002 and the fall of 2003. Nitrogen related habitat impairment within the Edgartown Great Pond Estuary shows a gradient of high to low moving from the inland reaches to the site of the inlet when it is created artificially at the time of a pond opening, primarily related to the configuration of the basin and its depositional basins. The result is that nitrogen management of the primary sub-embayments to the Edgartown Great Pond system is aimed at restoration, not protection or maintenance of existing conditions. In general, nutrient over-fertilization is termed “eutrophication” and in certain instances can occur naturally over long periods of time. When the nutrient loading is rapid and primarily from human activities leading to changes in a coastal watershed, nutrient enrichment of coastal waters is termed “cultural eutrophication”. Although the influence of human-induced changes has increased nitrogen loading to the systems and contributed to the degradation in ecological health, the Edgartown Great Pond basins are especially sensitive to nitrogen inputs, because of the lack of tidal exchange. The quantitative role of the tidal restriction of this system, as a natural process, was also considered in the MEP nutrient threshold analysis. As part of future restoration efforts, it is important to understand that it may not be possible to turn each embayment into a “pristine” system.

### I.4 WATER QUALITY MODELING

Evaluation of upland nitrogen loading provides important “boundary conditions” (e.g. watershed derived and offshore nutrient inputs) for water quality modeling of the Edgartown Great Pond System; however, a thorough understanding of estuarine circulation is required to accurately determine nitrogen concentrations within each system. Therefore, water quality modeling of tidally influenced estuaries must include 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. Numerical models provide a cost-effective method for evaluating tidal hydrodynamics since they require limited data collection and may be utilized to numerically assess a range of management alternatives. Once the hydrodynamics of an estuary system are understood, computations regarding the related coastal processes become relatively straightforward extensions to the hydrodynamic modeling. The spread of pollutants may be analyzed from tidal current information developed by the numerical models.

The MEP water quality evaluation examined the potential impacts of nitrogen loading into the Edgartown Great Pond System, including the tributary sub-embayments of Jobs Neck Cove, Slough Cove, Janes Cove, Wintucket Cove, Mashacket Cove and Turkeyland Cove. A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents during breaching events and water elevations was employed for each of the 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, based upon MEP refined (working with the USGS) watershed delineations originally developed by Earth Tech. Almost all nitrogen entering the Edgartown Great Pond System is transported by freshwater, predominantly groundwater. Concentrations of total nitrogen and salinity of Atlantic Ocean source waters and throughout the Edgartown Great Pond system were taken from the Town of Edgartown/MVC Water Quality Monitoring Program (a coordinated effort between the Town of Edgartown, Martha's Vineyard Commission and the Coastal Systems Program at SMAST). Measurements of current salinity and nitrogen and salinity distributions throughout estuarine waters of the Systems (1996-2006) were used to calibrate and validate the water quality model (under existing loading conditions).

## I.5 REPORT DESCRIPTION

This report presents the results generated from the implementation of the Massachusetts Estuaries Project linked watershed-embayment approach to the Edgartown Great Pond System for the Town of Edgartown. A review of existing water quality studies is provided (Section II). The development of the watershed delineations and associated detailed land use analysis for watershed based nitrogen loading to the coastal system is described in Sections III and IV. In addition, nitrogen input parameters to the water quality model are described. Since benthic flux of nitrogen from bottom sediments is a critical (but often overlooked) component of nitrogen loading to shallow estuarine systems, determination of the site-specific magnitude of this component also was performed (Section IV). Nitrogen loads from the watershed and sub-watersheds surrounding the estuary were derived from the Martha's Vineyard Commission data and offshore water column nitrogen values were derived from an analysis of monitoring stations in the Atlantic Ocean (Section IV). Intrinsic to the calibration and validation of the linked-watershed embayment modeling approach is the collection of background water quality monitoring data (conducted by municipalities) as discussed in Section IV. Results of hydrodynamic modeling of embayment circulation are discussed in Section V and nitrogen (water quality) modeling, as well as an analysis of how the measured nitrogen levels correlate to observed estuarine water quality are described in Section VI. This analysis includes modeling of current conditions, conditions at watershed build-out, and with removal of anthropogenic nitrogen sources. In addition, an ecological assessment of the component sub-embayments was performed that included a review of existing water quality information and the results of a benthic analysis (Section VII). The modeling and assessment information is synthesized and nitrogen threshold levels developed for restoration of the Pond in Section VIII. Additional modeling is conducted to produce an example of the type of watershed nitrogen reduction required to meet the determined threshold for restoration of the Pond. This latter assessment represents only one of many solutions and is produced to assist the Town in developing a variety of alternative nitrogen management options for this system. Finally, analyses of the Edgartown Great Pond System were undertaken relative to potential alterations of circulation and flushing, including an analysis to identify hydrodynamic restrictions and an examination of dredging/breach options to improve nitrogen related water quality. The results of the nitrogen modeling for each scenario have been presented in Section VIII.

# II. PREVIOUS STUDIES RELATED TO NITROGEN MANAGEMENT

Nutrient additions to aquatic systems cause shifts in a series of biological processes that can result in impaired nutrient related habitat quality. Effects include: 1) excessive plankton and macrophyte growth (which leads to reduced water clarity), 2) organic matter enrichment of waters and sediments, with the concomitant resulting increased rates of oxygen consumption and periodic depletion of dissolved oxygen, (especially in bottom waters), and 3) the limitation of the growth of desirable species such as eelgrass. Even without changes to water clarity and bottom water dissolved oxygen, the increased organic matter deposition to the sediments generally results in a decline in habitat quality for benthic infaunal communities (animals living in the sediments). This habitat change causes a shift in infaunal communities from high diversity deep burrowing forms (which include economically important species), to low diversity shallow dwelling organisms. This shift alone causes significant degradation of the resource and a loss of productivity to both the local shell fisherman and to the sport-fishery and offshore fin fishery, all of which are dependent upon these highly productive estuarine systems as a habitat and food resource during migration or during different life cycle phases. This process is generally termed “eutrophication” and in embayment systems, unlike in shallow lakes and ponds, it is not a necessarily a part of the natural evolution of a system.

In most marine and estuarine systems, such as the Edgartown Great Pond System, the limiting nutrient, and thus the nutrient of primary concern, is nitrogen. In large part, if nitrogen addition is controlled, then eutrophication is controlled. This approach has been formalized through the development of tools for predicting nitrogen loads from watersheds and the concentrations of water column nitrogen that may result. Additional development of this management approach has generated specific guidelines as to what is to be considered acceptable water column nitrogen concentrations to achieve desired water quality goals (e.g., see Cape Cod Commission 1991, 1998; Howes et al. 2002).

These tools for predicting loads and concentrations tend to be generic in nature, and overlook some of the specifics for any given water body. The present Massachusetts Estuaries Project (MEP) analysis focuses on linking water quality model predictions, based upon watershed nitrogen loading and embayment recycling and system hydrodynamics, to actual measured values for specific nutrient species. The linked watershed-embayment model is built using embayment specific measurements, thus enabling calibration of the prediction process for specific conditions in each of the coastal embayments of southeastern Massachusetts, including the Edgartown Great Pond System. As the MEP approach requires substantial amounts of site-specific data collection, part of the program is to review previous data collection and modeling efforts. These reviews are both for purposes of “data mining” and to gather additional information on an estuary’s habitat quality, unique features or temporal trends.

Among the most critical studies available for this system is the Edgartown Great Pond Water Quality Monitoring Program, spearheaded by the MVC and supported by private, municipal, county and state funds (most recently Massachusetts 604(b) grant program) with technical assistance by the Coastal Systems Program at SMAST-UMD. This Program was conducted under a Quality Assurance Project Plan, approved by the USEPA and MassDEP, with chemical analysis by the Coastal Systems Analytical Facility at SMAST-UMass Dartmouth. Review of the Water Quality Program showed that its protocols have been consistent with the MEP QAPP. Therefore, data collected by the Edgartown Great Pond Water Quality Monitoring Program has been used to provide the quantitative watercolumn nitrogen data (1996-2006) required for the implementation of the MEP's Linked Watershed-Embayment Approach used in the present study.

Since the initial results (Wilcox, 1998, Island Coastal Ponds Water Quality Survey, 1995-1996: Great Ponds Report. MV Shellfish, MV Commission, UMASS Extension) of the Water Quality Monitoring Program and the land-use studies indicated that parts of the Edgartown Great Pond system were presently impaired by land-derived nitrogen inputs, the Town of Edgartown and Martha's Vineyard Commission (MVC) undertook additional site-specific data collection related to the present MEP ecological assessment and modeling project. Some of these investigations were also related to the Town's Wastewater Treatment Facility upgrade effort. These investigations were generally management oriented and included both habitat assessments and studies relating to nitrogen loading, hydrodynamics and habitat health. However, none provided a holistic view of the Edgartown System or its many tributary coves (Wintucket, Mashacket, Turkeyland, Slough, Jobs Neck, Janes). These numerous reports and data sets have been reviewed by the MEP Technical Team for integration into this Technical Report.

The Town of Edgartown has been very active in collecting and compiling data on a variety of environmental and habitat health issues which have been helpful in the development of the MEP analysis. As reported regularly by the Town of Edgartown Shellfish Department, the Town of Edgartown has a substantial shellfishing enterprise that depends on the safeguarding of the estuarine environment of the Town (e.g. Edgartown Great Pond). By example in 2003 the Shellfish Department reported the 2003 Commercial Shellfish Catch in Edgartown was valued at $750,155.00 in the following categories:

- Clams 127 Bushels $16,510
- Quahogs 419 Bushels $38,020
- Oysters 285 Bushels $35,625
- Scallops 6,875 Bushels $660,000

The following (reported by the Shellfish Department in 2003 Town Report) is a breakdown by area and species of shellfish harvested, in bushels, both commercially and recreationally.

| | Clams | Quahogs | Oysters | Scallops |
|---|---|---|---|---|
| Katama Bay | 151 | 680 | 17 | 12 |
| Cape Pogue | 12 | 203 | 0 | 6,939 |
| Eel Pond | 7 | 17 | 32 | 5 |
| Calebs Pond | 2 | 50 | 0 | 0 |
| Sengekontacket | 26 | 27 | 9 | 34 |
| Pocha Pond | 0 | 3 | 0 | 0 |
| Edgartown Harbor | 4 | 3 | 0 | 95 |
| Trapps Pond | 20 | 23 | 0 | 0 |
| Edgartown Great Pond | 5 | 0 | 285 | 0 |
| Oyster Pond | 7 | 0 | 14 | 0 |

NOTE: Edgartown Harbor includes both inner and outer harbor.

In addition to the wild shellfish harvest, aquaculturists in Edgartown raised 500 bushels of oysters worth $162,500 in 2003. The Shellfish Department continually monitors shellfish diseases within Town waters and reported as far back as 2003 that for the first time juvenile oyster disease was found in oysters received from the hatchery by aquaculturists in Edgartown. Moreover, the shellfish disease Dermo, another oyster disease, continued to be prevalent on Oyster Pond and Edgartown Great Pond as reported in 2003. In spite of the Demo infection, (which only harms the shellfish) Edgartown Great Pond has been able to support a small commercial fishery despite the effects of this disease. In a study funded by the Northeast Regional Aquaculture Center, Edgartown Great Pond oysters are currently being investigated as a potential disease resistant population, which would greatly benefit the shellfish industry.

The Town continues to work with the Massachusetts Division of Marine Fisheries to monitor all shellfishing areas to ensure public health. As reported in 2003 Edgartown Great Pond was able to be opened for year-round shellfishing because of improved water quality (indicator bacteria). The Town of Edgartown continues to actively manage this Great Salt Pond toward the goal of improving the quality of this resource. The periodic management openings through the barrier beach to provide tidal exchange with Atlantic Ocean waters appears to have helped in the observed lowering of bacterial counts in the pond. Additionally, working towards enhancement of circulation in Edgartown Great Pond, significant dredging was undertaken in the late 2000 / early 2001 time frame as the summer 2001 had a 70+ day opening. Touch up dredging occurred in November 2003 inside of Edgartown Great Pond for maintenance associated with the "opening" site and in the spring of 2003, the sluiceway to Crackatuxet Cove was rebuilt.

The most comprehensive management planning effort to date has been by the Martha's Vineyard Commission, as detailed in their report "Edgartown Great Pond: Nutrient Loading and Recommended Management Program 1996-1998". This effort included a review of nutrient loading to the Pond (including previous studies) and the Herring Creek Farm which is within the watershed of both Edgartown Great Pond and Crackatuxet Cove. The analysis included evaluating the loading terms and assumptions, checking calculations and reviewing the underpinnings of the nitrogen loading limits. Most of the analysis was based upon determining nitrogen loading to Edgartown Great Pond, primarily from its watershed. An attempt was also made to determine the nitrogen loading level to the Pond that would support a healthy resource. However, this survey approach does not include processes within the Salt Pond, and yields only approximate management loading levels. The MVC effort did reveal several major findings as they relate to watershed delineations, recharge or nitrogen loading and are as follows:

1) Watershed delineations based upon well data and topography, while generally correct, should receive further analysis, if possible employing groundwater modeling.

2) The lawn analysis suggests that a shift to mainland landscaping practices would cause a large increase in N load without any increase in development.

3) Prior efforts to determine the critical nitrogen loading limit to the Pond required more scientific data and modeling support. Some of the investigations indicated that Edgartown Great Pond could tolerate even higher nitrogen loadings (Appendix C. by A. Gaines), yet the 1999 N load to the Pond had resulted in loss of eelgrass and shellfish, algal blooms and possible periodic low oxygen conditions. It appeared clear that increasing the N loading at the water exchange rates of the time would further degrade the EGP ecosystem. However, the precise nitrogen loading target was still unknown and remained the critical information for proper management of this system.

In addition to the review of the Edgartown Great Pond: Nutrient Loading and Recommended Management Program 1996-1998, members of the MEP Technical Team also conducted a review of the Herring Creek Farm Study (Horsley & Witten Inc). This report was a site-specific study, but as it contained some detailed analysis and data, the MEP reviewed the document for integration with the MEP analysis. This report was deemed to provide useful information on the hydrology related to the changing water levels of Edgartown Great Pond and Crackatuxet Cove, and potential small scale changes in watershed delineation in this region of the Great Pond watershed.

A number of other studies have been reviewed by the MEP Technical Team relative to the MEP assessment and modeling effort for Edgartown Great Pond. The most useful to the MEP effort are as follows:

- Data collected by the Town of Edgartown and the Martha's Vineyard Commission (funded by the Great Pond Foundation) regarding the status of the treated wastewater plume from the "old" Edgartown Treatment Facility which was discharged to the watershed. These data included nutrient measurements of groundwater and plume tracking and are presented as part of the watershed analysis in Chapter IV. Additional data from Main Engineers (Geohydrologic Study For the Edgartown Water Pollution Control Facility 1986) was also considered.

- Historical eelgrass and infaunal animal habitat surveys showing locations of eelgrass beds and animal community data (Gaines, A. 1993, Coastal Resources Planning and Management: Edgartown Great Pond. WHOI, Woods Hole, MA.; Pratt, S.D. and A. Gaines 1997, An environmental status report on Edgartown Great Pond: bottom habits and their flora and fauna).

- Earth Tech Inc., Groundwater Modeling, provided critical information for the delineation of the watershed to Edgartown Great Pond. The data and model was provided to SMAST and USGS as part of the task to determine the contributing watershed area (Chapter III). This effort also incorporated information from Llewellyn-Smith, (The Hydrogeology of Martha's Vineyard, Mass. MS Thesis, UMASS Dept. Geology and Geography 1987) and Anderson Nichols & Co.(Edgartown Water Resource Protection Program 1984)

As briefly discussed above, a wide variety of work has previously been undertaken on the Edgartown Great Pond system in advance of the MEP analysis. The most pertinent reports have been summarized above while other studies considered by the MEP are simply listed below:

Earth Tech (1998) Preliminary Data: Meeting House Golf LLC

Gaines, A. (1996) An Artificial Inlet for Application on a Seasonally High Energy Barrier Beach. Proposal to Boldwater Homeowners by Coast & Harbor Consultants

Martha's Vineyard Commission (1998) Data Report, Dukes County, MA. 1998

Mass. Division of Water pollution Control (1977) Martha's Vineyard Water Quality Study

Saunders Associates (1989) M. V. Landfill Monitoring Well Sampling Program: Final Report

Skomal, G.B. (1998) Finfish Survey: Edgartown Great Pond. Third Quarterly Report: Mass. Div. Of Mar. Fish.

Smith & Mahoney (1991) M. V. Landfill Groundwater Quality Monitoring Program: Final Report

Whitman & Howard (1994) A Numerical Groundwater Flow Model and Zone II Delineation for the Farm Neck Well, Oak Bluffs, Mass.. Wellesley, Ma.

Whitman & Howard (1996) Letter Report on Second Phase of Nitrate Plume Investigation

Wilcox, W.M. (1998) Island Coastal Ponds Water Quality Survey, 1995-1996: Great Ponds Report. MV Shellfish, MV Commission, UMASS Extension

Wilcox, W.M. (1986) Vineyard Farm Survey. Unpublished Survey.

# III. DELINEATION OF WATERSHEDS

## III.1 BACKGROUND

The Massachusetts Estuaries Project team includes technical staff from the United States Geological Survey (USGS). These USGS groundwater modelers were central to the development of the groundwater modeling approach used by the Estuaries Project. Martha's Vineyard has not been extensively modeled by the USGS, but a satisfactory revision of a pre-existing sub-regional model was completed by the MEP technical staff with review by the USGS in order to delineate a watershed to Edgartown Great Pond and its sub-embayments (coves).

Martha's Vineyard Island is located along the southern edge of late Wisconsinan glaciation (Oldale and Barlow, 1986). As such, the geology of the island is largely composed of outwash plain and morainal deposits. Re-working of these geologic structures by the ocean since the retreat of the glaciers has significantly affected the physiography of the Island. The main portion of the island was located between the Cape Cod Bay and Buzzards Bay lobes of the Laurentide ice sheet. As such, the areas where the glacial ice lobes moved back and forth with warming and cooling of the climate are moraine areas and these are located along the Nantucket Sound and Vineyard Sound sides of the island. These moraines generally consist of unsorted sand, clay, silt, and gravel. The middle portion of the island is generally outwash plain and is composed of stratified sands and gravel deposited by glacial meltwater. Edgartown Great Pond and its watershed are located within this outwash plain.

The relatively transmissive sand and gravel deposits that comprise most of the Vineyard outwash plain create a hydrologic environment where watershed boundaries are usually better defined by elevation of the groundwater and its direction of flow, rather than by land surface topography (Cambareri and Eichner 1998, Millham and Howes 1994a,b). Freshwater discharge to estuaries is usually composed of surface water inflow from streams, which receive much of their water from groundwater base flow, and direct groundwater discharge. For a given estuary, differentiating between these two water inputs and tracking the sources of nitrogen that they carry requires determination of the portion of the watershed that contributes directly to a stream and the portion of the groundwater system that discharges directly into an estuary as groundwater seepage. In the case of the Edgartown Great Pond system, there were no significant surface water features requiring delineation or stream gauging as is typical of other embayments in the MEP study region. As such, freshwater flux to the systems was exclusively driven by groundwater conditions and direct precipitation on the embayment water surface.

The groundwater system of Martha's Vineyard is generally characterized by a shallow, unconfined aquifer generally situated less than 160 feet below NGVD (1929) throughout the majority of the outwash plain (Delaney, 1980). The groundwater system in the western moraine has not been well characterized and its mix of clay, till, sand and peat produces both unconfined and confined aquifer conditions. Regional studies of groundwater within the outwash plain have refined the understanding of the geology and hydrology in the area (MVC, 1999) and further information has been provided by regular monthly monitoring of 14 long-term monitoring wells by the Martha's Vineyard Commission. All of this information has been useful for subsequent activities, including the delineation of estuary watersheds completed by the Massachusetts Estuaries Project Technical Team.

## III.2 EDGARTOWN GREAT POND CONTRIBUTORY AREAS

MEP technical staff reviewed a sub-regional groundwater model originally prepared by Whitman Howard (1994) and subsequently updated by Earth Tech. This model organized much of the historic geologic data collected on the Vineyard and provided a satisfactory basis for incorporating the refinements necessary to complete the Edgartown Great Pond watershed delineation.

The MEP Technical Team with assistance from the USGS revised the model grid to match orthophotographs of the island, which resulted in a grid with 126 rows oriented southwest and 167 columns oriented southeast. Hydraulic conductivities were reworked to match the revised grid. Outputs from the revised model were compared with water table elevations generated for previously approved MassDEP Zone II drinking water well contributing area delineations and the match was acceptable. The MEP Technical Team then used the revised model to define the watershed or contributing area to Edgartown Great Pond and its sub-embayments. The Edgartown Great Pond watershed is situated along the southern edge of Martha's Vineyard and is bounded by the Atlantic Ocean to the south (Figure III-1).

The MEP Technical Team utilized the Edgartown Great Pond watershed to develop daily discharge volumes for various sub-watersheds as calculated from the watershed areas and an island-specific recharge rate. In order to develop the groundwater discharge volumes, MEP Technical Team members determined a recharge rate of 28.7 inches per year for Martha's Vineyard. In order to develop this recharge rate estimate, the MEP Technical Team reviewed the recharge and precipitation rates used on Cape Cod. In the preparation of the Cape Cod groundwater models, the USGS used a recharge rate of 27.25 in/y for calibration of the models to measured water levels (Walter and Whealan, 2005). The Cape Cod recharge rate is 61% of the estimated 44.5 in/yr of precipitation on the Cape. Precipitation data collected by the National Weather Service at Edgartown since 1947 yields a 20 year average precipitation of 46.9 in/yr (http://www.mass.gov/dcr/waterSupply/rainfall/precipdb.htm). If the Cape Cod relationship between precipitation and recharge is applied to the average Vineyard precipitation rate, the estimated recharge rate on Martha's Vineyard is 28.7 in/yr. This rate was used to estimate groundwater flow to Edgartown Great Pond and its various sub-watersheds (Table III-1). The discharge volumes developed for the sub-watersheds were used to assist in the salinity calibration of the tidal hydrodynamic models. The overall estimated groundwater flow into Edgartown Great Pond from the MEP delineated watershed is 36,437 m3/d.

The area and estimated discharge for the MEP watershed delineation are similar to previous delineations. Gaines (1993) estimated a 4,200-acre groundwater watershed to Edgartown Great Pond based on Delaney's (1980) water table map. The watershed delineation based on Whitman and Howard's (1994) modeled water table map resulted in a watershed area of 3,854 acres (MVC, 1999). The Martha's Vineyard Commission refinement of water table contours in selected areas along Gaines' historical watershed boundary resulted in some reassessment of the boundaries and the subsequent watershed area increased to 5,100 acres (MVC, 1999). Given the additional groundwater well water level data provided by the MVC as well as the model grid refinements completed by the MEP Technical Team with assistance from the USGS, the current delineation being utilized by the MEP in this analysis (as presented in Figure III-1) is likely most reflective of actual groundwater fluxes to the Edgartown Great Pond systems in comparison to historical delineations. As such, the MEP and the USGS determined that the current version of the delineations presented herein serve as an appropriate basis for completion of the Linked Watershed-Embayment Model for the Edgartown Great Pond system.

Table III-1. Daily groundwater discharge from each of the sub-watersheds to the Edgartown Great Pond Estuary.

| Watershed | Watershed # | Watershed Area (acres) | Discharge | |
|---|---|---|---|---|
| | | | $m^3$/day | $ft^3$/day |
| Jobs Point | 1 | 13 | 106 | 3,739 |
| Jobs Neck Cove | 2 | 340 | 2,749 | 97,089 |
| Pocketapaces | 3 | 435 | 3,519 | 124,265 |
| Wintucket Cove | 4 | 1,084 | 8,771 | 309,753 |
| Janes Cove | 5 | 367 | 2,965 | 104,715 |
| Kanomika Neck | 6 | 50 | 407 | 14,362 |
| Mashacket Cove | 7 | 890 | 7,195 | 254,092 |
| Turkeyland Cove | 8 | 239 | 1,936 | 68,372 |
| King Point | 9 | 255 | 2,066 | 72,945 |
| Slough Cove | 10 | 648 | 5,241 | 185,092 |
| Butler Neck | 11 | 142 | 1,145 | 40,443 |
| South Beach | 12 | 42 | 337 | 11,910 |
| TOTAL | | 4,505 | 36,437 | 1,286,777 |

NOTE: Discharge rates are based on 28.7 inches per year of recharge.

Review of watershed delineations for Edgartown Great Pond allows new hydrologic data to be reviewed and the watershed delineation to be reassessed. The evaluation of older data and incorporation of new data during the development of the MEP watershed model is important as it decreases the level of uncertainty in the final calibrated and validated Linked Watershed-Embayment Model used for the evaluation of nitrogen management alternatives. Errors in watershed delineations do not necessarily result in proportional errors in nitrogen loading as errors in loading depend upon the land-uses that are included/excluded within the contributing areas. Small errors in watershed area can result in large errors in loading if a large source is counted in or out. Conversely, large errors in watershed area that involve only natural woodlands have little effect on nitrogen inputs to the down gradient estuary. The MEP watershed delineation was used to develop the watershed nitrogen loads to each of the aquatic systems and ultimately to the estuarine waters of the Edgartown Great Pond system (Section V.1).

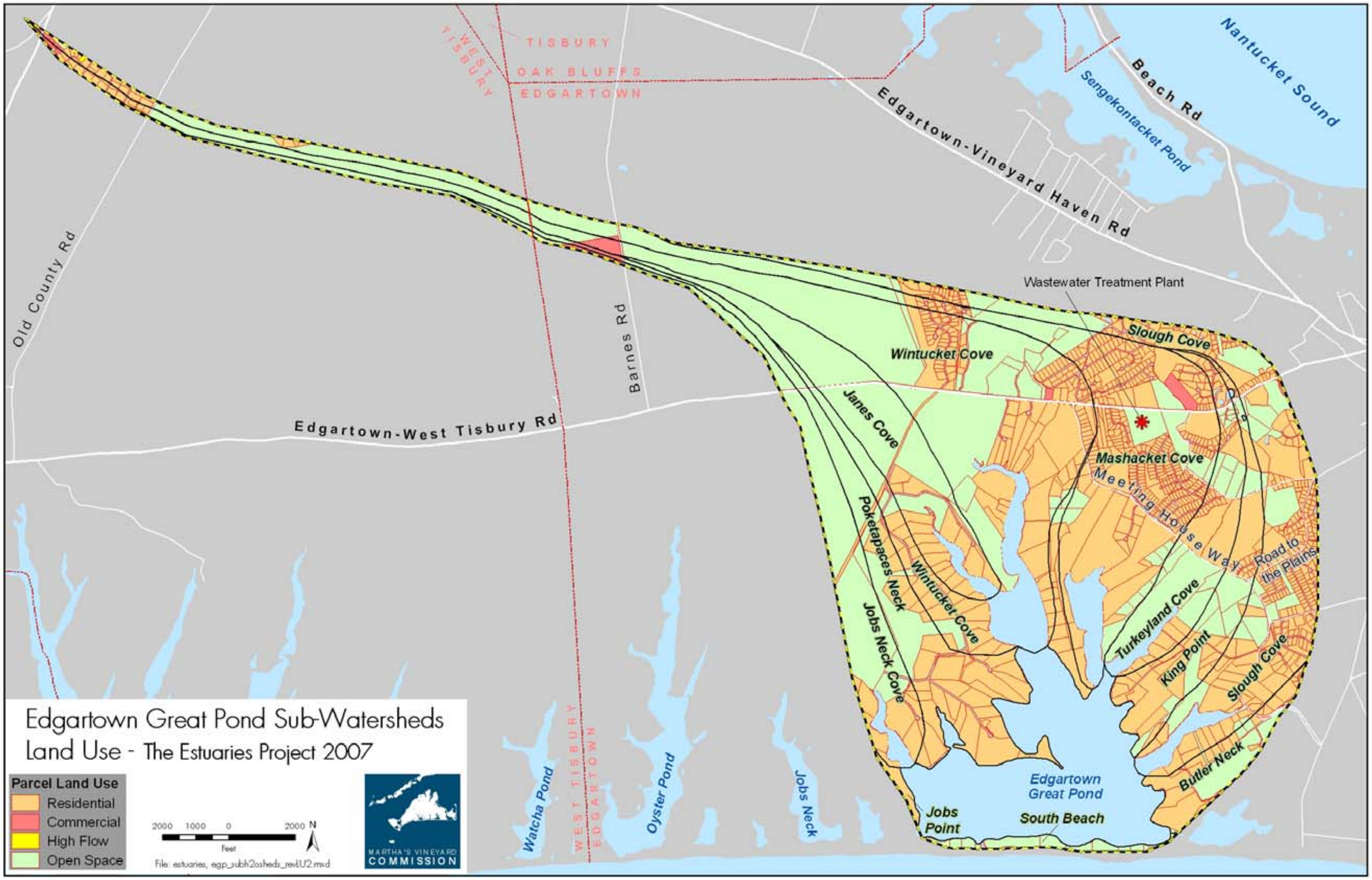



Figure III-1. Watershed and sub-watershed delineations for the Edgartown Great Pond estuary system. Sub-watersheds to embayments were selected based upon the functional estuarine sub-units in the water quality model (see section VI).

# IV. WATERSHED NITROGEN LOADING TO EMBAYMENT: LAND USE, STREAM INPUTS, AND SEDIMENT NITROGEN RECYCLING

## IV.1 WATERSHED LAND USE BASED NITROGEN LOADING ANALYSIS

Management of nutrient related water quality and habitat health in coastal waters requires determination of the amount of nitrogen transported by freshwaters (surface water flow, groundwater flow) from the surrounding watershed to the receiving embayment of interest. In southeastern Massachusetts, the nutrient of management concern for estuarine systems is nitrogen and this is true for the Edgartown Great Pond system. Determination of watershed nitrogen inputs to these embayment systems requires the (a) identification and quantification of the nutrient sources and their loading rates to the land or aquifer, (b) confirmation that a groundwater transported load has reached the embayment at the time of analysis, and (c) quantification of nitrogen attenuation that can occur during travel through lakes, ponds, streams and marshes. This latter natural attenuation process results from biological processes that naturally occur within ecosystems. Failure to account for attenuation of nitrogen during transport results in an over-estimate of nitrogen inputs to an estuary and an underestimate of the sensitivity of a system to new inputs (or removals). In addition to the nitrogen transport from land to sea, the amount of direct atmospheric deposition on each embayment surface must be determined as well as the amount of nitrogen recycling within the embayment, specifically nitrogen regeneration from sediments. Sediment nitrogen recycling results primarily from the settling and decay of phytoplankton and macroalgae (and eelgrass when present). During decay, organic nitrogen is transformed to inorganic forms, which may be released to the overlying waters or lost to denitrification within the sediments. Burial of nitrogen is generally small relative to the amount cycled. Sediment nitrogen regeneration can be a seasonally important source of nitrogen to embayment waters or in some cases a sink for nitrogen reaching the bottom. Failure to include the nitrogen balance of estuarine sediments generally leads to errors in predicting water quality, particularly in determination of summertime nitrogen load to embayment waters.

The MEP Technical Team includes technical staff from the Cape Cod Commission (CCC). With the guidance of CCC staff, Martha's Vineyard Commission (MVC) staff developed nitrogen-loading rates (Section IV.1) to the Edgartown Great Pond embayment system (Section III). The Edgartown Great Pond watershed was sub-divided to define contributing areas to each of the major sub-embayments to Edgartown Great Pond. A total of twelve (12) sub-watersheds were delineated for the Edgartown Great Pond Estuarine System. The nitrogen loading effort also involved further refinement of watershed delineations to accurately reflect shoreline areas to each portion of the embayment (see Chapter III).

In order to determine nitrogen loads from the watersheds, detailed individual lot-by-lot data is used for some portion of the loads, while information developed from other in-depth studies is applied to other portions. The Linked Watershed-Embayment Management Model (Howes and Ramsey, 2001) uses a land-use Nitrogen Loading Sub-Model based upon sub-watershed specific land uses and pre-determined nitrogen loading rates. For the Edgartown Great Pond embayment system, the model used MVC-supplied land-use data transformed to nitrogen loads using both regional nitrogen loading factors and local watershed specific data (such as average water use data provided by the Edgartown Water Department). Determination of the nitrogen loads required obtaining watershed specific information regarding wastewater, fertilizers, runoff from impervious surfaces and atmospheric deposition. The primary regional factors were derived for southeastern Massachusetts from direct measurements. The resulting nitrogen loads represent the “potential” or unattenuated nitrogen load to each receiving embayment, since attenuation during transport has not yet been included. Stream flow and associated surface water attenuation is included in the MEP nitrogen attenuation calculation and freshwater flow investigation, presented in Section IV.2 as applicable.

Natural attenuation during stream transport or in passage through fresh ponds of sufficient size to effect groundwater flow patterns (area and depth) is a standard part of the data collection effort of the MEP. However, the watershed to Edgartown Great Pond contains only smaller aquatic features that do not have separate watersheds delineated and, thus they are not explicitly included in the watershed analysis. If these small features were providing additional attenuation of nitrogen, nitrogen loading to the estuary would only be slightly (~10%) overestimated given the distribution of nitrogen sources and these features within the watershed. Based upon these considerations, the MEP Technical Team used the Nitrogen Loading Sub-Model estimate of nitrogen loading for the twelve sub-watersheds that directly discharge groundwater to the estuary. Internal nitrogen recycling was also determined throughout the tidal reaches of the Edgartown Great Pond Estuarine System; measurements were made to capture the spatial distribution of sediment nitrogen regeneration from the sediments to the overlying water-column. Nitrogen regeneration focused on summer months, the critical nitrogen management interval and the focal season of the MEP approach and application of the Linked Watershed-Embayment Management Model (Section IV.3).

### IV.1.1 Land Use and Water Use Database Preparation

Martha’s Vineyard Commission (MVC) staff, with the guidance of Estuaries Project staff, combined digital parcel and tax assessors data from the MVC Geographic Information Systems Department. Digital parcels and land use/assessors data are from 2005. These land use databases contain traditional information regarding land use classifications (MADOR, 2002) plus additional information developed by the MVC.

Figure IV-1 shows the land uses within the Edgartown Great Pond Estuary watershed area. Land uses in the study area are grouped into eight land use categories: 1) residential, 2) commercial, 3) mixed use, 4) undeveloped (including residential open space), 5) agricultural, 6) public service/government, including road rights-of-way, 7) golf courses and 8) freshwater (e.g., ponds). These land use categories are generally aggregations derived from the major categories in the Massachusetts Assessors land uses classifications (MADOR, 2002). “Public service” in the MADOR system is tax-exempt properties, including lands owned by government (e.g., wellfields, schools, golf courses, open space, roads) and private groups like churches and colleges.

In the overall Edgartown Great Pond System watershed, the predominant land use based on area is public service (government owned lands, roads, and rights-of-way), which accounts for 44% of the overall watershed area; residential is the second highest percentage of the system watershed (32%) (Figure IV-2). However, 68% of the parcels in the system watershed are classified as residential. Single-family residences (MADOR land use code 101) are 87% of the residential parcels and 68% of the residential land area. Public service land uses are the dominant land use category in four of the individual sub-watersheds and the overall watershed. Residential land uses are the dominant land use in seven of the remaining sub-watersheds; in the South Beach sub-watershed land use classified as commercial is the dominant type (the

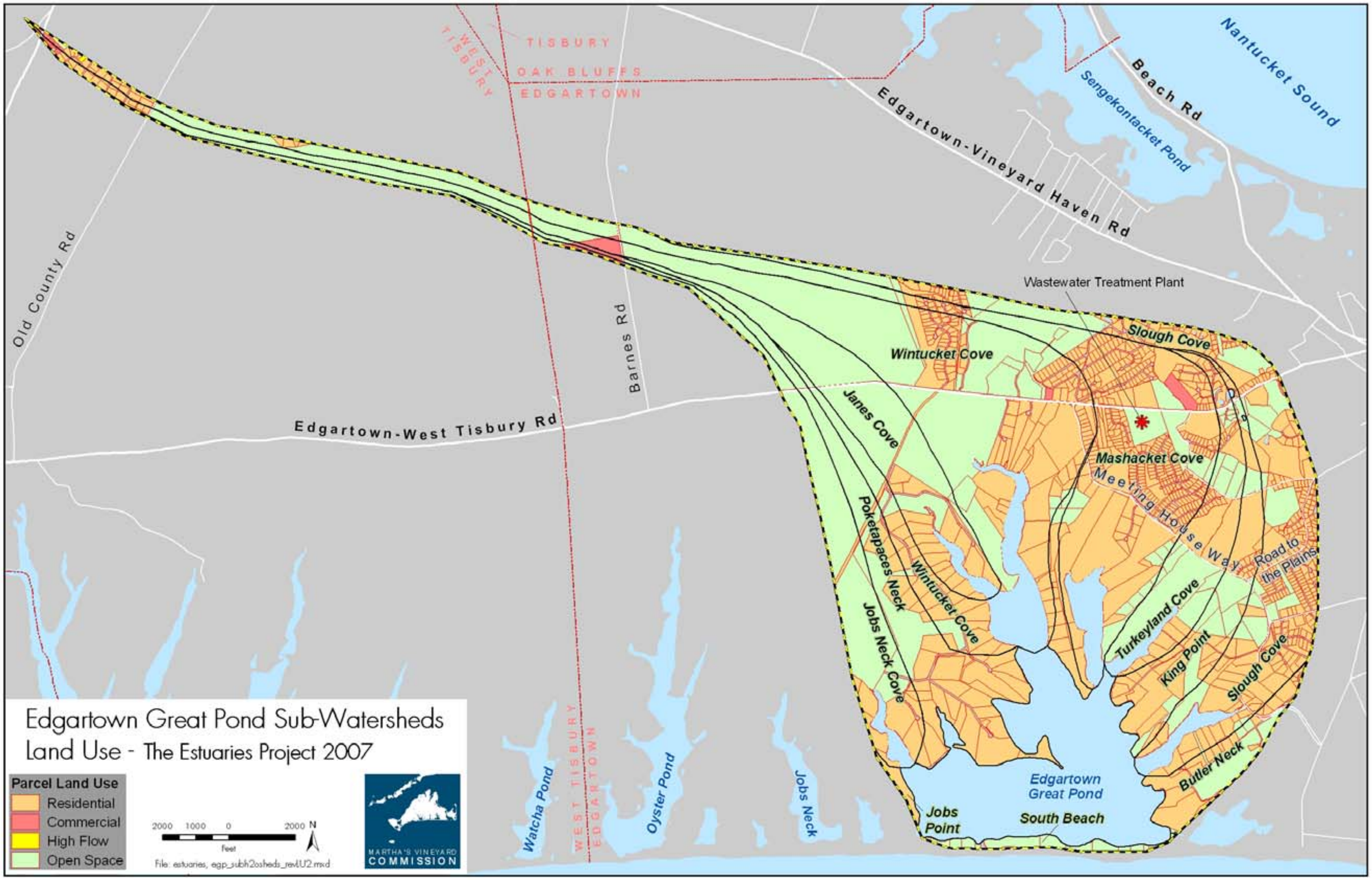



Figure IV-1. Land-use in the Edgartown Great Pond watershed. Most of the watershed is within the Town of Edgartown; a small portion extends into West Tisbury. Land use classifications are based on assessors' records provided by the town.

primary commercial use in this sub-watershed is a beach). Undeveloped parcels are generally the third highest land use area classification, although in some cases, like the Turkeyland Cove sub-watershed, it is the second highest classification. Overall, undeveloped land uses account for 16% of the entire Edgartown Great Pond watershed area, while golf course properties account for the next highest percentage at 4%.

In order to estimate wastewater flows, MEP staff generally work with municipal or water supplier partners in the study watershed to obtain parcel-by-parcel water use information. With this in mind, MVC staff contacted Fred Domont, Superintendent of the Edgartown Water Department (EWD) and obtained average water use information for properties in and near the Edgartown Great Pond watershed. MVC Staff reviewed two years of water use records (4/04-4/05 and 4/05-4/06) for approximately 400 accounts. This review found the average water use account used 67,590 gallons per year with a range among the accounts reviewed from zero use to 739,000 gallons per year. This average water use translates into 185 gallons per day and this average was used as a proxy for wastewater generation from septic systems on all developed properties in the Edgartown Great Pond watershed. Wastewater-based nitrogen loading from the individual parcels using on-site septic systems is based upon the average water-use, nitrogen concentration, and consumptive loss of water before the remainder is treated in a septic system (see Section IV.1.2).

### IV.1.2 Nitrogen Loading Input Factors

#### *Wastewater/Water Use*

The Massachusetts Estuaries Project septic system nitrogen-loading rate is fundamentally based upon a per Capita Nitrogen load to the receiving aquatic system. Specifically, the MEP septic system wastewater nitrogen loading is based upon a number of studies and additional information that directly measured septic system and per capita loads on Cape Cod or in similar geologic settings (Nelson et al. 1990, Weiskel and Howes 1991, 1992, Koppelman 1978, Frimpter et al. 1990, Brawley et al. 2000, Howes and Ramsey 2000, Costa et al. 2001). Variation in per capita nitrogen load has been found to be relatively small, with average annual per capita nitrogen loads generally between 1.9 to 2.3 kg person-yr$^{-1}$.

However, given the seasonal shifts in occupancy and rapid population growth throughout southeastern Massachusetts, decennial census data yields accurate estimates of total population only in selected watersheds. To correct for this uncertainty and more accurately assess current nitrogen loads, the MEP employs a water-use approach. The water-use approach is generally applied on a parcel-by-parcel basis within a watershed, where annual water meter data is linked to assessors parcel information using GIS techniques. The parcel specific water use data is converted to septic system nitrogen discharges (to the receiving aquatic systems) by adjusting for consumptive use (*e.g.*, irrigation) and applying a wastewater nitrogen concentration. The water use approach focuses on the nitrogen load, which reaches the aquatic receptors down gradient in the aquifer.

All nitrogen losses within the septic system are incorporated into the MEP analysis. For example, information developed at the MASSDEP Alternative Septic System Test Center at the Massachusetts Military Reservation on Title 5 septic systems have shown nitrogen removals between 21% and 25%. Multi-year monitoring from the Test Center has revealed that nitrogen

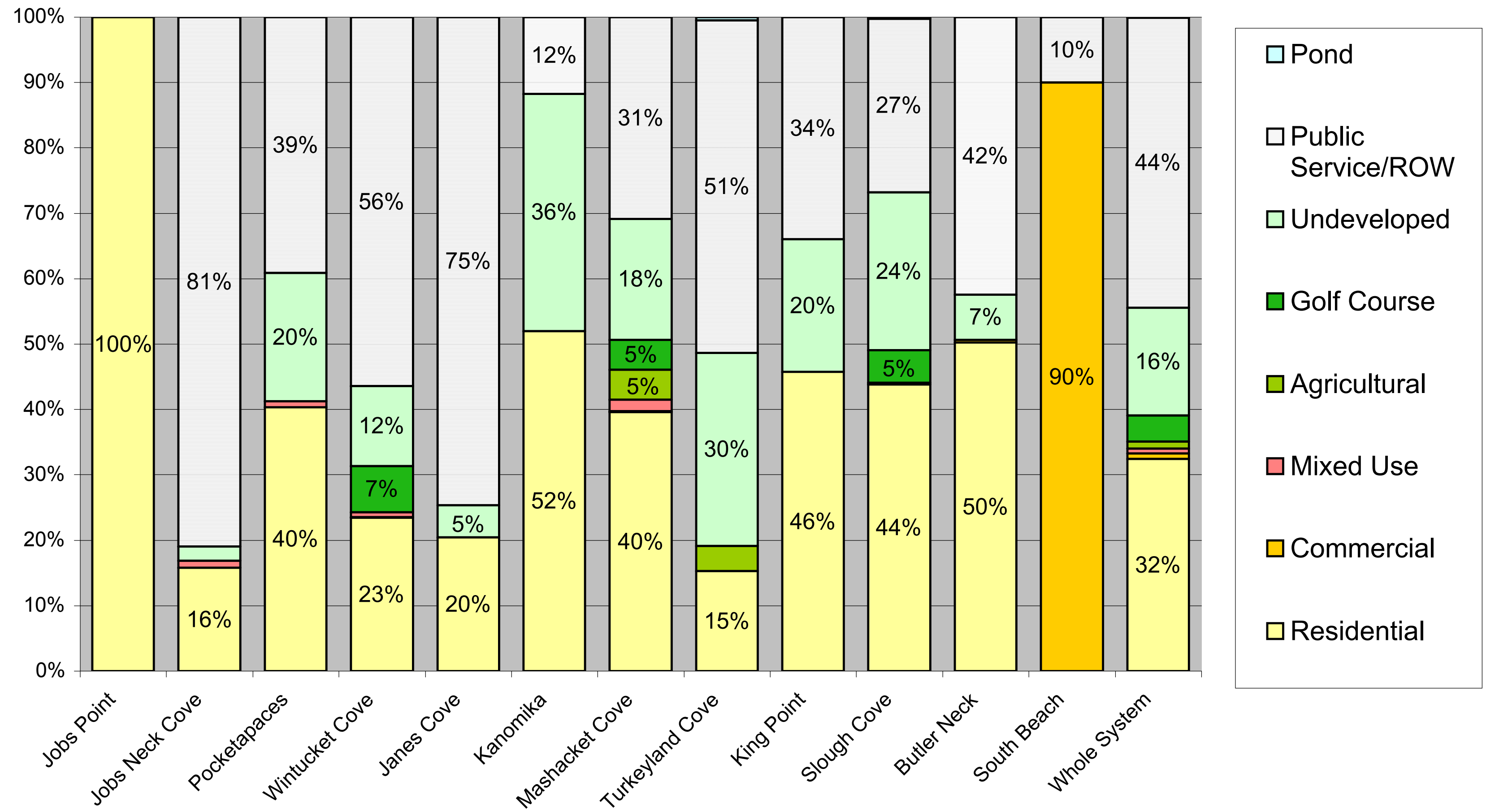



Figure IV-2. Distribution of land-uses within the sub-watersheds and whole watershed to Edgartown Great Pond. Only percentages greater than or equal to 5% are shown.

removal within the septic tank was small (1% to 3%), with most (20 to 22%) of the removal occurring within five feet of the soil adsorption system (Costa et al. 2001). Down gradient studies of septic system plumes indicate that further nitrogen loss during aquifer transport is negligible (Robertson et al. 1991, DeSimone and Howes 1996).

In its application of the water-use approach to septic system nitrogen loads, the MEP has ascertained for the Estuaries Project region that while the per capita septic load is well constrained by direct studies, the consumptive use and nitrogen concentration data are less certain. As a result, the MEP has derived a combined term for an effective N Loading Coefficient (consumptive use times N concentration) of 23.63, to convert water (per volume) to nitrogen load (N mass). This coefficient uses a per capita nitrogen load of 2.1 kg N person-yr$^{-1}$ and is based upon direct measurements and corrects for changes in concentration that result from per capita shifts in water-use (e.g. due to installing low plumbing fixtures or high versus low irrigation usage).

The nitrogen loads developed using this approach have been validated in a number of long and short-term field studies where integrated measurements of nitrogen discharge from watersheds could be directly measured. Weiskel and Howes (1991, 1992) conducted a detailed watershed/stream tube study that monitored septic systems, leaching fields and the transport of the nitrogen in groundwater to adjacent Buttermilk Bay. This monitoring resulted in estimated annual per capita nitrogen loads of 2.17 kg (as published) to 2.04 kg (if new attenuation information is included). Modeled and measured nitrogen loads were determined for a small sub-watershed to Mashapaquit Creek in West Falmouth Harbor (Smith and Howes, manuscript in review) where measured nitrogen discharge from the aquifer was within 5% of the modeled N load. Another evaluation was conducted by surveying nitrogen discharge to the Mashpee River in reaches with swept sand channels and in winter when nitrogen attenuation is minimal. The modeled and observed loads showed a difference of less than 8%, easily attributable to the low rate of attenuation expected at that time of year in this type of ecological situation (Samimy and Howes, unpublished data).

While census based population data has limitations in the highly seasonal MEP region, part of the regular MEP analysis is to compare expected water used based on average residential occupancy to measured average water uses. This is performed as a quality assurance check to increase certainty in the final results. This comparison has shown that the larger the watershed the better the match between average water use and occupancy. For example, in the cases of the combined Great Pond, Green Pond and Bournes Pond watershed in the Town of Falmouth and the Popponesset Bay/Eastern Waquoit Bay watershed, which covers large areas and have significant year-round populations, the septic nitrogen loading based upon the census data is within 5% of that from the water use approach. This comparison matches some of the variability seen in census data itself. Census blocks, which are generally smaller areas of any given town, have shown up to a 13% difference in average occupancy form town-wide occupancy rates. These analyses provide additional support for the use of the water use approach in the MEP study region.

Overall, the MEP water use approach for determining septic system nitrogen loads has been both calibrated and validated in a variety of watershed settings. The approach: (a) is consistent with a suite of studies on per capita nitrogen loads from septic systems in sandy outwash aquifers; (b) has been validated in studies of the MEP Watershed “Module”, where there has been excellent agreement between the nitrogen load predicted and that observed in direct field measurements corrected to other MEP Nitrogen Loading Coefficients (e.g., stormwater, lawn fertilization); (c) the MEP septic nitrogen loading coefficient agrees in specific studies of consumptive water use and nitrogen attenuation between the septic tank and the discharge site; and (d) the watershed module provides estimates of nitrogen attenuation by freshwater systems that are consistent with a variety of ecological studies. It should be noted that while points b-d support the use of the MEP Septic N Coefficient, they were not used in its development. The MEP Technical Team has developed the septic system nitrogen load over many years, and the general agreement among the number of supporting studies has greatly enhanced the certainty of this critical watershed nitrogen loading term.

The independent validation of the water quality model (Section VI) adds additional weight to the nitrogen loading coefficients used in the MEP analyses and a variety of other MEP embayments. While the MEP septic system nitrogen load is the best estimate possible, to the extent that it may underestimate the nitrogen load from this source reaching receiving waters provides a safety factor relative to other higher loads that are generally used in regulatory situations. The lower concentration results in slightly higher amounts of nitrogen mitigation (estimated at 1% to 5%) needed to lower embayment nitrogen levels to a nitrogen target (e.g. nitrogen threshold, cf. Section VIII). The additional nitrogen removal is not proportional to the septic system nitrogen level, but is related to the how the septic system nitrogen mass compares to the nitrogen loads from all other sources that reach the estuary (i.e. attenuated loads).

In order to provide an independent validation of the average residential water use within the Edgartown Great Pond System watershed, MEP staff reviewed US Census population values for the Town of Edgartown. The state on-site wastewater regulations (*i.e.*, 310 CMR 15, Title 5) assume that two people occupy each bedroom and each bedroom has a wastewater flow of 110 gallons per day (gpd), so for the purposes of Title 5 each person generates 55 gpd of wastewater. Based on data collected during the 2000 US Census, average occupancy within Edgartown is 2.39 people per occupied housing unit, while year-round occupancy of available housing units is 39%. Based on the average occupancy rate, the average water use by this calculation should be approximately 131 gpd. Given that such a high percentage of housing units are occupied on only a seasonal basis and the average includes this factor, the comparatively high average water use suggests that a significant portion of the water use occurs during summer months and seasonal dwellings use a disproportionally high amount of water.

In most previously completed MEP studies, average population and average water use have generally agreed fairly well. Since the Edgartown Great Pond analysis is dependent on an average water use rather than parcel-by-parcel water use, MEP staff also reviewed more refined US Census information. Besides reviewing data on town and state levels, the US Census also develops information for smaller areas (i.e., tracts and block groups). The majority of the watershed to Edgartown Great Pond is contained within two Census block groups; block group 4 of tract 2003, which generally covers the main portion of the southern and western sub-watershed, and block group 3 of tract 2003, which generally covers the northeast portion of the watershed and extends to Sengekontacket Pond. Year 2000 Census residential occupancy rates in the block groups are 2.49 and 2.48 people per house, respectively. This population information suggests that the average flow within the Edgartown Great Pond watershed should be slightly higher, approximately 137 gpd, but still does not account for the higher average measured flow when accounting for seasonal occupancy. As previously discussed above, average water use based on parcel by parcel water use information was used to determine that a 185 gallons per day average water use would be most appropriate as a proxy for wastewater generation from septic systems on all developed properties in the Edgartown Great Pond watershed.

Commercial and industrial properties were treated the same as residential properties. There are only 22 commercial properties in the Edgartown Great Pond watershed, which is approximately 2% of the total number of parcels.

***Edgartown Wastewater Treatment Facility***

The Town of Edgartown maintains a municipal wastewater treatment facility (WWTF) with discharge basins within the Mashacket Cove sub-watershed to Edgartown Great Pond (Figure IV-1). The WWTF imports wastewater from a sewer collection system generally concentrated in the main town center of Edgartown, which is located to the east of the Great Pond watershed. The WWTF treats the collected wastewater and discharges it into six effluent discharge beds at the facility just off West Tisbury Road. MEP staff obtained six years (2001-2006) worth of effluent flow and total nitrogen discharge information from Edgartown WWTF website (http://www.edgartownwastewater.org/). Staff also reviewed previous evaluations of the WWTF, including MVC (1999), in order to evaluate potential groundwater travel-time delays. This information was used to review the current and historic nitrogen loading from the WWTF.

According to MVC (1999), the Edgartown WWTF produced an annual nitrogen load of 2,404 kg prior to an upgrade of the facility in 1996. In the more recent years between 2001 and 2006, the Edgartown WWTF has had little fluctuation in total annual flow and nitrogen load between 2001 and 2006 (Figure IV-3). Total annual flow during these more recent years fluctuates between 52 and 64 million gallons with an average of 59 million gallons. Annual nitrogen load fluctuates slightly more than flow with a range of 558 to 700 kg and an average of 636 kg. The average annual load over the last three years (2004-2006) is 695 kg with a range of 691 to 700 kg.

MEP staff reviewed potential groundwater travel times to Edgartown Great Pond based on the distance from the WWTF discharge and a generalized flow of 1 ft/d. This groundwater flow rate is a general rule of thumb on Cape Cod for first approximation of travel times and has been supported by analyses including the travel time of the groundwater plume from the Town of Falmouth WWTF (Howes, *et al*., 2006). Based on this approximation, it is estimated that the WWTF discharge will take between 10 and 12 years to reach the pond.

Because of this travel time, the load from the WWTF reaching the pond could be either pre- or post-upgrade. Review of the available water quality data suggests that the results of the upgrade have not reached the pond, but should be arriving within the next year or two (See Chapter VI). Based on this analysis, the current conditions include an annual load of 2,404 kg.

Build out load for the Edgartown WWTF is based on the assumption that the design flow of the facility (750,000 gpd) will be attained in August and flow in all other months will be adjusted based on their percentage of the 2005 annual flow. The resulting buildout annual flow is 140 million gallons or a 137% increase in flow over 2005. The effluent total nitrogen concentration assigned to these flows is 2.85 ppm, which is the flow-weighted average concentration from 2005. The resulting buildout annual load from the Edgartown WWTF based on these assumptions is 1,707 kg. Based on this analysis, annual nitrogen loads to Edgartown Great Pond from the Edgartown WWTF will decline from 2,404 kg to approximately 695 and, if build out for the WWTF is achieved, increase to annual load of 1,707 kg. The annual build out load from the Edgartown WWTF is 697 kg less than current conditions.

### *Nitrogen Loading Input Factors: Fertilized Areas*

The second largest source of estuary watershed nitrogen loading is usually fertilized lawns, golf courses, and cranberry bogs, with lawns being the predominant source within this category. In the Edgartown Great Pond watershed, there are also 143 acres of farmland producing a variety of crops. In order to add all of these sources to the nitrogen-loading model for the Edgartown Great Pond system, MVC staff under the guidance of MEP staff reviewed available information about residential lawn fertilizing practices, crop fertilizer usage, and obtained information on fertilizer application rates at the Vineyard Golf Club. No cranberry bogs were identified within the watershed.

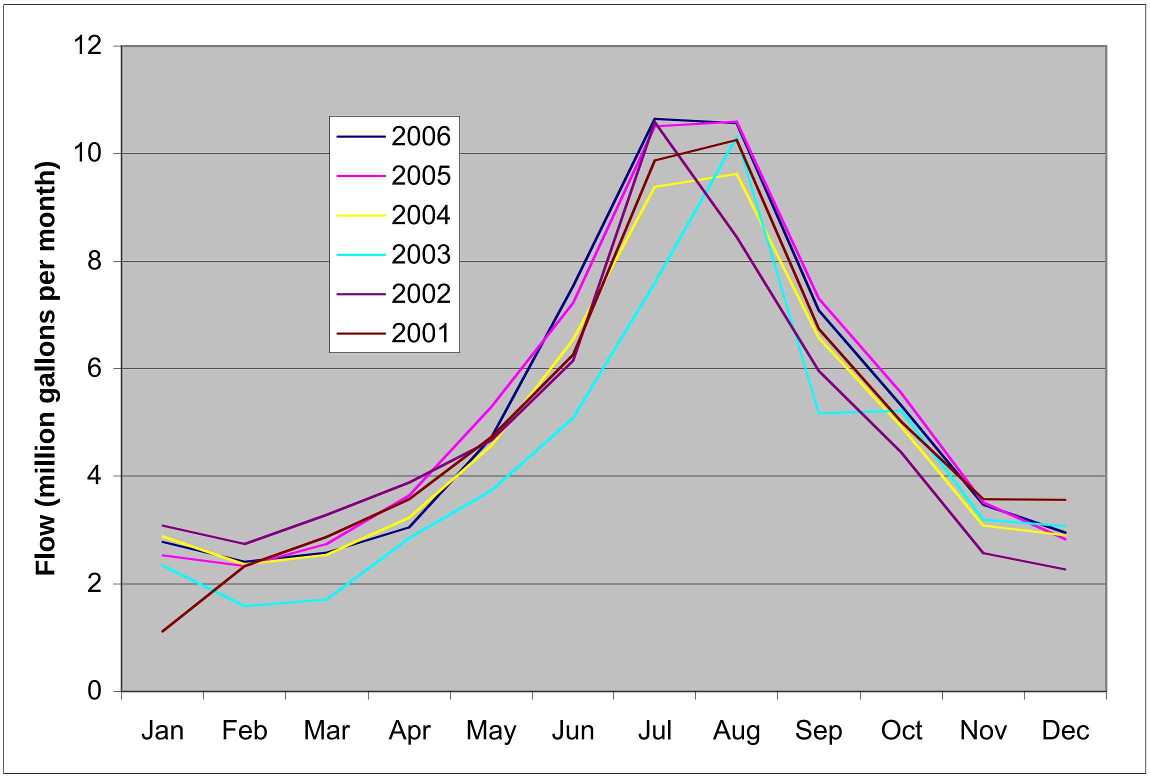
Residential lawn fertilizer use has rarely been directly measured in watershed-based nitrogen loading investigations. Instead, lawn fertilizer nitrogen loads have been estimated based upon a number of assumptions: a) each household applies fertilizer, b) cumulative annual applications are 3 pounds of nitrogen per 1,000 sq. ft. of lawn, c) each lawn is 5000 sq. ft., and d) only 25% of the nitrogen applied reaches the groundwater (leaching rate). Because many of these assumptions had not been rigorously reviewed in over a decade, the MEP Technical Staff undertook an assessment of lawn fertilizer application rates and a review of leaching rates for inclusion in the Watershed Nitrogen Loading Sub-Model.

The initial effort in this assessment was to determine nitrogen fertilization rates for residential lawns in the Towns of Falmouth, Mashpee and Barnstable. The assessment accounted for proximity to fresh ponds and embayments. Based upon ~300 interviews and over 2,000 site surveys, a number of findings emerged: 1) average residential lawn area is ~5000 sq. ft., 2) half of the residences did not apply lawn fertilizer, and 3) the weighted average application rate was 1.44 applications per year, rather than the 4 applications per year recommended on the fertilizer bags. Integrating the average residential fertilizer application rate with a leaching rate of 20% results in a fertilizer contribution of N to groundwater of 1.08 lb N per residential lawn; these factors are generally used in the MEP nitrogen loading calculations.

In 1999, a land use survey was conducted on Martha's Vineyard (MV Commission, 1999). This survey found that the average lawn size was 3,100 sq. ft. and that household application rates averaged 0.55 lb N per residential lawn. MEP Technical staff reviewed these factors with MVC staff and included these factors in the development of the Edgartown Great Pond watershed nitrogen-loading model. Other factors in the model are those generally used in MEP nitrogen loading calculations.

MVC staff contacted Vineyard Golf Club staff and obtained the following nitrogen application rates for the various portions of the Club: greens, 2.0 pounds per 1,000 sq. ft; tees, 2.6 pounds per 1,000 sq. ft; and fairways and roughs, 2.7 pounds per 1,000 sq. ft (Jeff Carlson, Course Manager, personal communication). These loads are reduced by the amount reaching the groundwater, i.e., the leaching rate. The area of each of these portions was determined from a review of orthophotographs and use of GIS techniques. Since the Golf Club is located in two sub-watersheds, the load was appropriately split between these sub-watersheds. The overall annual load from the Golf Club is 318 kg.

MVC staff also contacted various farms within the watershed to obtain information on fertilization practices. Crop types are row crops, hay, pasture, and greenhouse/nursery. Application rates range from 18 to 68 kg per acre. Leaching rates were determined based on estimates of soil disturbance and range between 0.1 and 0.33. Overall, farming occurs on 143 acres and adds 1,162 kg per year to the Edgartown Great Pond watershed.



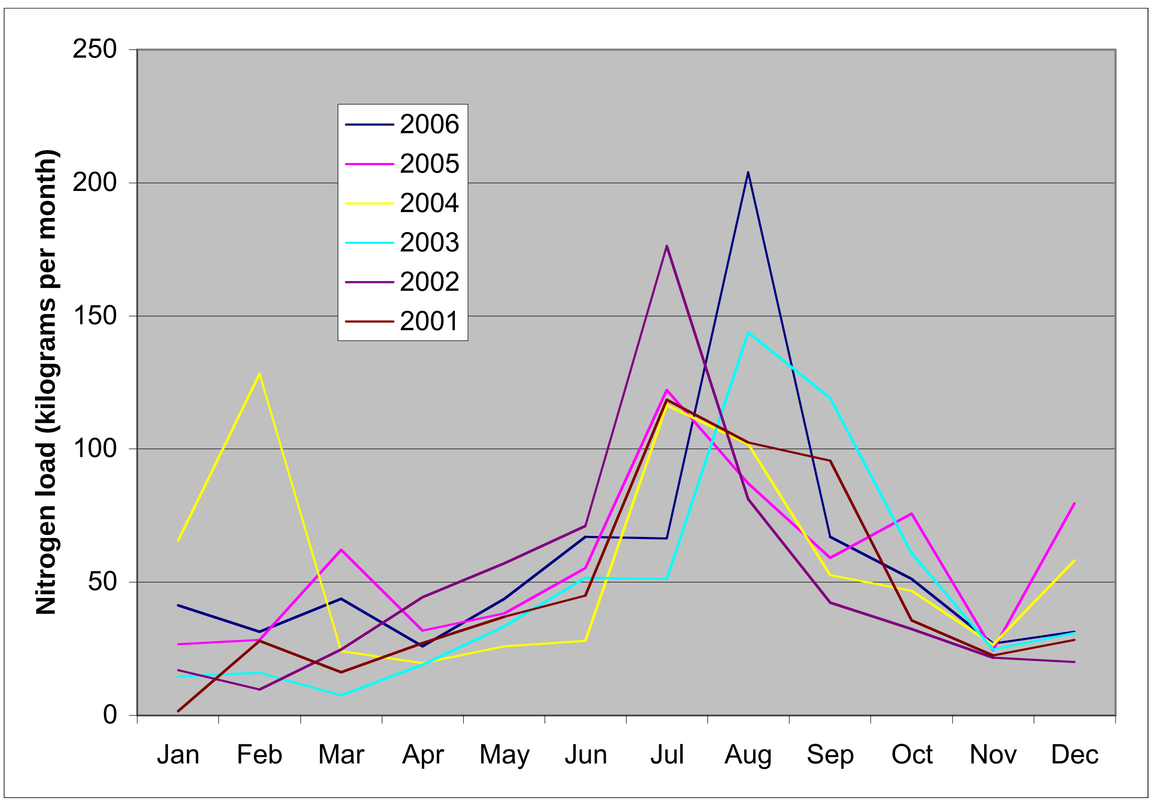




Figure IV-3. Effluent flow and total nitrogen-loading data from Town of Edgartown Wastewater Treatment Facility (2001-06).

### *Nitrogen Loading Input Factors: Other*

One of the other key factors in the nitrogen loading calculations is recharge rates associated with impervious surfaces and natural areas. As discussed in Chapter III, Martha's Vineyard-specific recharge rates were developed and utilized based on comparison to the precipitation data in Edgartown and results of the USGS groundwater modeling effort on Cape Cod. Other nitrogen loading factors for atmospheric deposition, impervious surfaces and natural areas are from the MEP Embayment Modeling Evaluation and Sensitivity Report (Howes and Ramsey 2001). The factors are similar to those utilized by the Cape Cod Commission's Nitrogen Loading Technical Bulletin (Eichner and Cambareri, 1992) and Massachusetts MASSDEP's Nitrogen Loading Computer Model Guidance (1999). Factors used in the MEP nitrogen loading analysis for the Edgartown Great Pond watershed are summarized in Table IV-1.

Table IV-1. Primary Nitrogen Loading Factors used in the Edgartown Great Pond MEP analyses. General factors are from MEP modeling evaluation (Howes and Ramsey 2001). Site-specific factors are derived from Edgartown or Martha's Vineyard data. *Data from 1999 Martha's Vineyard lawn analysis.

| Nitrogen Concentrations: | mg/l | Recharge Rates: | in/yr |
|---|---|---|---|
| Road Run-off | 1.5 | Impervious Surfaces | 42.2 |
| Roof Run-off | 0.75 | Natural and Lawn Areas | 28.7 |
| Direct Precipitation on Embayments and Ponds | 1.09 | Water Use/Wastewater: | |
| Natural Area Recharge | 0.072 | Existing developed residential parcels and buildout residential parcels: | 185 gpd |
| Wastewater | | | |
| Wastewater Coefficient | 23.63 | | |
| Edgartown WWTF load – current (kg/yr) | 2,404 | Commercial and industrial buildout additions: | 21 gpd/1,000 ft2 of building |
| Edgartown WWTF load – buildout (kg/yr) | 1,707 | Commercial and industrial building coverage accounts and buildout additions: | 28% |
| WWTF buildout effluent TN (mg/l) | 2.85 | | |
| Fertilizers: | | Golf Course Fertilizers | lbs/1,000 sq ft |
| Average Residential Lawn Size (sq ft)* | 3,100 | **FAIRWAYS AND ROUGHS** | 2.7 |
| Residential Watershed Nitrogen Rate (lbs/lawn)* | 0.55 | Greens | 2.0 |
| | | Tees | 2.6 |

### IV.1.3 Calculating Nitrogen Loads

Once all the land and water use information was linked to the parcel coverages, parcels were assigned to various watersheds based initially on whether at least 50% or more of the land area of each parcel was located within a respective watershed. Following the assigning of boundary parcels, all large parcels were examined individually and were split (as appropriate) in order to obtain less than a 2% difference between the total land area of each sub-watershed and the sum of the area of the parcels within each sub-watershed. The resulting "parcelized" watersheds to Edgartown Great Pond are shown in Figure IV-4.

The review of individual parcels straddling watershed boundaries included corresponding reviews and individualized assignment of nitrogen loads associated with lawn areas, septic systems, and impervious surfaces. Individualized information for parcels with atypical nitrogen loading (condominiums, golf courses, etc.) was also assigned at this stage. It should be noted that small shifts in nitrogen loading due to the above assignment procedure generally have a negligible effect on the total nitrogen loading to the Edgartown Great Pond estuary. The assignment effort was undertaken to better define the sub-embayment loads and enhance the use of the Linked Watershed-Embayment Model for the analysis of management alternatives.

Following the assignment of all parcels, sub-watershed modules were generated for each of the twelve sub-watersheds summarizing water use, parcel area, frequency, sewer connections, private wells, and road area. The individual sub-watershed modules were then integrated to create the Edgartown Great Pond Watershed Nitrogen Loading module with summaries for each of the individual sub-embayments. The sub-embayments represent the functional embayment units for the Linked Watershed-Embayment Model's water quality component.

For management purposes, the aggregated embayment watershed nitrogen loads are partitioned by the major types of nitrogen sources in order to focus development of nitrogen management alternatives. Within the Edgartown Great Pond System, the major types of nitrogen loads are: wastewater (e.g., septic systems), fertilizer, impervious surfaces, direct atmospheric deposition to water surfaces, and recharge within natural areas (Table IV-2). The output of the watershed nitrogen-loading model is the annual mass (kilograms) of nitrogen added to the contributing area of component sub-embayments, by each source category (Figure IV-5). In general, the annual watershed nitrogen input to the watershed of an estuary is then adjusted for natural nitrogen attenuation during transport to the estuarine system before use in the embayment water quality sub-model.

***Buildout***

Part of the regular MEP watershed nitrogen loading modeling is to prepare a buildout assessment of potential development within the study area watershed. For the Edgartown Great Pond modeling, MVC staff under the guidance of MEP staff reviewed individual properties for potential additional development. This review included assessment of minimum lot sizes under current zoning, potential additional development on existing developed lots, and review of guesthouse provisions available under local regulations. The buildout procedure used in this watershed and generally completed by MEP staff is to evaluate town zoning to determine minimum lot sizes in each of the zoning districts, including overlay districts (*e.g.*, water resource protection districts). Larger lots are subdivided by the minimum lot size to determine the total number of new lots and existing developed properties are reviewed for additional development potential; for example, residential lots that are twice the minimum lot size, but have only one residence. Most of the focus of new development is for properties classified as developable by the local assessor (state class land use codes 130 and 131 for residential properties). Properties classified by the Edgartown assessor as "undevelopable" (e.g., codes 132 and 392) were not assigned any development at buildout. Commercially developable properties were not subdivided; the area of each parcel and the factors in Table IV-1 were used to determine a wastewater flow for these properties. Based on the buildout assessment completed for this review, there are 1,059 potential additional residential dwellings and 21.7 acres of developable commercial land in the Edgartown Great Pond watershed. All the parcels included in the buildout assessment of the Edgartown Great Pond watershed are shown in Figure IV-4.

Table IV-2 presents a sum of the additional nitrogen loads by sub-watershed. This includes the wastewater, fertilizer, and impervious surface loads from additional residential dwellings added under the buildout scenario, as well as wastewater and impervious surface loads from projected commercial buildout additions. The buildout load also includes the additions estimated for the Edgartown WWTF when it reaches its design flow capacity (750,000 gpd) and anticipated reductions in farm fertilizers due to development at buildout. Overall, buildout additions within the entire Edgartown Great Pond System watershed will increase the unattenuated loading rate by 44%.

## IV.2 ATTENUATION OF NITROGEN IN SURFACE WATER TRANSPORT

### IV.2.1 Background and Purpose

Modeling and predicting changes in coastal embayment nitrogen related water quality is based, in part, on determination of the inputs of nitrogen from the surrounding contributing land or watershed. This watershed nitrogen input parameter is the primary term used to relate present and future loads (build-out or sewering analysis) to changes in water quality and habitat health. Therefore, nitrogen loading is the primary threshold parameter for protection and restoration of estuarine systems. Rates of nitrogen loading to the watershed of the Edgartown Great Pond System were based upon the delineated watersheds (Section III) and their land-use coverages (Section IV.1). If all of the nitrogen applied or discharged within a watershed reaches an embayment the watershed land-use loading rate represents the nitrogen load to the receiving waters. This condition exists in watersheds where nitrogen transport is through groundwater in sandy outwash aquifers. The lack of nitrogen attenuation in these aquifer systems results from the lack of biogeochemical conditions needed for supporting nitrogen sorption and denitrification. This is the case for the Edgartown Great Pond watershed. Unlike most watersheds in southeastern Massachusetts, nitrogen does not pass through a surface water ecosystem on its path to the adjacent embayment. It is in these surface water systems that the needed conditions for nitrogen retention and denitrification exist. As there were no streams or great fresh ponds within the Edgartown Great Pond watershed, the watershed loading approach considered that nitrogen reaching the water table was transported without attenuation in the groundwater system until discharge to the estuary.

## IV.3 BENTHIC REGENERATION OF NITROGEN IN BOTTOM SEDIMENTS

The overall objective of the benthic nutrient flux Surveys was to quantify the summertime exchange of nitrogen, between the sediments and overlying waters throughout the Edgartown Great Pond System. The mass exchange of nitrogen between water column and sediments is a fundamental factor in controlling nitrogen levels within coastal waters. These fluxes and their associated biogeochemical pools relate directly to carbon, nutrient and oxygen dynamics and the nutrient related ecological health of these shallow marine ecosystems. In addition, these data are required for the proper modeling of nitrogen in shallow aquatic systems, both fresh and salt water.

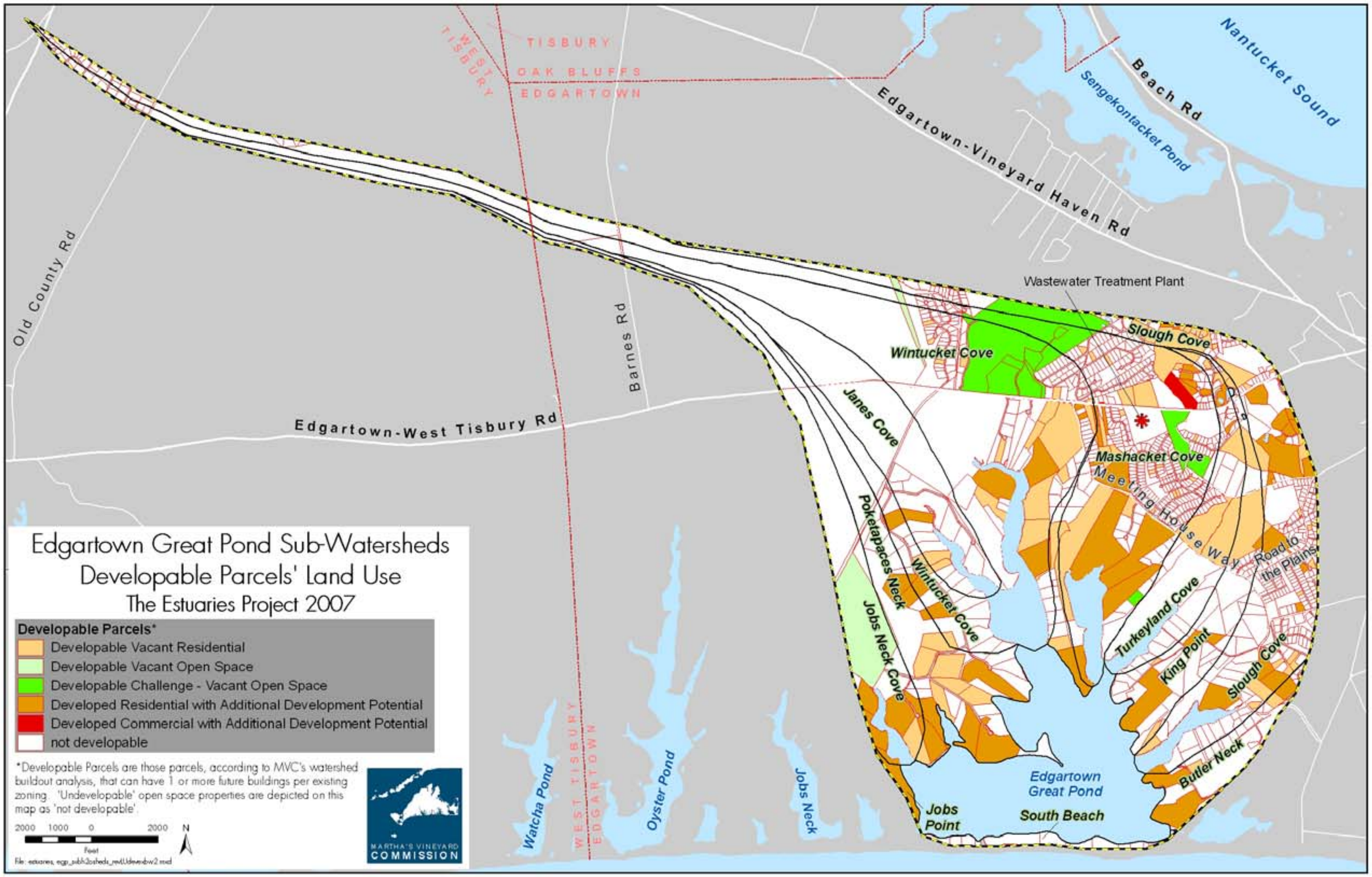



Figure IV-4. Parcels, Parcelized Watersheds, and Developable Parcels in the Edgartown Great Pond system watershed and sub-watersheds.

Table IV-2. Edgartown Great Pond Nitrogen Loads. Presents nitrogen loads based on current conditions including import of nitrogen into the watershed by the Edgartown WWTF. Buildout loads include septic, fertilizer, and impervious surface additions from developable properties, as well as increased flows to the WWTF. All values are kg N $yr^{-1}$.

| | | Edgartown Great Pond N Loads by Input (kg/y): | | | | | | | | % of Pond Outflow | Present N Loads | | | Buildout N Loads | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Watershed ID# | Wastewater | Treatment Facility | Fertilizers | Impervious Surfaces | Agriculture | Water Body Surface Area | "Natural" Surfaces | Buildout | | UnAtten N Load | Atten % | Atten N Load | UnAtten N Load | Atten % | Atten N Load |
| **Edgartown Great Pond Total** | | **5536** | **2404** | **659** | **1157** | **368** | **4068** | **931** | **6706** | | **15125** | | **15125** | **21831** | | **21831** |
| Jobs Neck Cove Total | | 24 | 0 | 1 | 24 | 0 | 92 | 79 | 300 | | 221 | | 221 | 520 | | 520 |
| Jobs Neck Cove | 2 | 24 | 0 | 1 | 24 | 0 | | 79 | 300 | | 129 | | 129 | 428 | | 428 |
| Jobs Neck Cove Estuary Surface | | | | | | | 92 | | | | 92 | | 92 | 92 | | 92 |
| Wintucket Cove Total | | 886 | 0 | 210 | 312 | 17 | 593 | 316 | 1017 | | 2334 | | 2334 | 3351 | | 3351 |
| Wintucket Cove | 4 | 843 | 0 | 208 | 259 | 17 | | 237 | 964 | | 1564 | | 1564 | 2528 | | 2528 |
| Janes Cove | 5 | 42 | 0 | 2 | 53 | 0 | | 79 | 53 | | 177 | | 177 | 230 | | 230 |
| Wintucket Cove Estuary Surface | | | | | | | 508 | | | | 508 | | 508 | 508 | | 508 |
| Janes Cove Estuary Surface | | | | | | | 85 | | | | 85 | | 85 | 85 | | 85 |
| Mashacket Cove Total | | 2215 | 2404 | 222 | 332 | 134 | 257 | 169 | 1247 | | 5733 | | 5733 | 6979 | | 6979 |
| Mashacket Cove | 7 | 2215 | 2404 | 222 | 332 | 134 | | 169 | 1247 | | 5476 | | 5476 | 6722 | | 6722 |
| Mashacket Cove Estuary Surface | | | | | | | 257 | | | | 257 | | 257 | 257 | | 257 |
| Turkeyland Cove Total | | 199 | 0 | 6 | 50 | 28 | 109 | 52 | 1032 | | 444 | | 444 | 1476 | | 1476 |
| Turkeyland Cove | 8 | 199 | 0 | 6 | 50 | 28 | | 52 | 1032 | | 335 | | 335 | 1367 | | 1367 |
| Turkeyland Cove Estuary Surface | | | | | | | 109 | | | | 109 | | 109 | 109 | | 109 |
| Slough Cove Total | | 1668 | 0 | 200 | 283 | 88 | 151 | 125 | 1894 | | 2514 | | 2514 | 4408 | | 4408 |
| Slough Cove | 10 | 1668 | 0 | 200 | 283 | 88 | | 125 | 1894 | | 2364 | | 2364 | 4257 | | 4257 |
| Slough Cove Estuary Surface | | | | | | | 151 | | | | 151 | | 151 | 151 | | 151 |
| Main Pond Total | | 544 | 0 | 20 | 156 | 102 | 2867 | 190 | 1217 | | 3879 | | 3879 | 5096 | | 5096 |
| Jobs Point | 1 | 6 | 0 | 0 | 0 | 0 | 0 | 3 | 20 | | 9 | | 9 | 29 | | 29 |
| Pocketapaces | 3 | 145 | 0 | 6 | 62 | 0 | 0 | 89 | 317 | | 302 | | 302 | 619 | | 619 |
| King Point | 9 | 242 | 0 | 9 | 46 | 0 | 0 | 51 | 729 | | 348 | | 348 | 1077 | | 1077 |
| Kanomika Neck | 6 | 18 | 0 | 0 | 1 | 3 | 0 | 10 | 54 | | 33 | | 33 | 87 | | 87 |
| Butler Neck | 11 | 133 | 0 | 4 | 47 | 99 | 0 | 28 | 97 | | 311 | | 311 | 408 | | 408 |
| South Beach | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | | 8 | | 8 | 8 | | 8 |
| Mid-Pond Estuary | | 0 | 0 | 0 | 0 | | 1073 | 0 | 0 | | 1073 | 0 | 1073 | 1073 | | 1073 |
| Lower-Pond Estuary Surface | | 0 | 0 | 0 | 0 | | 1795 | 0 | 0 | | 1795 | 0 | 1795 | 1795 | | 1795 |

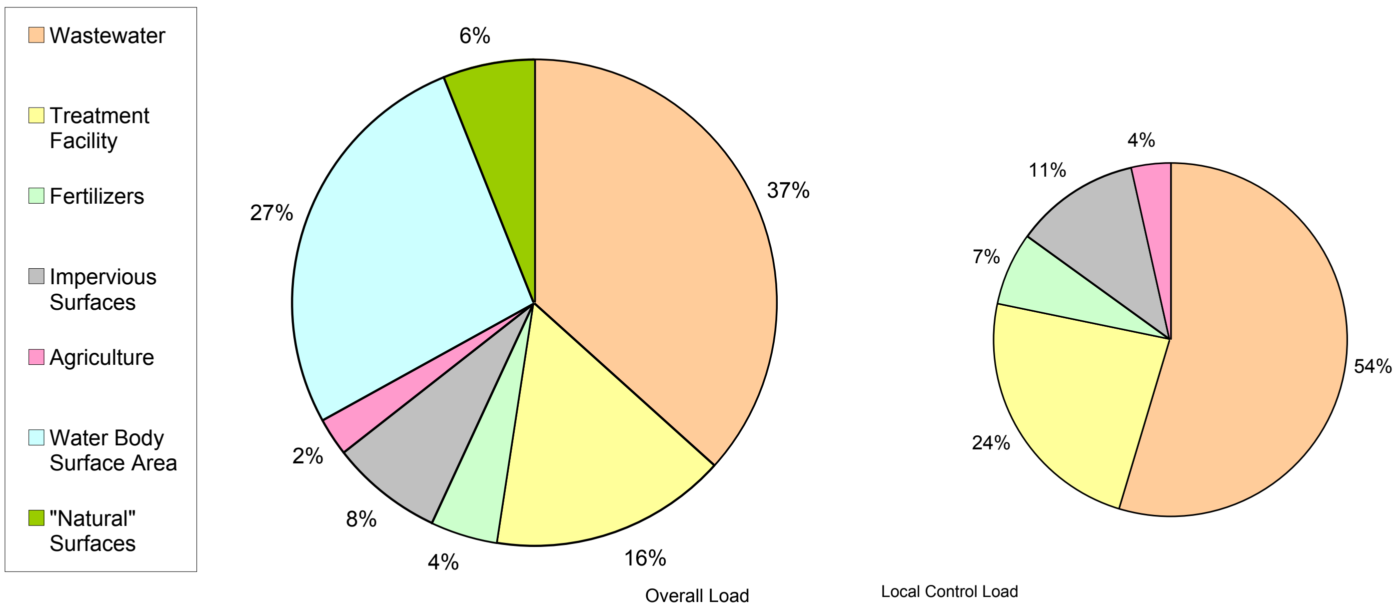



Figure IV-5. Land use-specific unattenuated nitrogen load (by percent) to the overall Edgartown Great Pond System watershed. "Overall Load" is the total nitrogen input within the watershed, while the "Local Control Load" represents only those nitrogen sources that could potentially be under local regulatory control.

### IV.3.1 Sediment-Watercolumn Exchange of Nitrogen

As stated in above sections, nitrogen loading and resulting levels within coastal embayments are the critical factors controlling the nutrient related ecological health and habitat quality within a system. Nitrogen enters the Edgartown Great Pond System predominantly in highly bioavailable forms from the surrounding upland watershed and more refractory forms in the inflowing tidal waters. If all of the nitrogen remained within the water column (once it entered) then predicting water column nitrogen levels would be simply a matter of determining the watershed loads, dispersion, and hydrodynamic flushing. However, as nitrogen enters the embayment from the surrounding watersheds it is predominantly in the bioavailable form nitrate. This nitrate and other bioavailable forms are rapidly taken up by phytoplankton for growth, i.e. it is converted from dissolved forms into phytoplankton "particles". Most of these "particles" remain in the water column for sufficient time to be flushed out to a down gradient larger water body (like Atlantic Ocean or Nantucket Sound). However, some of these phytoplankton particles are grazed by zooplankton or filtered from the water by shellfish and other benthic animals and deposited on the bottom. Also, in longer residence time systems (greater than 8 days) these nitrogen rich particles may die and settle to the bottom. In both cases (grazing or senescence), a fraction of the phytoplankton with their associated nitrogen "load" become incorporated into the surficial sediments of the bays.

In general the fraction of the phytoplankton population which enters the surficial sediments of a shallow embayment: (1) increases with decreased hydrodynamic flushing, (2) increases in low velocity settings, (3) increases within enclosed tributary basins, particularly if they are deeper than the adjacent embayment. To some extent, the settling characteristics can be evaluated by observation of the grain-size and organic content of sediments within an estuary.

Once organic particles become incorporated into surface sediments they are decomposed by the natural animal and microbial community. This process can take place both under oxic (oxygenated) or anoxic (no oxygen present) conditions. It is through the decay of the organic matter with its nitrogen content that bioavailable nitrogen is returned to the embayment water column for another round of uptake by phytoplankton. This recycled nitrogen adds directly to the eutrophication of the estuarine waters in the same fashion as watershed inputs. In some systems that have been investigated by SMAST and the MEP, recycled nitrogen can account for about one-third to one-half of the nitrogen supply to phytoplankton blooms during the warmer summer months. It is during these warmer months that estuarine waters are most sensitive to nitrogen loadings. In contrast in some systems, with deep depositional basins or salt marsh tidal creeks, the sediments can be a net sink for nitrogen even during summer (e.g. Mashapaquit Creek Salt Marsh, West Falmouth Harbor; Centerville River Salt Marsh or Sesachacha Pond). Embayment basins can also be net sinks for nitrogen to the extent that they support relatively oxidized surficial sediments, for example in the margins of the main basin to Lewis Bay. In contrast, most embayments show low rates of nitrogen release throughout much of basin area and in regions of high deposition typically support anoxic sediments with high release rates during summer months. The consequence of high deposition rates is that the basin sediments are unconsolidated, organic rich and sulfidic nature (MEP field observations).

Failure to account for the site-specific nitrogen balance of the sediments and its spatial variation from the tidal creeks and embayment basins will result in significant errors in determination of the threshold nitrogen loading to the Edgartown Great Pond System. In addition, since the sites of recycling can be different from the sites of nitrogen entry from the watershed, both recycling and watershed data are needed to determine the best approaches for nitrogen mitigation.

In the specific case of Edgartown Great Pond, which only has periodic tidal exchange (on the order of 30 days per year), the importance of nitrogen cycling in the sediments becomes a larger part of the nitrogen balance compared to fully tidal systems. The closed basin of Edgartown Great Pond allows for both the standard MEP core incubation method to determine sediment nitrogen release, as well as a second integrated system approach that MEP has employed in other closed basins (e.g. Sesachacha Pond, Nantucket; Oyster Pond, Falmouth). This latter approach uses a mass balance of nitrogen within the basin combined with the watershed model to estimate average system-wide nitrogen release (Section IV.3.3).

### IV.3.2 Method for Determining Sediment-Watercolumn Nitrogen Exchange

For the Edgartown Great Pond Embayment System in order to determine the contribution of sediment regeneration to nutrient levels during the most sensitive summer interval (July-August), sediment samples were collected and incubated under *in situ* conditions. Sediment samples were collected from 19 sites (Figure IV-6) in July-August 2002, focusing on the main central basins, which account for most of the bottom area of the Pond. Measurements of total dissolved nitrogen, nitrate + nitrite, ammonium were made in time-series on each incubated core sample.

Rates of nitrogen release were determined using undisturbed sediment cores incubated for 24 hours in temperature-controlled baths. Sediment cores (15 cm inside diameter) were collected by SCUBA divers and cores transported by small boat to a shore side field lab. Cores were maintained from collection through incubation at *in situ* temperatures. Bottom water was collected and filtered from each core site to replace the headspace water of the flux cores prior to incubation. The number of core samples from each site (Figure IV-6) per incubation are as follows:

***Edgartown Great Pond System Benthic Nutrient Regeneration Cores***

- James Cove-9 1 core (Basin)
- Wintucket Cove-10 1 core (Basin)
- Wintucket Cove-11 1 core (Basin)
- Mashacket Cove-17 1 core (Basin)
- Turkeyland Cove-18 1 core (Basin)
- Slough Cove-20 1 core (Basin)
- Jobs Neck Cove-1 1 core (Basin)
- Main Basin Upper-12 1 core (Basin)
- Main Basin Upper-13/14 2 cores (Basin)
- Main Basin-Middle-15 1 core (Basin)
- Main Basin-Middle-16 1 core (Basin)
- Main Basin-Middle-19 1 core (Basin)
- Main Basin-Lower-2 1 core (Basin)
- Main Basin-Lower-3 1 core (Basin)
- Main Basin-Lower-4 1 core (Basin)
- Main Basin-Lower-5 1 core (Basin)
- Main Basin-Lower-6 1 core (Basin)
- Main Basin-Lower-7 1 core (Basin)
- Main Basin-Lower-8 1 core (Basin)

Sampling was distributed throughout the primary embayment sub-basins of this system: upper, middle and lower Edgartown Great Pond main basins; plus the major coves: Jobs Neck Cove, Janes Cove, Wintucket Cove, Mashacket Cove, Turkeyland Cove, Slough Cove and the results for each site combined for calculating the net nitrogen regeneration rates for the water quality modeling effort.

Sediment-water column exchange follows the methods of Jorgensen (1977), Klump and Martens (1983), and Howes *et al.* (1998) for nutrients and metabolism. Upon return to the field laboratory (Shellfish Department), the cores were transferred to pre-equilibrated temperature baths. The headspace water overlying the sediment was replaced, magnetic stirrers emplaced, and the headspace enclosed. Periodic 60 ml water samples were withdrawn (volume replaced with filtered water), filtered into acid leached polyethylene bottles and held on ice for nutrient analysis. Ammonium (Scheiner 1976) and ortho-phosphate (Murphy and Reilly 1962) assays were conducted within 24 hours and the remaining samples frozen (-20$^{o}$C) for assay of nitrate + nitrite (Cd reduction: Lachat Autoanalysis), and DON (D'Elia *et al.* 1977). Rates were determined from linear regression of analyte concentrations through time.

Chemical analyses were performed by the Coastal Systems Analytical Facility at the School for Marine Science and Technology (SMAST) at the University of Massachusetts in New Bedford, MA [*508-910-6325*]. The laboratory follows standard methods for saltwater analysis and sediment geochemistry.

In addition to the standard MEP sediment incubation approach for determining nitrogen cycling between sediments and water-column, a mass balance approach was used to determine integrated pond-wide nitrogen flux. The approach uses the fact that Edgartown Great Pond does not have tidal exchange with the Atlantic Ocean for much of the summer each year. In recent years, nitrogen and salinity measurements have been made by the Edgartown Shellfish Constable (Paul Bagnall) and the MVC, pre- and post- opening of the breach. Two such data sets exist which were used to support a mass-balance model to determine whole system sediment nitrogen exchange during the months of July and August. These model results are directly comparable to the incubation approach and provide an independent measurement of this key process. This mass balance approach has been used successfully by the MEP Technical Team in a similar, periodically tidal, great salt pond, Sesachacha Pond (Nantucket), and a micro-tidal great salt pond, Oyster Pond (Falmouth).

### IV.3.3 Rates of Summer Nitrogen Regeneration from Sediments

Water column nitrogen levels are the balance of inputs from direct sources (land, rain etc), losses (denitrification, burial), regeneration (water column and benthic), and uptake (e.g. photosynthesis). As stated above, during the warmer summer months the sediments of shallow embayments typically act as a net source of nitrogen to the overlying waters and help to stimulate eutrophication in organic rich systems. However, some sediments may be net sinks for nitrogen and some may be in “balance” (organic N particle settling = nitrogen release). Sediments may also take up dissolved nitrate directly from the water column and convert it to dinitrogen gas (termed “denitrification”), hence effectively removing it from the ecosystem. This process is typically a small component of sediment denitrification in embayment sediments, since the water column nitrogen pool is typically dominated by organic forms of nitrogen, with very low nitrate concentrations. However, this process can be very effective in removing nitrogen loads in some systems, particularly in streams, ponds and salt marshes, where overlying waters support high nitrate levels.

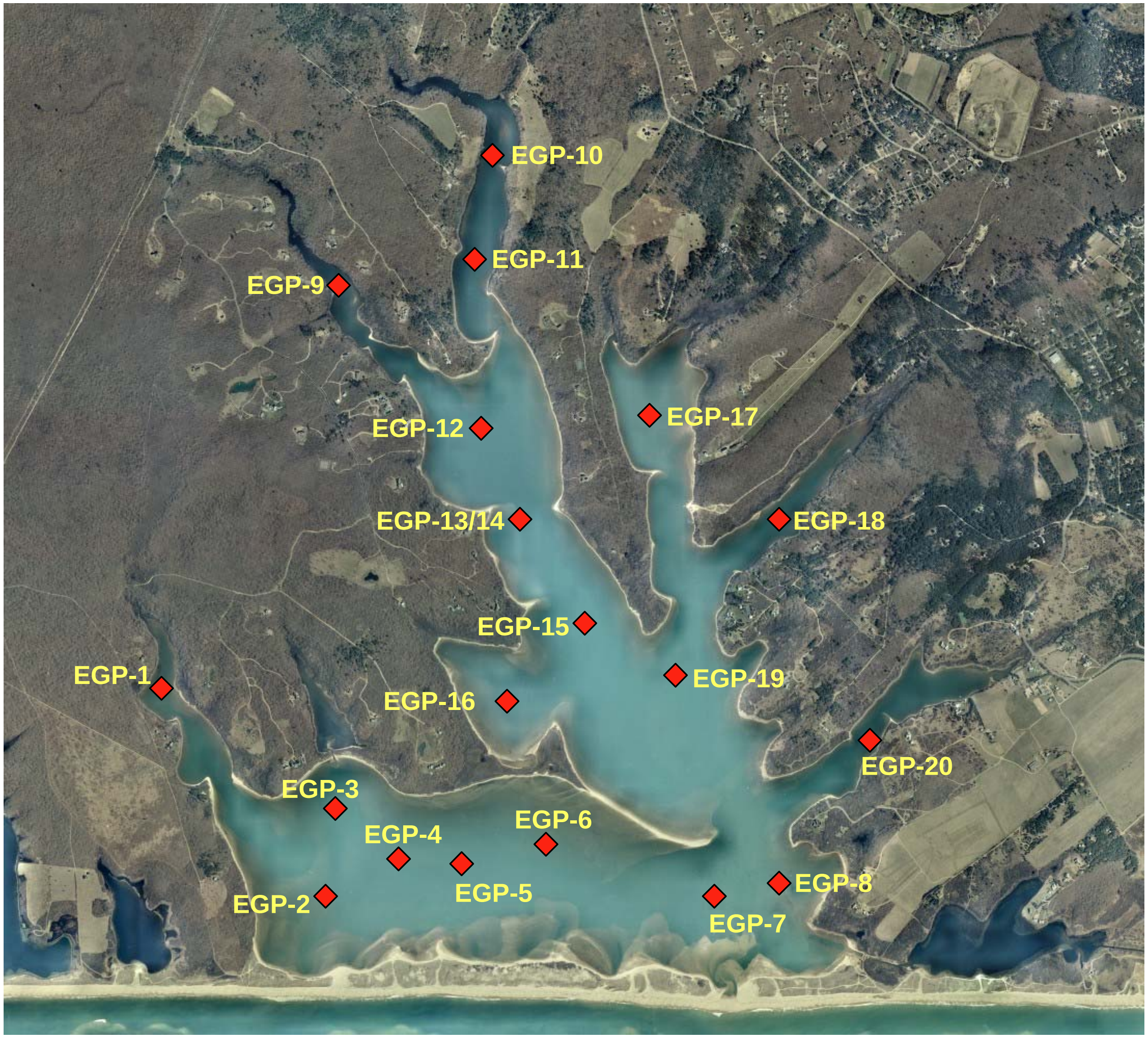



Figure IV-6. Edgartown Great Pond System locations (red diamonds) of sediment sample collection for determination of nitrogen regeneration rates. Numbers are for reference in Table IV-3

In addition to nitrogen cycling, there are ecological consequences to habitat quality of organic matter settling and mineralization within sediments, these relate primarily to sediment and water column oxygen status. However, for the modeling of nitrogen within an embayment it is the relative balance of nitrogen input from water column to sediment versus regeneration which is critical. Similarly, it is the net balance of nitrogen fluxes between water column and sediments during the modeling period that must be quantified. For example, a net input to the sediments represents an effective lowering of the nitrogen loading to down-gradient systems and net output from the sediments represents an additional load.

The relative balance of nitrogen fluxes ("in" versus "out" of sediments) is dominated by the rate of particulate settling (in), the rate of denitrification of nitrate from overlying water (in), and regeneration (out). The rate of denitrification is controlled by the organic levels within the sediment (oxic/anoxic) and the concentration of nitrate in the overlying water. Organic rich sediment systems with high overlying nitrate frequently show large net nitrogen uptake throughout the summer months, even though organic nitrogen is being mineralized and released to the overlying water as well. The rate of nitrate uptake, simply dominates the overall sediment nitrogen cycle.

In order to model the nitrogen distribution within an embayment it is important to be able to account for the net nitrogen flux from the sediments within each part of each system. This requires that an estimate of the particulate input and nitrate uptake be obtained for comparison to the rate of nitrogen release. Only sediments with a net release of nitrogen contribute a true additional nitrogen load to the overlying waters, while those with a net input to the sediments serve as an "in embayment" attenuation mechanism for nitrogen.

Overall, coastal sediments are not overlain by nitrate rich waters and the major nitrogen input is via phytoplankton grazing or direct settling. In these systems, on an annual basis, the amount of nitrogen input to sediments is generally higher than the amount of nitrogen release. This net sink results from the burial of reworked refractory organic compounds, sorption of inorganic nitrogen and some denitrification of produced inorganic nitrogen before it can "escape" to the overlying waters. However, this net sink evaluation of coastal sediments is based upon annual fluxes. If seasonality is taken into account, it is clear that sediments undergo periods of net input and net output. The net output is generally during warmer periods and the net input is during colder periods. The result can be an accumulation of nitrogen within late fall, winter, and early spring and a net release during summer. The conceptual model of this seasonality has the sediments acting as a battery with the flux balance controlled by temperature (Figure IV-7).

Unfortunately, the tendency for net release of nitrogen during warmer periods coincides with the periods of lowest nutrient related water quality within temperate embayments. This sediment nitrogen release is in part responsible for poor summer nutrient related health. Other major factors causing the seasonal water quality decline are the lower solubility of oxygen during summer, the higher oxygen demand by marine communities, and environmental conditions supportive of high phytoplankton growth rates.

In order to determine the net nitrogen flux between water column and sediments, all of the above factors were taken into account. The net input or release of nitrogen within a specific embayment was determined based upon the measured total dissolved nitrogen uptake or release, and estimate of particulate nitrogen input.

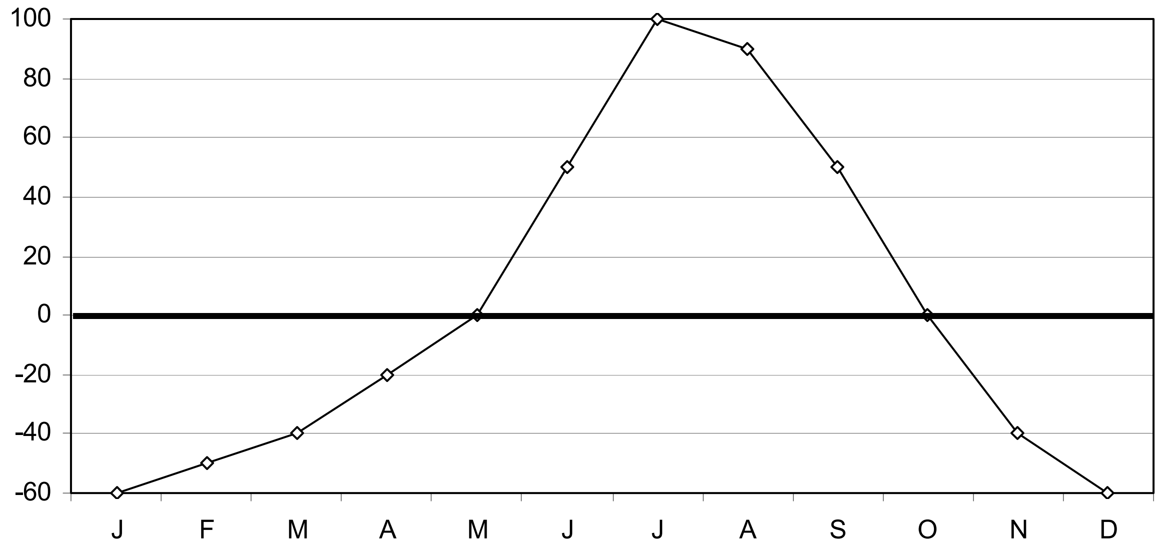



Figure IV-7. Conceptual diagram showing the seasonal variation in sediment N flux, with maximum positive flux (sediment output) occurring in the summer months, and maximum negative flux (sediment up-take) during the winter months.

**Sediment Nitrogen Release by Standard Core Approach:** Sediment sampling was conducted throughout the primary embayment sub-basins of this system: upper, middle and lower basins; plus the major coves: Jobs Neck Cove, Janes Cove, Wintucket Cove, Mashacket Cove, Turkeyland Cove, Slough Cove in order to obtain the nitrogen regeneration rates required for parameterization of the water quality model. The distribution of cores was established to cover gradients in sediment type, flow field and phytoplankton density and spatial differences among the various basins and coves. For each core the nitrogen flux rates (described in the section above) were evaluated relative to measured sediment organic carbon and nitrogen content, as well as sediment type and an analysis of each site's tidal flow velocities. As expected flow velocities are very low throughout Edgartown Great Pond. The maximum bottom water flow velocity at each coring site was determined from the hydrodynamic model. These data were then used to determine the nitrogen balance within each sub-embayment.

The magnitude of the settling of particulate organic carbon and nitrogen into the sediments was accomplished by determining the average depth of water within each sediment site, the average summer particulate carbon and nitrogen concentration within the overlying water and the tidal velocities from the hydrodynamic model (Chapter V). Based upon the low velocities, a water column particle residence time of 6-7 days was used (based upon phytoplankton and particulate carbon studies of poorly flushed basins). Adjusting the measured sediment releases was essential in order not to over-estimate the sediment nitrogen source and to account for those sediment areas that are net nitrogen sinks for the aquatic system. This approach has been previously validated in outer Cape Cod embayments (Town of Chatham) by examining the relative fraction of the sediment carbon turnover (total sediment metabolism) which would be accounted for by daily particulate carbon settling. This analysis indicated that sediment metabolism in the highly organic rich sediments of the wetlands and depositional basins is driven primarily by stored organic matter (ca. 90%). Also, in the more open lower portions of larger embayments, storage appears to be low and a large proportion of the daily carbon requirement in summer is met by particle settling (approximately 33% to 67%). This range of values and their distribution is consistent with ecological theory and field data from shallow embayments. Additional, validation has been conducted on other enclosed basins (with little freshwater inflow), where the fluxes can be determined by multiple methods. In this case the rate of sediment regeneration determined from incubations was comparable to that determined from whole system balance.

Rates of net nitrogen release or uptake from the sediments within the Edgartown Great Pond Embayment System were comparable to other embayments of similar depth in southeastern Massachusetts, even though this system is not regularly exposed to tidal flushing. There was a clear pattern of sediment N flux, with most of the shallow coves generally showing net uptake or low release, -16.0 to 7.4 mg N $m^{-2}$ $d^{-1}$. The main basin of Edgartown Great Pond is dominated by the lower lagoon, and had an average nitrogen release of 15.2 mg N $M^{-2}$ $d^{-1}$. Only Mashacket Cove departed from this general pattern, most likely due to its upper basin being nearly separated by a "shoal" from the rest of the Great Pond System creating a distinct sub-basin. This uppermost basin is also the most likely location for the entry of the nitrogen plume from the old WWTF, prior to upgrade, that was yet to "wash out" at the time of the assays.

Sediment nitrogen uptake and release rates in Edgartown Great Pond were similar to many tidal embayments in the region of similar proportions. For example in the Lewis Bay System the main basin (also a lagoon) averaged 6.9 mg N $M^{-2}$ $d^{-1}$, with the shallower regions of the main basin (analogous to the coves in Edgartown) showing nitrogen uptake rates of -11.6 to -32.0 mg N $m^{-2}$ $d^{-1}$. In addition, the lower reach of the Wareham River (bounded by Long Beach) including Marks Cove showed nitrogen release rates of 10.5 - 37.0 mg N m-1 d-1, while the upper Wareham River Basin averaged -4.9 mg N $M^{-2}$ $d^{-1}$ and similarly configured West Bay (Three Bays, Barnstable) 4.5 mg N $m^{-2}$ $d^{-1}$, comparable to the rates in the main basin and coves of the Edgartown Great Pond System.

Net nitrogen release rates for use in the water quality modeling effort for the component sub-basins of the Edgartown Great Pond Embayment System (Chapter VI) are presented in Table IV-3. There was a clear spatial pattern of sediment nitrogen flux, with net uptake of nitrogen in most of the shallow coves and upper main basin and net release by the sediments of the larger depositional regions comprised of the middle and lower main basin of Edgartown Great Pond. The sediments within the Great Pond System showed nitrogen fluxes comparable to many tidal embayments within the region and appear to be in balance with the overlying waters and the nitrogen flux rates consistent with the level of nitrogen loading to this system and periodic exposure to tidal flushing.

**System-wide Sediment Nitrogen Release:** In a closed basin, such as Edgartown Great Pond, it is possible to determine the system-wide rate of nitrogen return from the bottom sediments based upon time series water-column total nitrogen data and the rate of external nitrogen loading (watershed + atmosphere). In the case of Edgartown Great Pond the external loading rate is relatively low for an embayment of this scale in southeastern Massachusetts (41.4 kg N $d^{-1}$, see Chapter IV), but higher than Sesachacha Pond (Nantucket), 4.1 kg N $d^{-1}$, another periodically opened great salt pond. For comparison, Lewis Bay, Wareham River and Three Bays estuaries have loading rates on the order of 105.8, 130.3 and 146.4 kg N $d^{-1}$ respectively. The low rate of watershed+atmospheric nitrogen input to Edgartown Great Pond increases the potential sensitivity of using a basin-wide nitrogen mass balance approach to determine the rate of sediment nitrogen flux.

Table IV-3. Rates of net nitrogen return from sediments to the overlying waters of the Edgartown Great Pond Embayment System. These values are combined with the basin areas to determine total nitrogen mass in the water quality model (see Chapter VI). Measurements represent July -August rates.

| Location | Sediment Nitrogen Flux (mg N $m^{-2}$ $d^{-1}$) | | | i.d. * |
|---|---|---|---|---|
| | Mean | S.E. | # sites | |
| **Edgartown Great Pond Embayment System** | | | | |
| Janes Cove | 7.4 | 0.2 | 1 | EGP 9 |
| Wintucket Cove | -15.7 | 5.9 | 2 | EGP 10,11 |
| Mashacket Cove-Upper | 37.6 | 4.8 | 1 | EGP 17 |
| Turkeyland cove | -12.6 | 2.2 | 1 | EGP 18 |
| Slough Cove | -16.9 | 2.0 | 1 | EGP 20 |
| Jobs Neck Cove | -8.9 | 1.8 | 1 | EGP 1 |
| Edgartown Main Basin | 15.2 | 14.1 | 11 | EGP 2-8, 12-16, 19 |

* Station numbers refer to Figures IV-7.
Cores EGP 2,6 were disturbed during incubation.

Water-column average total nitrogen and salinity levels were available from the Town of Edgartown and the Martha's Vineyard Commission Water Quality Monitoring Program for 2000-2004. Note that there is little to no horizontal gradient across the pond (Chapter VI). The data was collected approximately monthly through a summer period when the Pond was not open to the ocean Figure IV-8. The linear increase in total nitrogen concentration observed in 2003 (0.0083 mg TN $L^{-1}$ $d^{-1}$), was also the multi-year average (0.0089 mg $L^{-1}$ $d^{-1}$ (s.e.=0.0025, N=4) and is directly related to the rate of net nitrogen release from the sediments, integrated over the entire pond. However, the temporal rise in nitrogen concentration also includes inputs from the watershed and atmosphere, in addition to release of nitrogen from the sediments. The 2003 water-column data were used to calculate the total change of nitrogen within the pond over the 49 day period of sampling. This rate was then integrated with the watershed and nitrogen loading data, incorporating small loss rates through the weir to Cracktuxet Cove and through the barrier beach to determine the sediment load (Chapter VI). This approach indicated a pond-wide average sediment release of 20.4 kg/pond/day and compared well with other partial data sets from summer opening events in other years, 1999-2004. The pond mass balance model results also compared well with the estimate of 24.7 kg/pond/day from the sediment incubations. The sediment incubation rates were applied to the basin areas with only minor adjustments for low/high water (~10%) and the basin configuration of Mashacket Cove (upper/lower cove). Given the agreement between the sediment nitrogen release rates from the two independent approaches and the that the mass balance approach is system-wide, a rate of 20.4 kg $d^{-1}$ was used in the nitrogen water quality modeling for this system (Chapter VI).

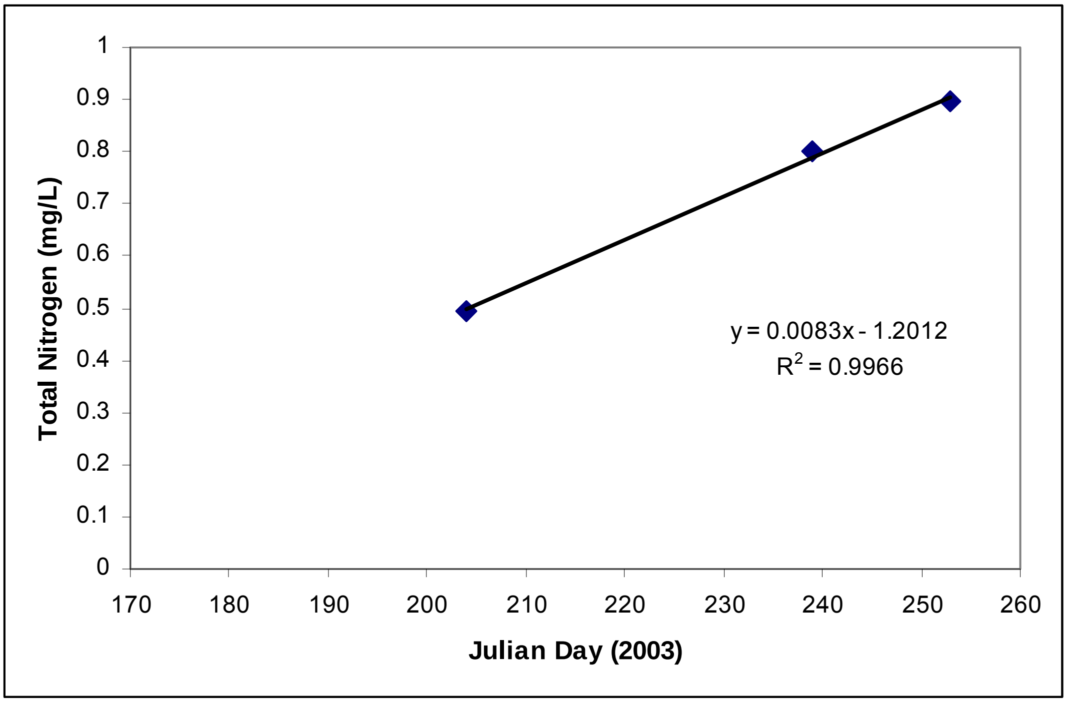



Figure IV-8. Change in total nitrogen during summer 2003, the rate of change was confirmed by similar data from 2000-2004 (N=4). Increase in nitrogen results from inputs from watershed+atmosphere+sediments and outputs through flows through the barrier beach and weir at Cracktuxet Cove. Salinity and water elevation data was used to assess these latter losses and groundwater inflow during this period (Chapter VI).

# V. HYDRODYNAMIC MODELING

## V.1 INTRODUCTION

This section summarizes field data collection effort and the development of hydrodynamic models for the Edgartown Great Pond system (Figure V-1). For this system, the model offers an understanding of water movement from the pond during a breach, and provides the first step towards evaluating water quality, as well as a tool for later determining nitrogen loading "thresholds". Nutrient loading data combined with measured environmental parameters within the system become the basis for an advanced water quality model based on total nitrogen concentrations. This type of model provides a tool for evaluating existing water quality parameters, as well as determining the likely positive impacts of various alternatives for improving health of the pond, facilitating the understanding how pollutant loadings into the estuary will affect the biochemical environment and its ability to sustain a healthy marine habitat.

In general, water quality studies of tidally influenced estuaries must include 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. Numerical models provide a cost-effective method for evaluating tidal hydrodynamics since they require limited data collection and may be utilized to numerically assess a range of management alternatives. Once the hydrodynamics of an estuary system are understood, computations regarding the related coastal processes become relatively straightforward extensions to the hydrodynamic modeling. For example, the spread of pollutants may be analyzed from tidal current information developed by the numerical models.

Coastal ponds like Edgartown Great Pond are the initial recipients of freshwater flows (i.e., groundwater and surfacewater) and the nutrients they carry. An embayment's shape influences the time that nutrients are retained in them before being flushed out to adjacent open waters, and their shallow depths both decrease their ability to dilute nutrient (and pollutant) inputs and increase the secondary impacts of nutrients recycled from the sediments. Degradation of coastal waters and development are tied together through inputs of pollutants in runoff, rainfall and groundwater flows. Excess nutrients, especially nitrogen, promote phytoplankton blooms, with adverse consequences including low oxygen, shading of submerged aquatic vegetation, and aesthetic problems.

### V.1.1 System Physical Setting

Edgartown Great Pond is set along the eastern shoreline of Martha's Vineyard. The layout of the Edgartown Great Pond system is shown in the aerial photograph detail of Figure V-1. The pond has a surface area of approximately 860 acres. The pond is fully enclosed, but is periodically opened by means of a trench dug across the beach to drain the pond into the Atlantic Ocean.

Similar systems, sometimes referred to as "blind", "intermittently open", or "seasonally open" estuaries, are also found in Australia, on the west coast of the United States, South America and India (Stretch and Parkinson, 2006). Perched estuaries are those that have water levels consistently above mean sea level (MSL) and tend to occur on coastlines that have an energetic wave climate with steep beaches and coarse sediments. It is common practice to artificially breach closed ponds/estuaries when water levels become high, typically to prevent flooding of upland properties and to flush the systems from a build-up of contaminants adversely impacting water quality. Other coastal ponds along the south coast of Martha's Vineyard, Nantucket, and the southern shoreline of Massachusetts/Rhode Island are local examples of where periodic breaching is a regular facet of pond management.


Figure V-1. Location of Edgartown Great Pond on Martha's Vineyard, Massachusetts.

### V.1.2 System Hydrodynamic Setting

In Edgartown Great Pond, the hydrodynamic regime is dominated by freshwater inputs to the system from groundwater recharge, surface flow run-off from the watershed, and direct precipitation to the pond's surface. The volume of water in the pond is governed by the balance between additions from freshwater inflow and losses due to evaporation and flow through the eastern beach face into the ocean. On average, the inputs are greater than the losses and the pond elevation gradually rises.

When the pond level is deemed high enough, a trench is cut across the southern barrier beach. Because the pond level is higher than the ocean, the pond drains. The initial outflow from the pond causes a relatively small channel to be scoured through the beach and the water level in the pond drops. The ephemeral channel across the beach is a balance between the scouring effect of water flowing through it and the filling effect of sediment transport along the beach. Although Edgartown Great Pond is large relative to other regional coastal ponds, the wave climate on the southern coast of Martha's Vineyard is one of the most energetic in Massachusetts. As a result, the breach channel typically closes very quickly, sometimes after only minimal tidal exchange has occurred. The result is that these short or failed breaches only remove the top layer of water from the pond. For these failed breaches, there is very little inflow of water from the ocean and little mixing of the nutrient rich water from the pond with low nutrient inflow. As a result, openings that do not allow influx of ocean waters simply lower the water levels and do little to improve the water quality inside the pond. Based on recent information from the Edgartown Shellfish Department collected between 2002 and 2007, the salinity of the pond rises approximately 1 ppt for every day the breach remains open to the Atlantic Ocean. Since an increase in salinity of the pond (resulting from a breach) is directly related to lowering of nutrient levels, a successful breach for water quality improvement will remain open for several days.

## V.2 GEOMORPHIC AND ANTHROPOGENIC EFFECTS TO THE SYSTEM

### V.2.1 Pond Management Practices

The barrier beach separating Edgartown Great Pond from the Atlantic Ocean was historically breached ~2.5 times per year since 1995 (Figure V-2). These man-made openings typically shoaled within two weeks of the breach creation. The reasons for breach creation at Edgartown Great Pond were primarily to enhance shellfish populations, allow passage of anadromous fish, and lower the water level to reduce flooding potential. Primarily, Edgartown Great Pond has been managed for shellfish. As reported regularly by the Town of Edgartown Shellfish Department, the Town of Edgartown has a substantial shellfishing enterprise that depends on the safeguarding of the estuarine environment of the Town (e.g. Edgartown Great Pond). By example in 2003 the Shellfish Department reported the 2003 Commercial Shellfish Catch in Edgartown was valued at approximately $750,000. In 2003, Edgartown Great Pond produced 95 bushels of scallops.

Based on available data, the average duration of openings through the barrier beach was slightly under 12 days. However, the average is slightly skewed by relatively long-lived inlets in 2001 (71 days) and 2006 (26 days) as shown in Figure V-3. The most common inlet opening lasts between 6 and 12 days, causing the water level within the pond to drop significantly (on the order of 3+ feet) and allowing exchange of lower nutrient concentration seawater to exchange with pond waters.

### V.2.2 Shoreline Change Analysis

Shoreline change maps can effectively be used to evaluate the effects of long-term coastal processes. In addition, shoreline change maps also can indicate the effects of short-term changes that often occur as the result of anthropogenic (e.g. development of extensive shore protection structures) or natural (e.g. inlet migration) processes. Prior to developing conclusions and/or management recommendations that depend on shoreline change estimates, it is critical to understand potential errors and uncertainties associated with this type of analysis.

Rates of change in high-water shoreline position between 1897 and 2003 and 1955 and 2003 were evaluated up to 1500 feet east and west of the Edgartown Great Pond inlet. The 1897 shoreline positions were mapped using traditional survey procedures in the field and compiled on U.S. Coast and Geodetic Survey Topographic Sheet 2299. The 1955 shoreline position was compiled from aerial surveys and supplemental land surveys on Topographic Sheets 10642 and 10643. Scans of the original T-sheets were geo-referenced in ArcGIS and the shorelines were extracted by on-screen digitizing using the line drawing tool. The 2003 shoreline position was visually interpreted from a color orthophotograph available from MassGIS.

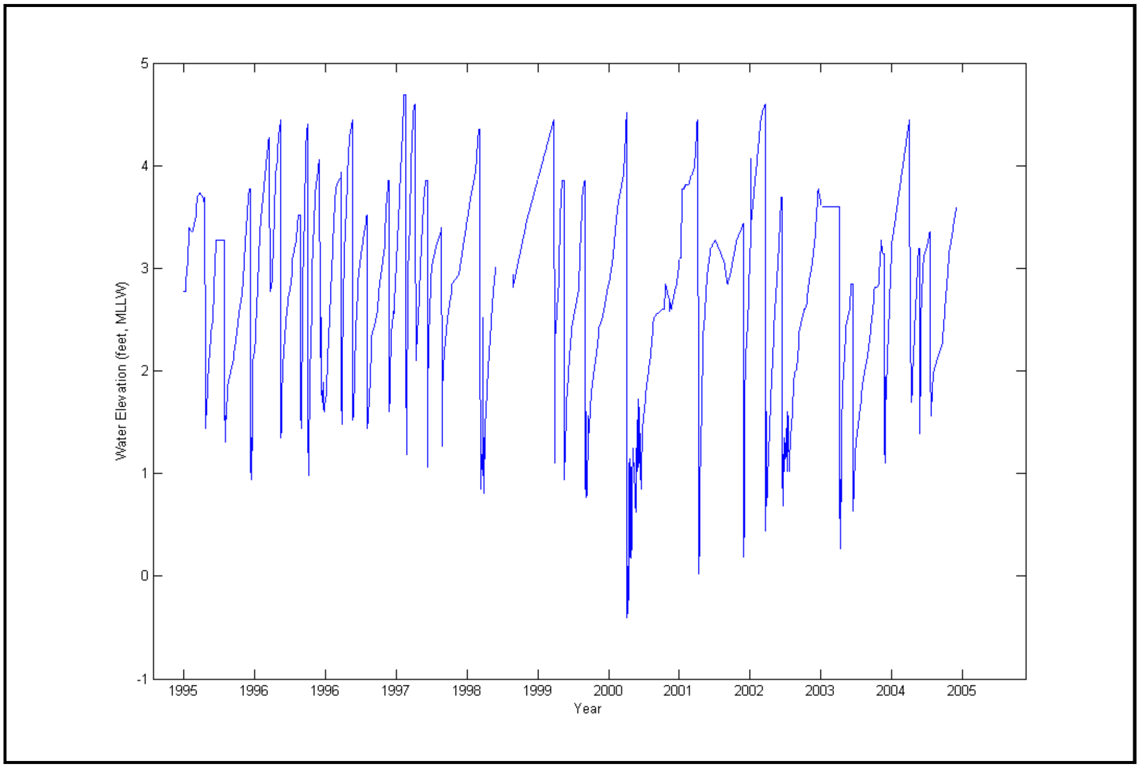



Figure V-2. Historic water levels in Edgartown Great Pond between 1995 and 2005 from observations made by John MacKenty (adjusted to MLLW datum).

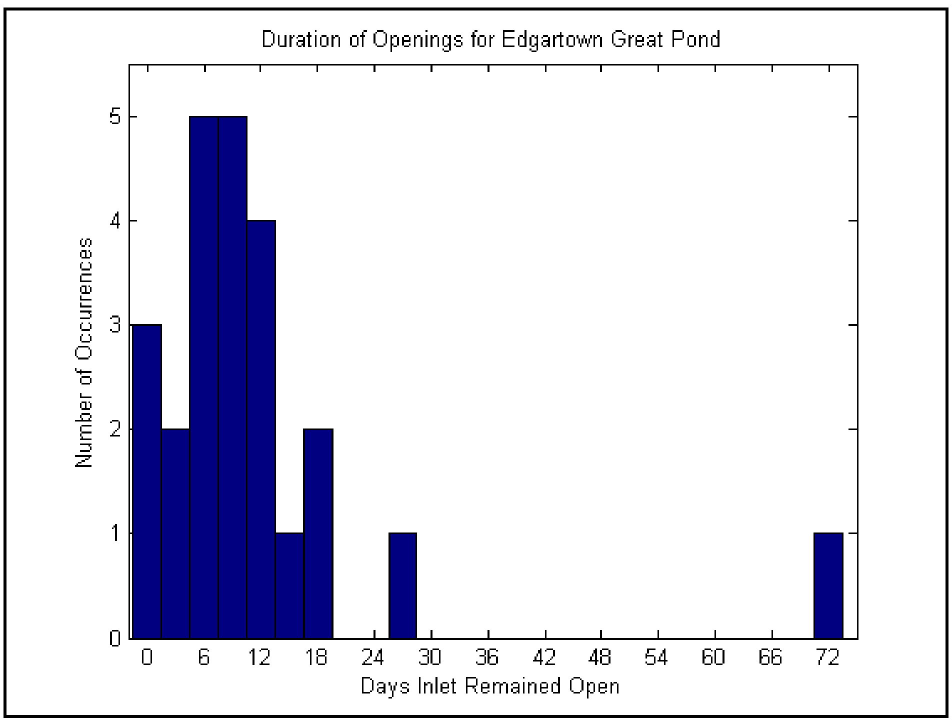



Figure V-3. Histogram illustrating the duration of openings for Edgartown Great Pond between 1995 and 2007. Data provided by Paul Bagnall (Edgartown Shellfish Department) and Bill Wilcox (Martha's Vineyard Commission).

The high-water shoreline position change rates were calculated in the Automated Shoreline Analysis Program that is run as an extension in ArcGIS (ArcASAP). This program requires a user-defined spatial interval (15 ft was used for this study) and the general shoreline orientation to determine the amount of shoreline advance or retreat for the time interval. ArcASAP performs the shoreline change calculations by casting transects normal to each "from" shoreline (the earliest shorelines were used in this study) at each analysis point specified along the input shoreline. The data output is a table of shoreline change magnitudes and rates for each transect where shoreline change denoted with a minus sign represents retreat. Figures V-4 and V-5 illustrate the shoreline change for the two time periods evaluated. During the 1897 to 2003 time interval, change rates ranged from -5.5 to -10.3 ft/yr along the shoreline in front of and to the east and west of Edgartown Great Pond and during the 1955 to 2003 time interval the change rates ranged from -3.7 to -9.8 ft/yr. Both time intervals experienced shoreline retreat along the entire stretch of coast in the study area, however, the average change rates, -7.1 and -6.0 ft/yr respectively, decreased during the most recent time interval. Some of the lowest shoreline change rates occurred directly in front of the inlet during both time intervals.

All shoreline position data contain inherent errors associated with field and laboratory compilation procedures. The potential measurement and analysis uncertainty between the data sets is additive when shoreline positions are compared. Because the individual uncertainties are considered to represent standard deviations, a root-mean-square (rms) method was used to estimate the combined potential uncertainties in the data sets. The positional uncertainty estimates for each shoreline were calculated using the information in Table V-1. These calculations estimated the total rms uncertainty to be ±52 ft or ±0.5 ft/year for the time interval 1897 to 2003 and ±31ft or ±0.6 ft/year for the 1955 to 2003 time interval.

Table V-1. Estimates of Potential Error Associated with Shoreline Position Surveys.

| | |
|---|---|
| **Traditional Engineering Field Surveys (1897)** | |
| Position of rodded points<br>Location of plane table<br>Interpretation of high-water shoreline position at rodded points<br>Error due to sketching between rodded points | ±3 ft<br>±7 to 10 ft<br>±10 to 13 ft<br>up to ±16 ft |
| **Cartographic Errors (1897, 1955)** | Map Scale 1:10,000 |
| Inaccurate location of control points on map relative to true field location<br>Placement of shoreline on map<br>Line width representing shoreline<br>Digitizer error<br>Operator error | Up to ±10 ft<br>±16 ft<br>±10 ft<br>±3 ft<br>±3 ft |
| **Historical Aerial Surveys (1955)** | Map Scale 1:10,000 |
| Delineating high-water shoreline position | ±16 ft |
| **Orthophotography (2003)** | |
| Delineating high-water shoreline position<br>Position of measured points | ±10 ft<br>±10 ft |

The relatively high shoreline change rate in the area of the Edgartown Great Pond openings is indicative of the significant sediment transport along the outer beach. Similar to much of the south coast of Martha's Vineyard, this beach system overwashes often and the rapid recession of the shoreline makes use of engineered structures to stabilize an inlet impractical. Therefore, future management of nitrogen within Edgartown Great Pond will require the historic practice of mechanically breaching the barrier beach.

## V.3 HYDRODYNAMIC FIELD DATA COLLECTION AND ANALYSIS

The field data collection portion of this study was performed to characterize the physical properties of Edgartown Great Pond. Bathymetry data were collected throughout the system so that it could be accurately represented as a computer hydrodynamic model, and so that flushing rates could be determined for the system. In addition to the bathymetry, tide data were also collected at three locations, to run the circulation model with real tides, and also to calibrate and verify its performance.

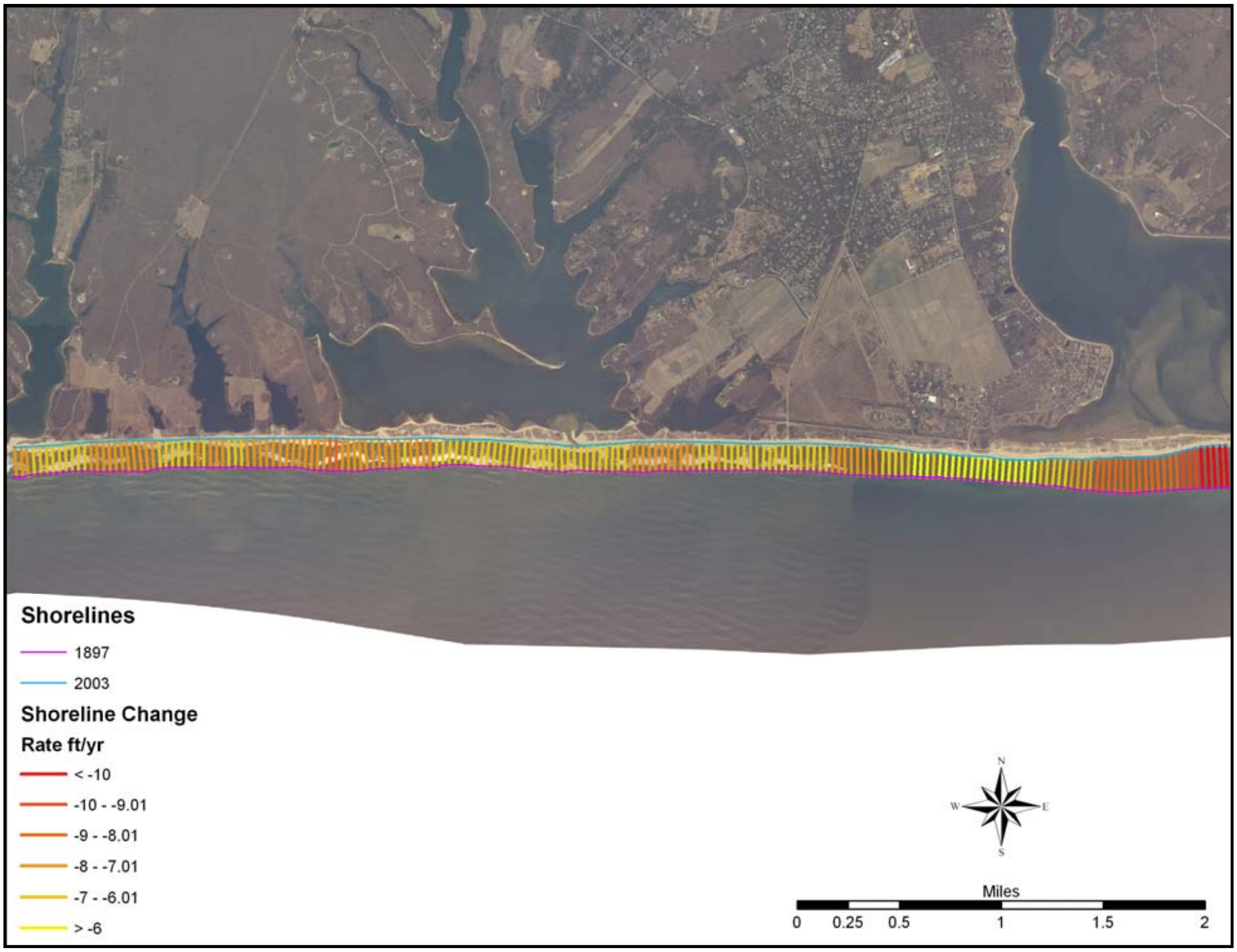



Figure V-4. Historical shoreline change rates (1897-2003) in the area of Edgartown Great Pond.

### V.3.1. Bathymetry

Bathymetry data (i.e., depth measurements) for the hydrodynamic model of the Edgartown Great Pond system was assembled from a recent boat based hydrographic survey The recent survey was executed specifically as part of the Massachusetts Estuaries Project analysis.

The hydrographic survey of September 2004 was designed to cover the entire main basin of Edgartown Great Pond, as well as the various coves within the pond. The survey was conducted from a 14' skiff with an installed precision fathometer (with a depth resolution of approximately 0.1 foot), coupled together with a differential GPS to provide horizontal position measurements accurate to approximately 1-3 feet. As the boat was maneuvered around the pond, digital data output from both the echo sounder fathometer and GPS were logged to a laptop computer, which integrated the data to produce a single data set consisting of water depth as a function of geographic position.

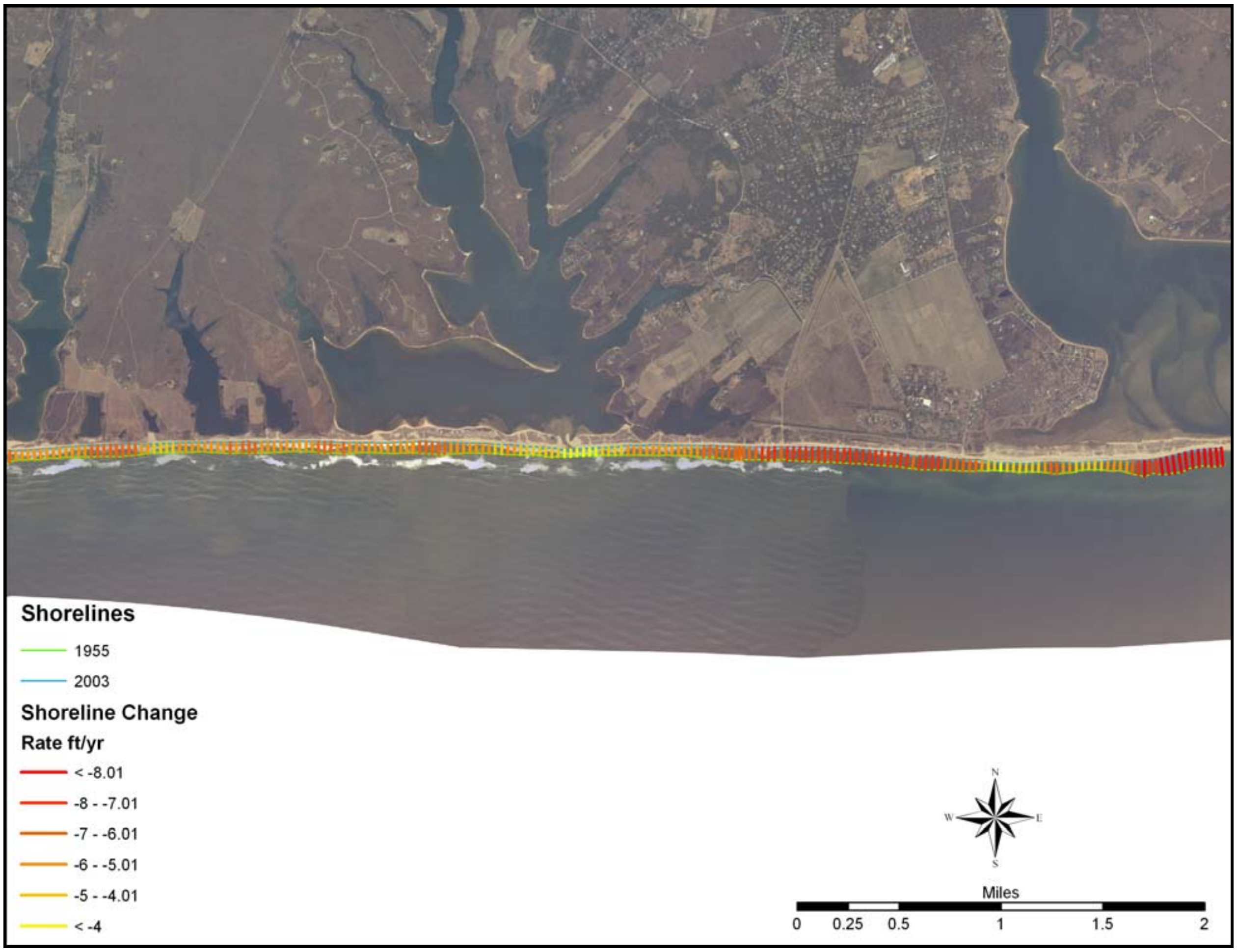



Figure V-5. Historical shoreline change rates (1955-2003) in the area of Edgartown Great Pond.

The raw measured water depths were merged with water surface elevation measurements to determine bathymetric elevations relative to the Mean Lower Low Water (MLLW) vertical datum. Once rectified, the finished processed data were archived as 'xyz' files containing x-y horizontal position (in Massachusetts State Plan 1983 coordinates) and vertical elevation of the bottom (z). These xyz files were then interpolated into the finite element mesh used for the hydrodynamic simulations. The tracks followed by the boat during the bathymetry survey are presented in Figure V-6.

### V.3.2 Tide Data

Tide data records were collected at three stations in the Edgartown Great Pond system: offshore in the Atlantic Ocean, the south end of the pond, and the north end of the pond. The locations of the stations within the pond are shown in Figure V-7. The Temperature Depth Recorders (TDR) used to record the tide data were deployed for a 4-month period between August and November 2004. The elevation of each gauge was leveled relative to MLLW. Two gauges were deployed together offshore of Katama Beach by SCUBA divers using a screw anchor; however, these gages could not be recovered. Therefore, available data from the Martha's Vineyard Coastal Observatory (MVCO) offshore of Katama Beach was utilized as the offshore boundary condition for the hydrodynamic model.

Once the data were downloaded from each instrument, the water pressure readings were corrected for variations in atmospheric pressure. Hourly atmospheric pressure readings were obtained from the NOAA station in Buzzards Bay, interpolated to 10-minute intervals, and subtracted from the pressure readings, resulting in variations in water pressure above the instrument. Further, a (constant) water density value of 1025 kg/m$^3$ was applied to the readings to convert from pressure units (psi) to head units (for example, feet of water above the tide gauge). Several sensors had been surveyed into local benchmarks to provide vertical rectification of the water level; these survey values were used to adjust the water surface to a known vertical datum. The result from each gauge is a time series record representing the variations in water surface elevation relative to the MLLW vertical datum. A plot of the observed tide signals is shown below in Figure V-8, where the two pond stations yielded identical tide signals.

### V.4 HYDRODYNAMIC MODEL DEVELOPMENT

The scour of a channel through the beach and the flow of water between the pond and ocean through this channel cannot be directly simulated with the RMA suite of models. Therefore, a computer model independent of RMA-2 was used to simulate the flow through the breach channel. Using this breach model, time varying boundary conditions were developed for RMA-2 model runs of the main portion of Edgartown Great Pond, up through the inlet channel.

#### V.4.1 Modeling flow through a breach

When the pond is first opened, the initial trench cut through the beach is scoured out by the rush of water leaving the super-elevated pond. The channel increases in width and depth during this time and over the first few tides cycles if the breach remains open. It would be beyond the scope of this study to model the dynamic growth of the channel during the breach event itself. However, the width and depth of the channel are important variables needed to model the flow between the ocean and Edgartown Great Pond. To parameterize variables pertinent to the Edgartown Great Pond breach, *in situ* data from a breach event in November 2004 were analyzed.

A survey of the breach at Edgartown Great Pond showed a channel width of 50-70 feet, which compared favorably to another breach monitored by Applied Coastal at Ellisville Harbor, where the breach was slightly larger at about 70-80 feet. For simulation purposes, an average channel width of 60 feet was selected as representative of the breach at Edgartown Great Pond.

To estimate the channel scour depth, the flow rate through the channel is needed. Using the data from the November 2004 breach event, the water levels following the initial opening could be observed (Figure V-8). This plot shows the elevated water level in the pond at about 3.2 feet MLLW. Around mid-day on November 23rd, the pond level drops steeply, indicating that the breach had been opened at this time. The pond continued to drain until the tide offshore was higher than the pond elevation. At this time ocean water flowed into the pond. When the tide lowered again, the pond drained until the next rising tide. This continued until approximately December 2nd, at which time the channel had almost closed and the pond level changes at a much slower rate. Around December 4th, tide data indicates that the breach had been completely filled in with sand and there was no longer exchange between the pond and the ocean. At the very end of the data set, around December 8th, the very high tide level reopened the breach at least partially and a small amount of exchange occurred.

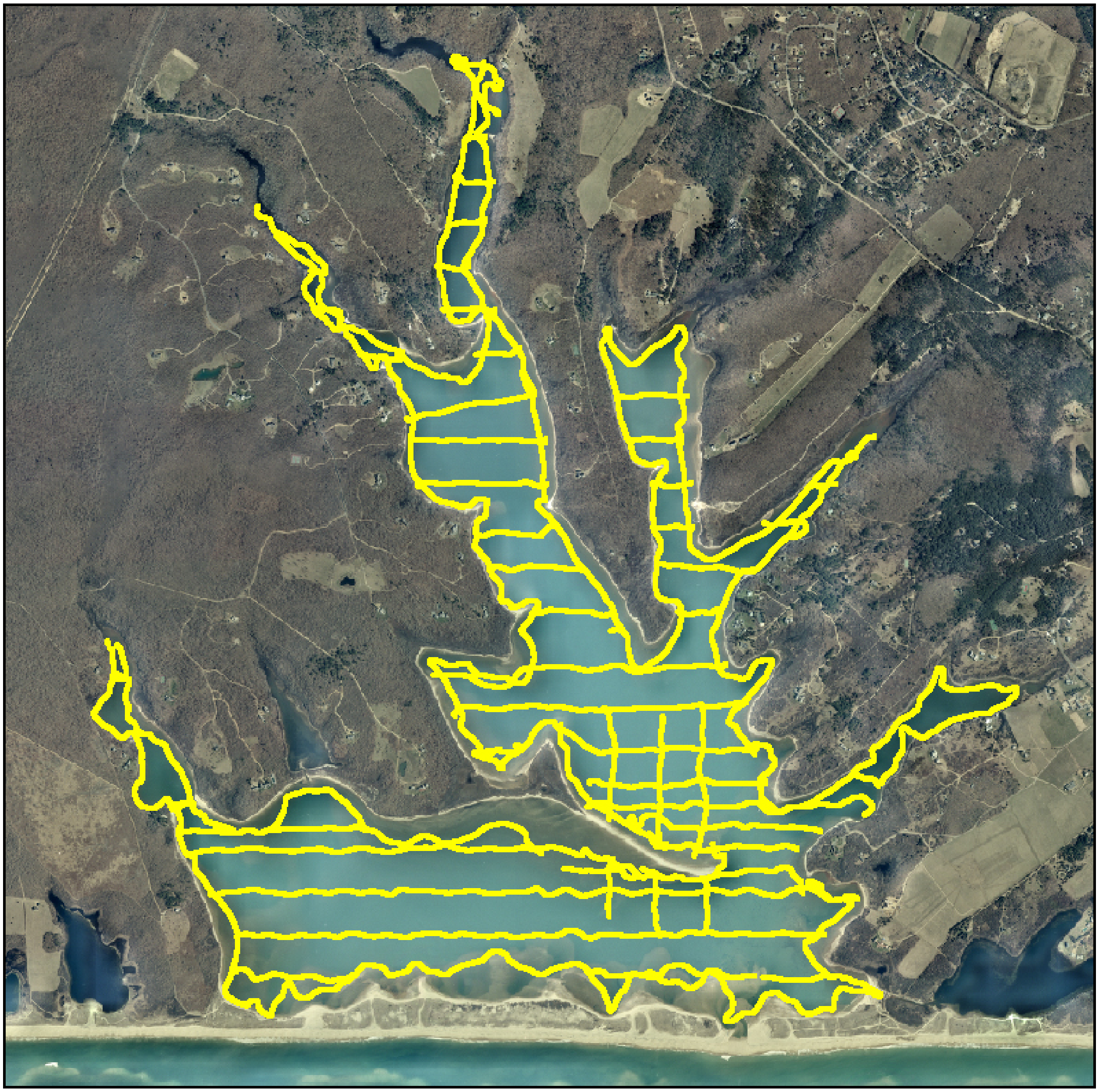


Figure V-6. Bathymetry survey lines (yellow) followed by the boat in Edgartown Great Pond.


Figure V-7. Tide gage locations within Edgartown Great Pond.

Using these data, an average flow rate out of the pond was measured. The first four times that the pond level was falling after the initial opening were examined to determine the drop in pond elevation and the time over which this drop occurred. Together with the surface area of the pond (approximately 860 acres), these values led to a calculation of 1200 $ft^3/s$ of water leaving the pond on average.

With the flow rate and channel width established, the channel depth was calculated using an approach described by the U.S. Army Corps of Engineers (USACE) for the analysis of scour depth at tidal inlets (Hughes, 1999). This equation predicts the depth of the channel, given the flow rate, sediment type and channel width as

$$h = \frac{0.234 q^{8/9}}{[g(S-1)]^{4/9} d^{1/3}}$$

where *h* is the elevation of the channel bottom relative to the high water level, *q* is the flow rate divided by the channel width, *S* is the specific gravity of the sand and *d* is the average diameter of the sand. A quartz sand (*S* = 2.65) of diameter 0.5mm was used to represent the sand in this case.

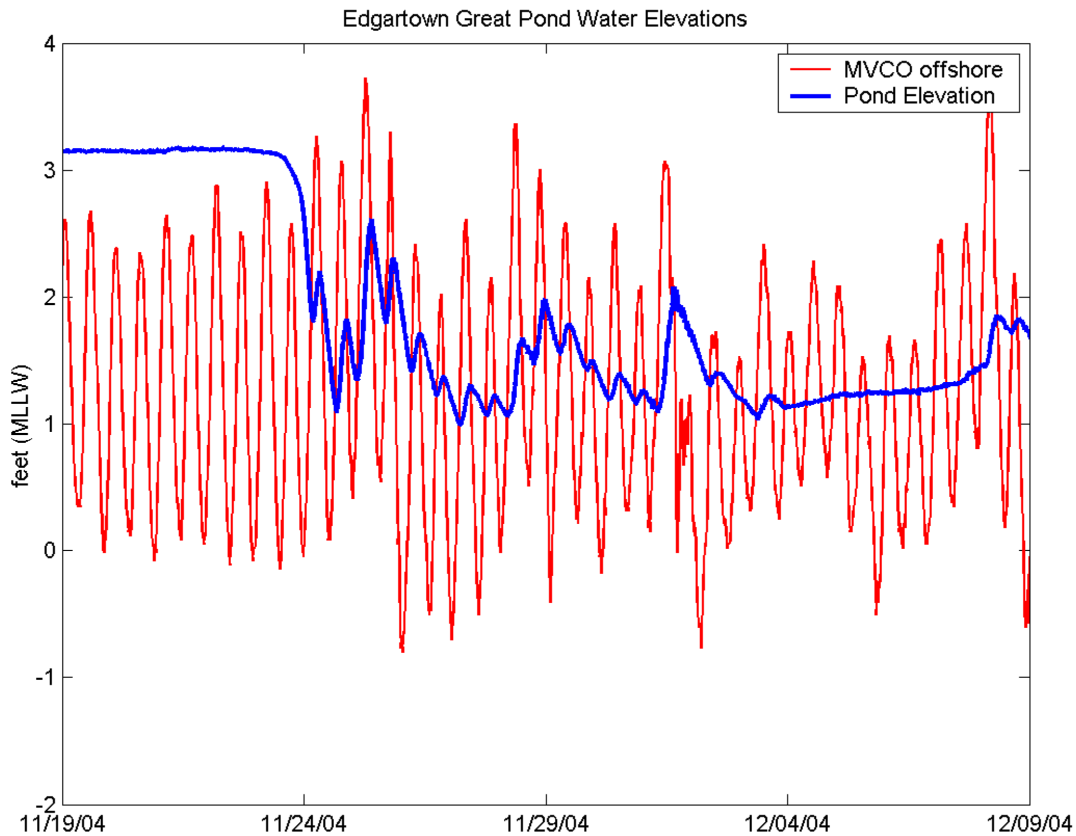



Figure V-8. Tide gage signals measured offshore at the MVCO and within Edgartown Great Pond. The figure represents a subset of the four-month dataset focused on the November 24, 2004 breach event. Elevations are referenced to MLLW.

With the initial pond elevation, offshore tides, channel width, and channel depth established, the final step was to estimate the flow in and out of Edgartown Great Pond during the breach event. To compute this volume exchange, the equation of flow over a broad-crested weir was employed. This equation relates the flow rate through the channel to the channel width and height of water above the channel bottom as

$$Q = 3.0bH^{3/2}$$

where Q is the predicted flow rate, b is the channel width and H is the difference in elevation between the high water and the channel bottom.

Using the starting pond level of 3.2 feet MLLW and the recorded offshore tides, a computer model was created to calculate the time-varying flow through the channel. The pond level and offshore tide every 10 minutes was input into the model and the flow rate was calculated. Multiplying the flow rate by the time step yields the total volume of water moving through the channel. If the pond level is higher than the offshore tide, this water is leaving the pond, while a higher water level in the ocean means that water is entering the pond. Knowing the surface area of the pond, the change in pond surface elevation was calculated at each time step. The comparison between the field data and the broad-crested weir model is shown in Figure V-9 below.

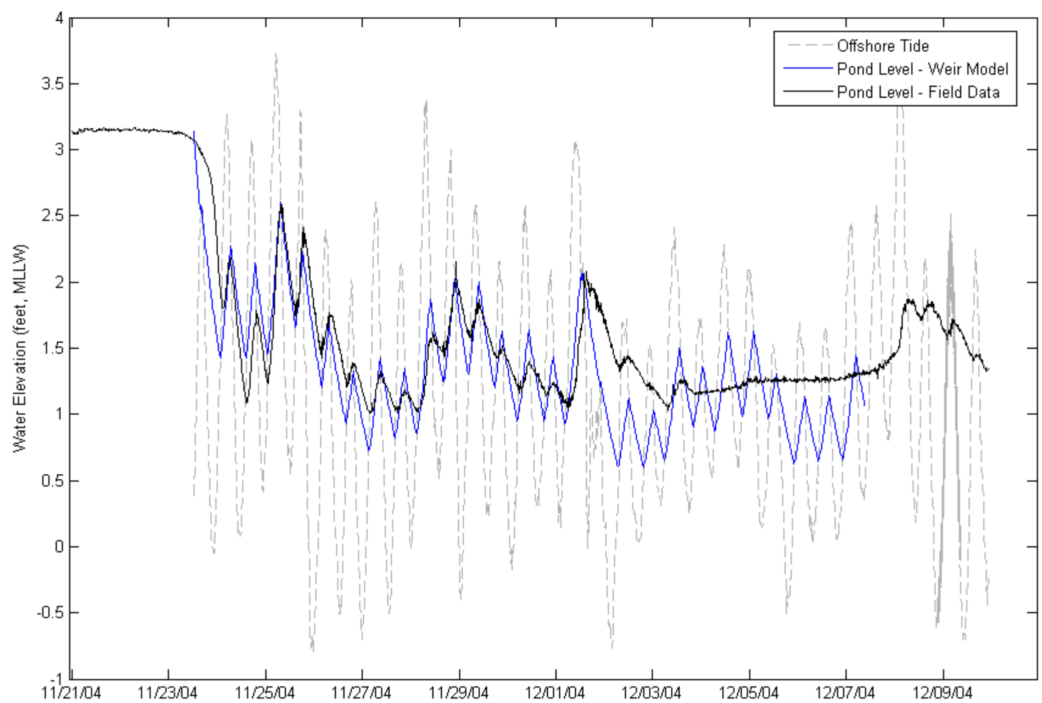



Figure V-9. A comparison of the broad-crested weir model results with the recorded pond elevations during the breach event at Edgartown Great Pond.

This simple modeling approach yielded excellent agreement with the field data. During the first 5 days (11/23-11/28) the slopes of the weir model prediction and the field data are similar, suggesting that the channel was conveying water in and out of the pond freely. The following 4 days (11/29-12/2) show the field data having a slightly shallower slope than the model as well as a smaller tide range inside the pond. This indicates that the water was not traveling through the channel freely, suggesting that the opening was beginning to shoal. This is a good reminder that the weir model assumes a fully open channel and makes no approximations for the natural shoaling and eventual closure of the breach. With that caveat in mind, these results provided confidence that the broad-crested weir modeling approach would yield a good approximation of flow during a typical breach event in Edgartown Great Pond. The resulting pond elevations were used as the boundary condition for the RMA2 model.

### V.4.3 RMA2 Model Theory

In its original form, RMA-2 was developed by William Norton and Ian King under contract with the U.S. Army Corps of Engineers (Norton et al., 1973). Further development included the introduction of one-dimensional elements, state-of-the-art pre- and post-processing data programs, and the use of elements with curved borders. Recently, the graphic pre- and post-processing routines were updated by Brigham Young University through a package called the Surfacewater Modeling System or SMS (BYU, 1998). Graphics generated in support of this report primarily were generated within the SMS modeling package.

RMA-2 is a finite element model designed for simulating one- and two-dimensional depth-averaged hydrodynamic systems. The dependent variables are velocity and water depth, and the equations solved are the depth-averaged Navier Stokes equations. Reynolds assumptions are incorporated as an eddy viscosity effect to represent turbulent energy losses. Other terms in the governing equations permit friction losses (approximated either by a Chezy or Manning formulation), Coriolis effects, and surface wind stresses. All the coefficients associated with these terms may vary from element to element. The model utilizes quadrilaterals and triangles to represent the system. Element boundaries may either be curved or straight.

The time dependence of the governing equations is incorporated within the solution technique needed to solve the set of simultaneous equations. This technique is implicit; therefore it is unconditionally stable. Once the equations are solved, corrections to the initial estimate of velocity and water elevation are employed, and the equations are re-solved until the convergence criteria is met.

### V.4.4 RMA2 Model Development

A two-dimensional hydrodynamic model of Edgartown Great Pond was developed using inputs of bathymetry and modeled water surface elevations determined using the broad-crested weir model (Figure V-9). This hydrodynamic model in turn is used as input into the final two-dimensional water quality of the pond.

The finite element mesh with interpolated bathymetry is shown in Figure V-10. The grid is composed of 600 quadratic finite elements (both triangular and quadrilateral elements) and 2037 computational nodes. The grid has a maximum depth of -16.5 ft MLLW, which is located in the deep area in the northeastern region of the pond. The bathymetry in the area around the breach in the northeast edge of the pond was edited to be deeper than actually occurs there. This small change was made to ensure model stability and has little impact on the modeled pond elevations and subsequent water quality analysis.

## V.5. FLUSHING CHARACTERISTICS

During a sustained breach event, the freshwater inflow would be negligible in comparison to the tidal exchange through the temporary inlet. A rising tide in the Atlantic Ocean creates a slope in water surface from the ocean into the pond. Consequently, water flows into (floods) the pond. Similarly, the pond drains on an ebbing tide. This exchange of water between the pond and ocean is defined as tidal flushing. The calibrated hydrodynamic model is a tool to evaluate quantitatively tidal flushing of the system, and was used to compute flushing rates (residence times) and tidal circulation patterns.

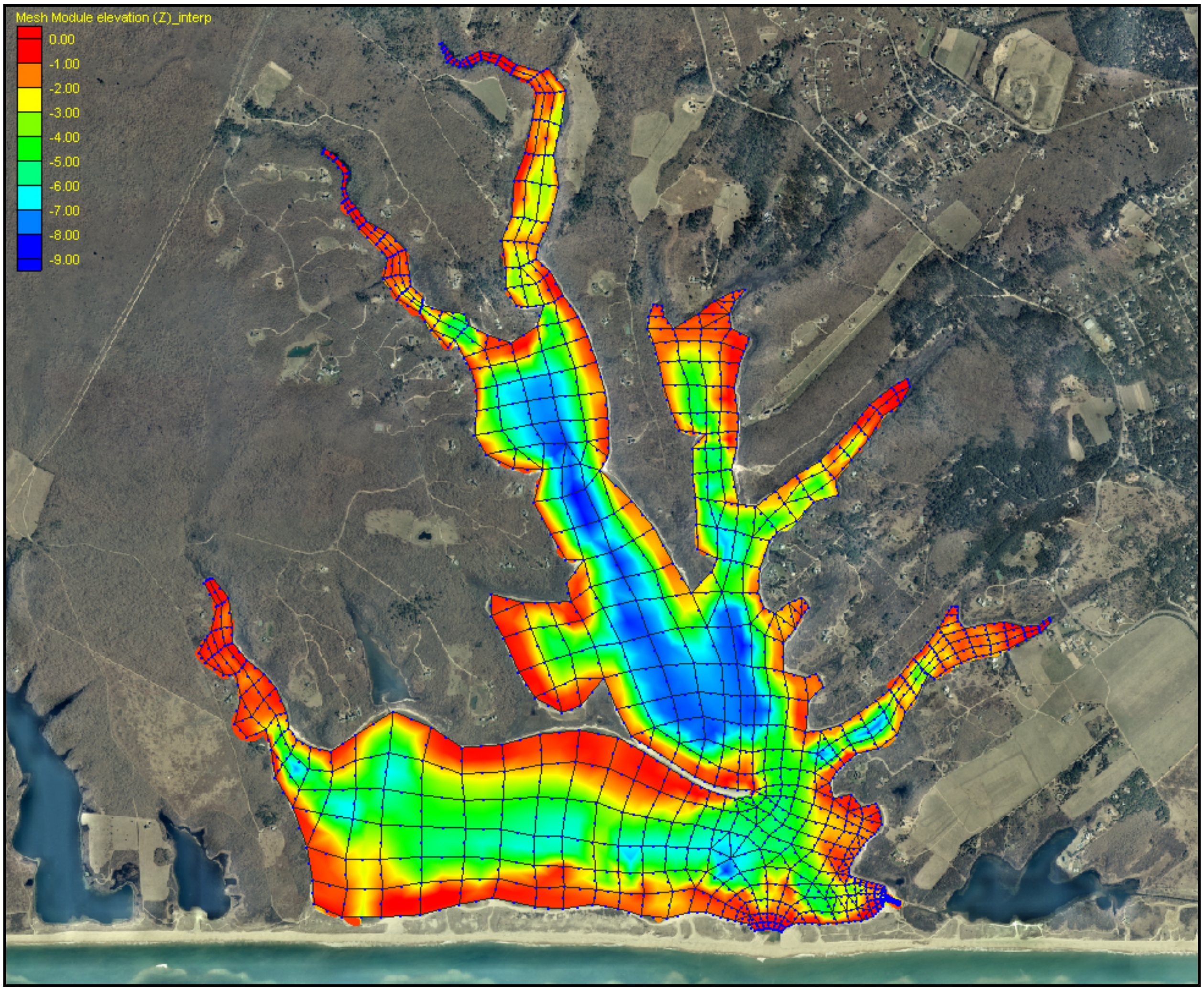



Figure V-10. Interpolated bathymetric contours (feet) of the final RMA2 computational mesh of Edgartown Great Pond. Depth contours are relative to the MLLW.

Flushing rate, or residence time, is defined as the average time required for a parcel of water to migrate out of an pond from points within the system. For this study, a **system residence time** was computed as the average time required for a water parcel to migrate from a point within the pond to the entrance of the channel. System residence times are computed as follows:

$$T_{system} = \frac{V_{system}}{P} t_{cycle}$$

where $T_{system}$ denotes the residence time for the system, $V_{system}$ represents volume of the pond at mean tide level, $P$ equals the tidal prism (or volume entering the pond through a single tidal cycle), and $t_{cycle}$ the period of the tidal cycle, typically 12.42 hours (or 0.52 days).

Residence times are provided as a first order evaluation of estuarine water quality. Lower residence times generally correspond to higher water quality; however, residence times may be misleading depending upon pollutant/nutrient loading rates and the overall quality of the receiving waters. As a qualitative guide, system residence times are applicable for systems where the water quality within the entire estuary is degraded and higher quality waters provide the only means of reducing the high nutrient levels. This is a valid approach in this case, since it assumes the ocean has higher quality water relative to the pond.

The rate of pollutant/nutrient loading and the quality of water outside the estuary both must be evaluated in conjunction with residence times to obtain a clear picture of water quality. Efficient tidal flushing (low residence time) is not an indication of high water quality if pollutants and nutrients are loaded into the system faster than the tidal circulation can flush the system. Neither are low residence times an indicator of high water quality if the water flushed into the pond is of poor quality. Advanced understanding of water quality will be obtained from the calibrated hydrodynamic model by extending the model to include pollutant/nutrient dispersion. The water quality model will provide a valuable tool to evaluate the complex mechanisms governing water quality in the Edgartown Great Pond system.

The average volume calculated for Edgartown Great Pond is 166,037,664 $ft^3$ with a tidal prism of 22,982,905 $ft^3$when the inlet is open. This results in a residence time of approximately 3.7 days. This modest residence time provides some confidence that the temporary channel allows enough exchange to significantly improve water quality during a typical breach event. A detailed discussion of the water quality analysis and results is found in Section VI.

# VI. WATER QUALITY MODELING

The water quality modeling analysis approach that has been typically used for other systems that have been studied as part of the Massachusetts Estuaries Project was slightly modified for Edgartown Great Pond.

This system differs from most other systems modeled up to this point in time mainly because it does not have inlet that is open at all times to the ocean. Water quality in the Pond is managed presently by opening an inlet 2 to 3 times per year (average = 2.65 based on record of openings between 1995 and 2005), once in the spring and once in autumn. The period of time that the inlet remains open after it is breached varies between 1 and 71 days, based on observations of openings made from 1995 through 2007. On average, the pond is open 23 days total a year, which means it is closed off from the ocean nearly 94% of the time.

Because Edgartown Great Pond is actively managed in such a fashion, the water quality analysis has to include methods for determining conditions in the Pond at times when it is both open and closed to tidal exchange with the ocean. During times when the Pond inlet is breached, the RMA-4 model was used to model water quality constituent dispersion throughout the Pond's main basin and the series of coves. During the long periods when the breach is closed, a simple mass balance model was developed. As used together in this analysis, these two modeling techniques accurately simulate conditions in the Pond throughout the critical summer months, and provide a method of investigating alternatives to manage pond health.

## VI.1 DATA SOURCES FOR THE MODEL

Several different data types and calculations are required to support the water quality modeling effort for the Edgartown Great Pond system. These include the output from the hydrodynamics model, calculations of external nitrogen loads from the watersheds, measurements of internal nitrogen loads from the sediment (benthic flux), and measurements of salinity and nitrogen in the water column.

### VI.1.1 Hydrodynamics and Tidal Flushing in the Embayments

Field measurements and hydrodynamic modeling of the embayment provide essential preparatory input to the water quality model development effort. The pond breach simulation discussed in Chapter V is an important tool for determining the water quality dynamics that are in effect presently, and also for investigating how possibly the pond could be managed differently in the future to further improve water quality conditions. Files of node locations and node connectivity for the RMA-2V model grids were transferred to the RMA-4 water quality model; therefore, the computational grid for the hydrodynamic model also was the computational grid for the water quality model. For each of the modeling scenarios presented in this chapter, the breach model was run for a typical 12-day period, based on the tide data record measured offshore of Katama Beach, beginning on November 23, 2004. These tide data were input into the analytical breach model to develop the boundary condition used to force the RMA-2 model of Edgartown Great Pond. The hydrodynamics of the breach model are not strongly dependent upon the small inter-monthly variations of the astronomical tide; therefore, the selected 12-day period is considered representative of typical tidal conditions year-round.

### VI.1.2 Nitrogen Loading to the Embayments

Three primary nitrogen loads to Edgartown Great Pond are recognized in this modeling study: external loads from the watersheds, nitrogen load from direct rainfall on the embayment surface, and internal loads from the sediments. Additionally, there is a fourth load to Edgartown Great Pond, consisting of the background concentrations of total nitrogen (TN) in the waters entering from the Atlantic Ocean during the brief periods when the inlet is open. This load is represented as a constant concentration along the seaward boundary of the RMA-4 model grid during the pond breach simulation period.

### VI.1.3 Measured Nitrogen Concentrations in the Embayments

In order to create a model that realistically simulates salinity and total nitrogen concentrations in Great Pond in response to the existing flushing conditions and loadings, it was necessary to calibrate the model to actual measurements. The refined and approved data for the monitoring station used in the water quality modeling effort are presented in Table VI-1. Station locations are indicated in the area map presented in Figure VI-1. The multi-year averages present the "best" comparison to the water quality model output, since factors of tide, temperature and rainfall may exert short-term influences on the individual sampling dates and even cause inter-annual differences. Three years of baseline field data are the minimum required to provide a baseline for MEP analysis. For Edgartown Great Pond, eight years of salinity and TN measurements are available between 1995 and 2006.

Table VI-1. Measured nitrogen concentrations and salinities for Edgartown Great Pond. "Data mean" values are calculated as the average of the separate yearly means. TN data represented in this table were collected in 2003 through 2006 in Great Pond and 2002 through 2004 for salinity. The offshore Atlantic Ocean data are from the summer of 2005.

| Sampling Station Location | total nitrogen | | | salinity | | |
|---|---|---|---|---|---|---|
| | data mean (mg/L) | s.d. all data (mg/L) | N | data mean (ppt) | s.d. all data (ppt) | N |
| Jobs Neck Cove – EGP8 | 0.583 | 0.174 | 9 | 17.9 | 5.1 | 11 |
| Jane's Cove – EGP10 | 0.582 | 0.153 | 7 | 16.5 | 3.4 | 10 |
| Wintucket Cove – EGP9 | 0.597 | 0.123 | 10 | 18.0 | 3.8 | 11 |
| Upper Mash Cove – EGP1 | 0.650 | 0.170 | 9 | 18.9 | 4.6 | 14 |
| Lower Mash Cove – EGP2 | 0.613 | 0.159 | 9 | 18.2 | 5.6 | 14 |
| Turkeyland Cove – EGP11 | 0.639 | 0.107 | 5 | 19.8 | 3.4 | 11 |
| Upper Slough Cove – EGP4 | 0.711 | 0.193 | 10 | 16.2 | 4.6 | 32 |
| Upper EGP Basin – EGP3 | 0.587 | 0.175 | 10 | 18.4 | 5.1 | 14 |
| Lower EGP West – EGP5 | 0.595 | 0.187 | 11 | 20.9 | 4.6 | 14 |
| Lower EGP East – EGP6 | 0.591 | 0.205 | 9 | 22.1 | 5.4 | 14 |
| Atlantic Ocean | 0.232 | 0.044 | 17 | 32.3 | 0.6 | 5 |

## VI.2 MODEL DESCRIPTION AND APPLICATION

The overall approach used in the analysis of Edgartown Great Pond involves first developing a salinity model of the Pond. Salinity is a conservative water quality constituent, meaning that is has no active sources or sinks other than tidal exchange with the ocean. Because salinity data are conservative, they are excellent calibration data for systems such as Great Pond. In such simple systems it is an easy task to compute water recharge and rainfall rates based on the observed salinity record.

The Great Pond analysis requires that both periods when the inlet is open and closed be considered, so a two-part approach was developed. The initial period (when the Pond inlet is breached in the early summer and there is tidal exchange with the ocean) is modeled using the RMA-4 dispersion model. The following period when the inlet is closed, and the Pond behaves like a simple reservoir, is simulated using a simple mass balance model which considers fresh water inputs and constituent mass flux into the Pond (which is 0 for the salinity simulation) throughout the simulation period.

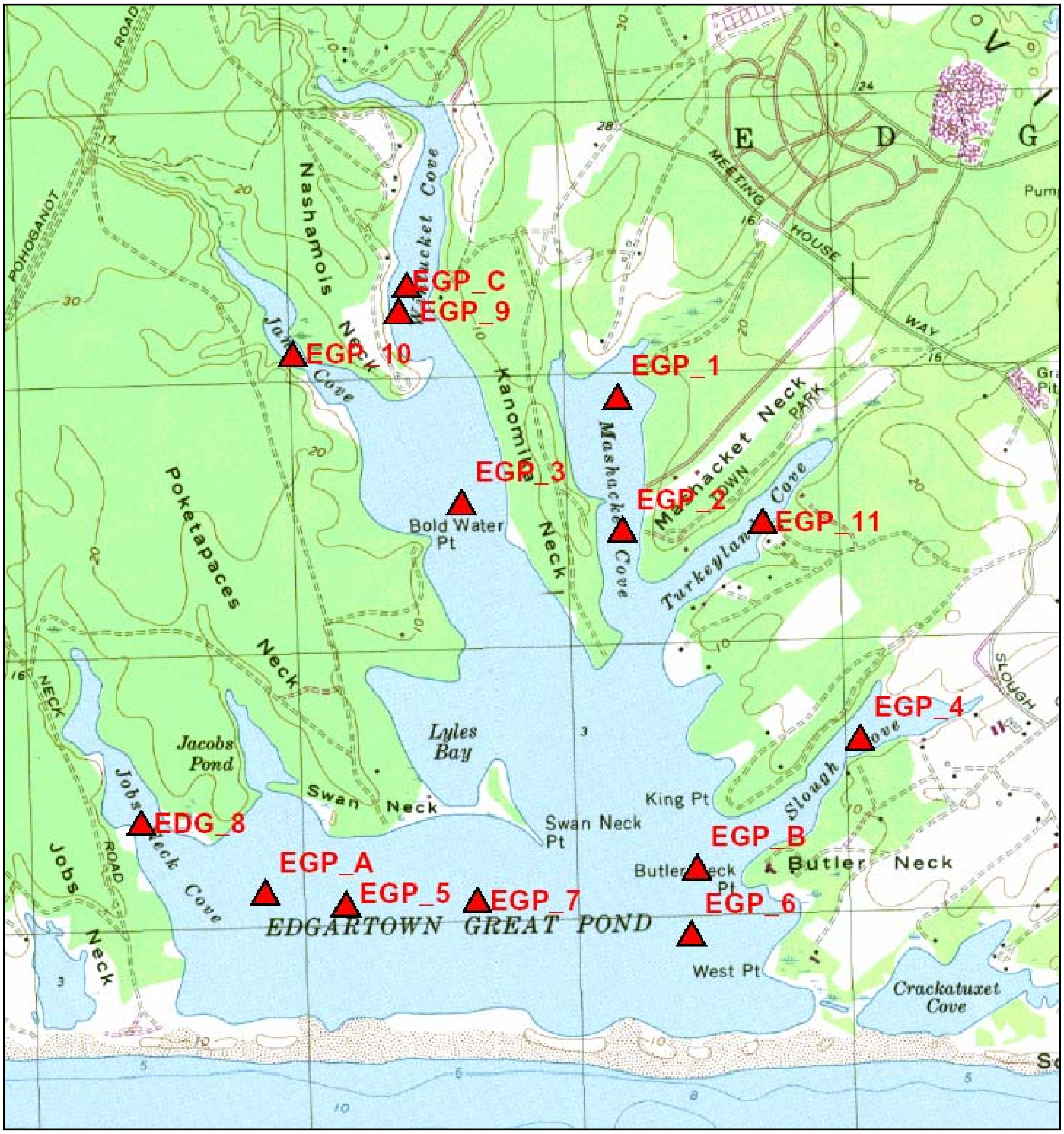



Figure VI-1. USGS topographic map showing monitoring station locations in Edgartown Great Pond that were used in the water quality analysis.

With a calibrated salinity model, a verification of the model is performed using total nitrogen, which is a non-conservative constituent. For TN, bottom sediments act as a source or sink of nitrogen, based on local biochemical characteristics. The TN model considers summertime loading conditions, when algal growth is at its maximum. Total nitrogen modeling is based upon various data collection efforts and analyses presented in previous sections of this report. Nitrogen loading information was derived from the joint Martha's Vineyard Commission/ Cape Cod Commission watershed loading analysis, as well as the measured bottom sediment nitrogen fluxes. Water column nitrogen measurements were utilized as model boundaries and as calibration data.

### VI.2.1 Model Formulation

#### VI.2.1.1 Dispersion Model

A two-dimensional finite element water quality model, RMA-4 (King, 1990), was employed to study the effects of water quality constituent dispersion in Great Pond during the periods when it is open to the ocean. The RMA-4 model has the capability for the simulation of advection-diffusion processes in aquatic environments. It is the constituent transport model counterpart of the RMA-2 hydrodynamic model used to simulate the fluid dynamics of the Pond. Like RMA-2 numerical code, RMA-4 is a two-dimensional, depth averaged finite element model capable of simulating time-dependent constituent transport. The RMA-4 model was developed with support from the US Army Corps of Engineers (USACE) Waterways Experiment Station (WES), and is widely accepted and tested. Applied Coastal staff have utilized this model in water quality studies of other Cape Cod embayments, including other Massachusetts estuarine systems such as Pleasant Bay (Howes *et al*., 2006); Falmouth (Howes *et al*., 2005); and Mashpee, MA (Howes *et al*., 2004), and including other periodically breached coastal ponds like Sesachacha Pond on Nantucket Island (Howes *et al*., 2006).

The formulation of the model is for two-dimensional depth-averaged systems in which concentration in the vertical direction is assumed uniform. The depth-averaged assumption is justified since vertical mixing by wind and tidal processes prevent significant stratification in the modeled sub-embayments. The governing equation of the RMA-4 constituent model can be most simply expressed as a form of the transport equation, in two dimensions:

$$\left(\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y}\right) = \left(\frac{\partial}{\partial x}D_x\frac{\partial c}{\partial x} + \frac{\partial}{\partial y}D_y\frac{\partial c}{\partial y} + \sigma\right)$$

where $c$ in the water quality constituent concentration; $t$ is time; $u$ and $v$ are the velocities in the $x$ and $y$ directions, respectively; $D_o$ and $D_{ee}$ are the model dispersion coefficients in the $x$ and $y$ directions; and $\sigma$ is the constituent source/sink term. Since the model utilizes input from the RMA-2 model, a similar implicit solution technique is employed for the RMA-4 model.

The model is therefore used to compute spatially and temporally varying concentrations $c$ of the modeled constituent (i.e., total nitrogen), based on model inputs of 1) water depth and velocity computed using the RMA-2 hydrodynamic model; 2) mass loading input of the modeled constituent; and 3) user selected values of the model dispersion coefficients. Dispersion coefficients used for each system sub-embayment were developed during the calibration process. During the calibration procedure, the dispersion coefficients were incrementally changed until model concentration outputs matched measured data.

The RMA-4 model can be utilized to predict both spatial and temporal variations in total nitrogen for a given embayment system. At each time step, the model computes constituent concentrations over the entire finite element grid and utilizes a continuity of mass equation to check these results. Similar to the hydrodynamic model, the water quality model evaluates model parameters at every element at 20-minute time intervals throughout the grid system. For this application, the RMA-4 model was used to predict time varying salinity and total nitrogen concentrations throughout Pond during an inlet opening. For demonstration purposes, the model was used to simulate a 30 day opening to investigate how salinity and total nitrogen change with opening duration, although openings of <12 days are the norm in practice.

### VI.2.1.2 Mass Balance Model

During the extended periods when Great Pond is closed off from the Ocean, the system is modeled as a simple well mixed reservoir. The concentration *c* is a function of time *t*, and can be determined using the relationship

$$c(t) = \frac{m_o + t\,\dfrac{dm}{dt}}{V_o + t\,\dfrac{dV}{dt}},$$

Where *m* is the total mass of the modeled constituent, *V* is the volume of the Pond and the subscript *o* is used to designate the initial conditions. For the salinity model, the mass flux of salt (dm/dt) into the pond is zero. Using salinity data records from the summers of 1999, 2000, 2003 and 2004, a mass balance analysis of salt was performed to determine the rate of groundwater flow and salt flux through the barrier beach to the Ocean and through the weir between Great Pond and Crackatuxet Cove. These flows are the only possible sinks for salinity in the Pond system. The four years used for this analysis were selected because in each of these years there was adequate salinity data to base the simulation. These breechings raised salinities in the Pond initially, and over the course of the summer, salinities slowly dropped as the Pond was diluted by ground water recharge and rainfall. For each simulation, the model was tuned to replicate both the fall in salinity and rise in pond surface elevation.

By this analysis, the groundwater flow out of the Pond is seen to vary based upon annual variations in rainfall and stage of the pond. In Sept-Oct 1999, the recharge rate and flow though were computed to be 13.5 $ft^3$/sec and 10 $ft^3$/sec respectively. The high flow through rate is due to the high elevation of the pond during this period (up to 3.5 ft MLLW), and indicates a large flow through the beach and to Crackatuxet Cove. In July-Aug 2000 the recharge was computed to be 13.5 $ft^3$/sec, with a flow through of 0.25 $ft^3$/sec. In June-July 2004, the computed recharge and flow through (13.7 $ft^3$/sec and 0.35 $ft^3$/sec respectively) are similar to those computed for 2000. For the final period, in July-Sept 2003, a lower recharge rate was computed of 11.0 $ft^3$/sec, with a flow through of 1.5 $ft^3$/sec.

The lower recharge rate (11.0 $ft^3$/sec) determined using the summer 2003 data was used in the simulations of the following water quality scenarios (e.g., build-out and no-anthropogenic loading) since it represents the likely low-end range of summertime recharge rates. This rate makes the simulations of the different load scenarios show conservative estimates of TN concentrations in the Pond (i.e., a greater increase) compared to average recharge rates.

### VI.2.2 Boundary Condition Specification

Mass loading of nitrogen into the model included 1) sources developed from the results of the watershed analysis, 2) estimates of direct atmospheric deposition, and 3) summer benthic regeneration. Nitrogen loads from each separate sub-embayment watershed were distributed across the sub-embayment. For example, the combined watershed, direct atmospheric deposition and benthic flux loads for the whole Pond were evenly distributed across the cells that make up the RMA computational grid.

The loadings used to model present conditions in Edgartown Great Pond are given in

Table VI-2. Watershed and depositional loads were taken from the results of the analysis of Section IV. The watershed load in this table assumes that the WWTF plume had not washed out to its present 2007 level. Summertime benthic flux loads were computed based on the analysis of sediment cores in Section IV. The area rate (g/sec/m$^2$) of nitrogen flux from that analysis was applied to the surface area coverage computed for each sub-embayment, resulting in a total flux for the system (as listed in Table VI-2). Due to the highly variable nature of bottom sediments and other estuarine characteristics of coastal embayments in general, the measured benthic flux for existing conditions also is variable. The benthic flux presented in Table VI-2 represents the net flux for the entire pond. Sediments in the northern basin of the Pond tend to have negative fluxes, which indicates that they are a nitrogen sink. The N production of the bottom sediment in other areas is greater than this sink, and as a result, the net flux from the whole pond is positive.

In addition to mass loading boundary conditions set within the model domain, concentrations along the model open boundary were specified for the dispersion model. The model uses concentrations at the open boundary during the flooding tide periods of the RMA-4 model simulations. TN concentrations of the incoming water are set at the value designated for the open boundary. The TN boundary concentration in the Atlantic Ocean region offshore the Pond was set at 0.232 mg/L, based on SMAST data collected offshore Pleasant Bay in the summer of 2005. As there is no offshore station relative to Edgartown Great Pond, the offshore station off Pleasant Bay is representative of Atlantic Ocean water that would be flowing into the Edgartown Great Pond system during a breach event. For the salinity model, the offshore concentration was set at 32.3 ppt.

Table VI-2. Embayment and surface water loads used for total nitrogen modeling of Edgartown Great Pond, with total watershed N loads, atmospheric N loads, and benthic flux. These loads represent 2003 present loading conditions for the listed sub-embayments.

| embayment | watershed load (kg/day) | direct atmospheric deposition (kg/day) | benthic flux net (kg/day) |
|---|---|---|---|
| Edgartown Great Pond | 30.282 | 11.445 | 20.445 |

### VI.2.3 Development of Present Conditions Model

To develop the water quality model of present conditions for Great Pond, the RMA-4 dispersion model and the mass balance model were separately developed to simulate salinities in the Pond.

First, three successful pond breaches were modeled using RMA-4 and the RMA-2 hydrodynamic model results. The dates and measured salinities (pre- and post-breach) are presented in Table VI-3. For each simulated time period, the dispersion model was run for the period of time that each breach was open, and the resulting pond-averaged salinity at the end of the simulation was compared to the measured value. This comparison is shown in Figure VI-2. The model output compares exceptionally well with Pond measurements made after each breach closing ($R^2$ correlation of 0.89 and RMS error of 0.57 ppt).

| Table VI-3. Breach dates and starting and ending salinities used in the calibration of the RMA-4 dispersion model of Edgartown Great Pond. | | | |
|---|---|---|---|
| Date of Opening | Days Open | Starting Salinity (ppt) | Ending Salinity (ppt) |
| July 16, 2005 | 10 | 15 | 27 |
| April 11, 2006 | 14 | 12 | 28 |
| October 16, 2006 | 7 | 12 | 24 |

For time periods when the pond was closed off from the ocean, the mass balance model was used. This model requires an initial salinity and pond volume, as well as a net fresh water flux and flow-though. The mass balance model was calibrated using data from summer 2003, which is a period where good-quality contemporaneous TN, salinity, and pond elevation data exist. The initial salinity (26.0 ppt) was measured on July 22. The initial Pond volume was determined to be 168,760,000 $ft^3$, based on results from the hydrodynamic model. The net freshwater input to the Pond was determined to be 11.0 $ft^3$/sec, with a flow through discharge from the pond of 1.5 $ft^3$/sec.

The comparison of modeled versus measured salinities between July and September 2003 are presented in Figures VI-3 and VI-4. The comparison of modeled versus measured pond elevations between July and September 2003 are presented in Figures VI-5 and VI-6. The comparison shows that the combined mass balance model is able to simulate both salinities and elevation changes with a high degree of skill, with an $R^2$ correlation of 0.99 and an rms error of 0.02 ppt for the salinity model, with also an $R^2$ correlation of 0.99 and rms error of 0.01 ft. Also in Figures VI-4 and VI-6, the results of a model sensitivity analysis are shown. Model output for two additional cases, where the recharge rates were changed to be 15.72 (the annual average from the Cape Cod Commission) and 7.6 $ft^3$/sec (determined by only considering the volume required to cause the observed increase in pond elevation), shows how the model behaves as the rate is varied. This shows that the model is very sensitive to the applied recharge rate, and further indication that the recharge and flow through rates used to simulate this summer period in 2003 are close to the actual conditions of the pond during at this time. A tabulation of the salinity calibration and elevation verification data is presented in Table VI-4.

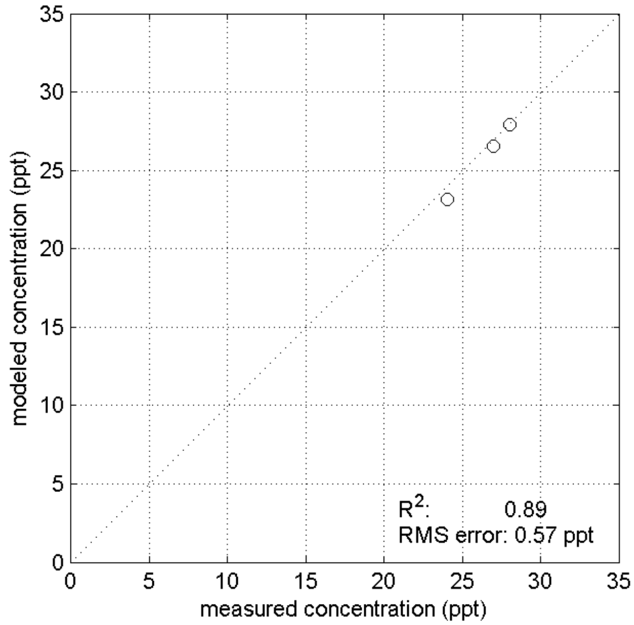



Figure VI-2. Comparison of measured and modeled salinities for successful Edgartown Great Pond breachings that occurred in July 2005, April 2006 and October 2006. RMA-4 salinity dispersion model output is compared to measured salinities at the close of each breach. For these opening events, the inlet allowed tidal exchange with the Atlantic Ocean.

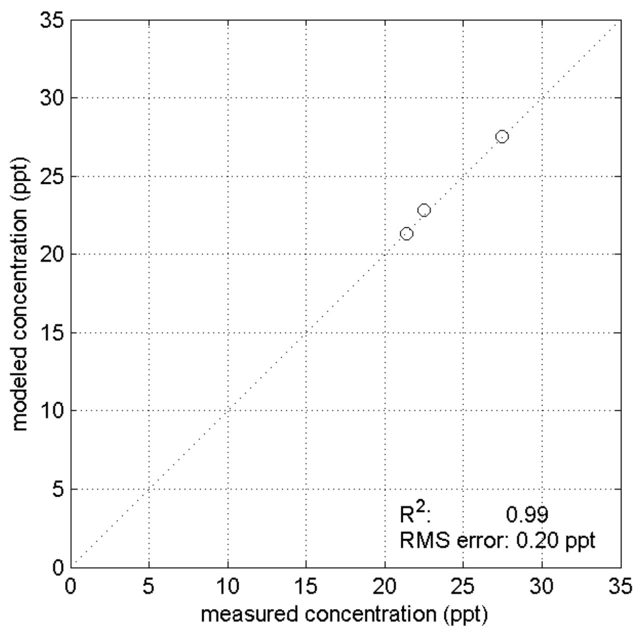



Figure VI-3. Model salinity target values are plotted against measured concentrations, together with the unity line, for the simulation period from July through September 2003. RMS error for this model verification run is 0.20 ppt and the $R^2$ correlation coefficient is 0.99.

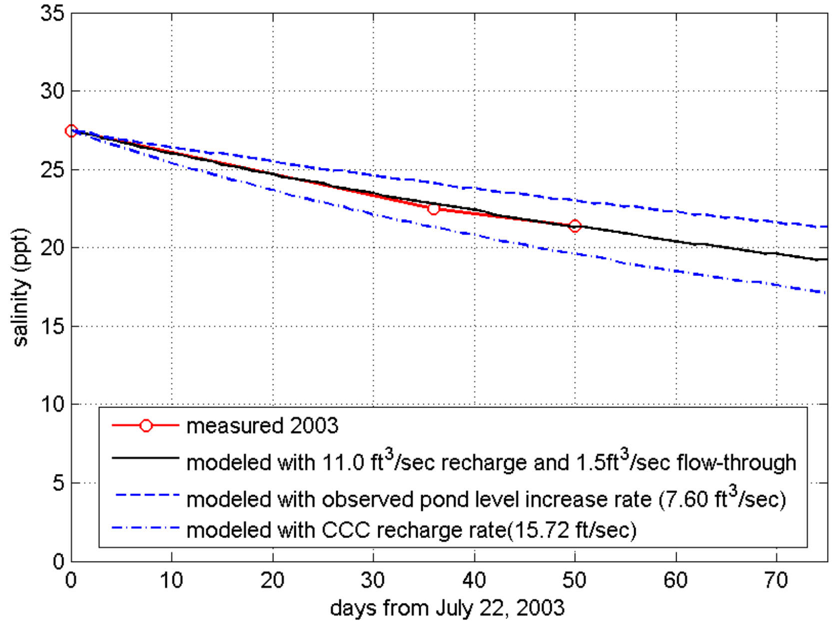



Figure VI-4. Comparison of measured (red line with circles) and modeled (black line) salinities through the summer of 2003, from after the June breaching of an inlet to the Atlantic Ocean. This period through the summer was simulated using the mass balance model. Results of the sensitivity analysis are also presented, showing model output using recharge rate reported by the Cape Cod Commission (CCC) and the rate determined using only the measured surface elevation increase of the pond during this same period.

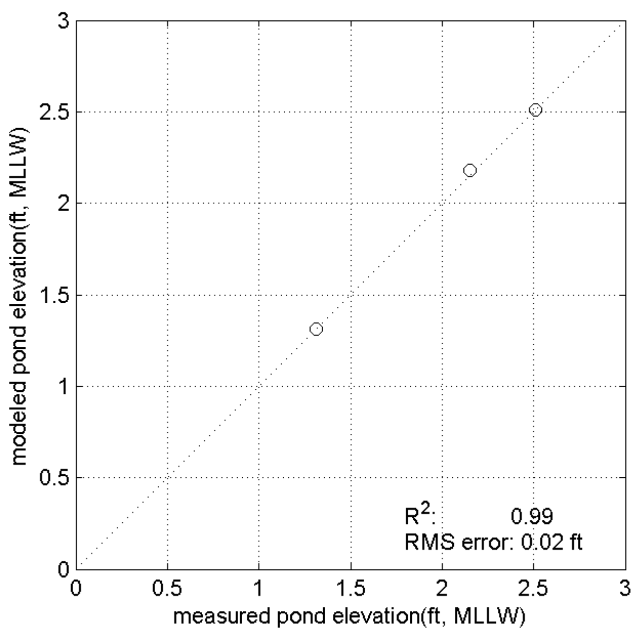



Figure VI-5. Model pond elevation target values are plotted against measured elevations, together with the unity line, for the simulation period from July through September 2003. RMS error for this model verification run is 0.02 ppt and the $R^2$ correlation coefficient is 0.99.

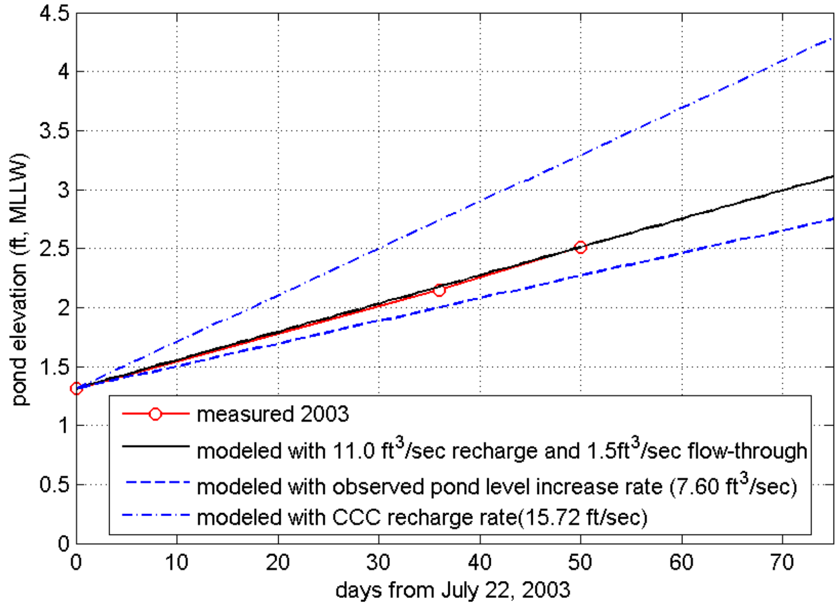



Figure VI-6. Comparison of measured (red line with circle markers) and modeled (black line) pond elevations through the summer of 2003, from after the June breaching of an inlet to the Atlantic Ocean. This period through the summer was simulated using the mass balance model. Results of the sensitivity analysis are also presented, showing model output using recharge rate reported by the Cape Cod Commission (CCC) and the rate determined using only the measured surface elevation increase of the pond during this same period.

Table VI-4. Comparison of measured data and model output for summer 2003 mass balance model calibration-verification period.

| Date, 2003 | measured salinity (ppt) | measured TN (mg/L) | measured pond elevation (ft, MLLW) | modeled salinity (ppt) | modeled TN (mg/L) | modeled pond elevation (ft, MLLW) |
|---|---|---|---|---|---|---|
| July 22 | 27.5 | 0.493 | 1.3 | 27.5 | 0.493 | 1.3 |
| August 26 | 22.5 | 0.802 | 2.2 | 22.6 | 0.815 | 2.2 |
| September 9 | 21.4 | 0.895 | 2.5 | 21.3 | 0.895 | 2.5 |

The Great Pond RMA-4 model can be used to show how pond salinities respond through a 30-day period. In Figure VI-7, output from the model in presented for three selected starting salinities. These model results are based on the minimum recharged rate of 11.0 $ft^3$/sec and a flow through rate of 1.5 $ft^3$/sec.

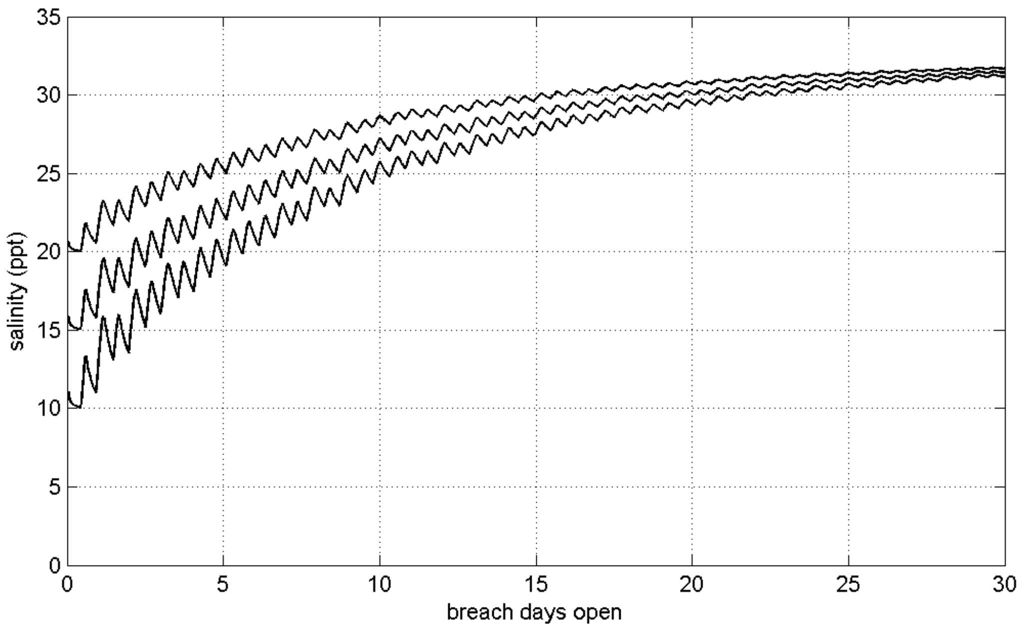



Figure VI-7. RMA-4 model output for Edgartown Great Pond showing how pond averaged salinities vary as a function of initial salinity concentration (here for 10, 15 and 20 ppt) and number of days open for the breach. Model results based on minimum recharge rate of 11.0 $ft^3$/sec with 1.5 $ft^3$/sec flow through. Model results also assume a fully open breach for the complete simulation period.

### VI.2.4 Total Nitrogen Model Development

With the completion of the salinity model, it was possible to use the components to simulate total nitrogen.

The mass balance model was used to simulate the period following the breach closure in June 2003. This model used the same N mass loading rates as the dispersion model and included the same 11.0 $ft^3$/sec freshwater input used in the calibration of the salinity model.

Model output is compared to measurements for the summer 2003 period in Figure VI-8 and VI-9. Similar to the results of the salinity model, the comparison demonstrates a high degree of modeling skill, with an $R^2$ correlation of 0.99 and an RMS error of 0.01 mg/L. Model sensitivity to the applied recharge rate is indicated also in Figure VI-9. Rates were varied between the CCC estimate of the rate (15.72 $ft^3$/sec) and 7.6 $ft^3$/sec (again, determined by only considering the volume required to cause the observed increase in pond elevation). Like the salinity analysis, the results show that the model is very sensitive to the applied recharge rate, and indicate that the recharge and flow-through rates used to simulate this period in 2003 is close to actual conditions.

Similar to the salinity model, the Edgartown Great Pond RMA-4 model can be used to show how pond TN concentrations respond through a 30-day period. In Figure VI-7, output from the model is presented for three selected starting TN concentrations and uses TN concentrations (2003-2006) and present loading conditions. These model results are based on the minimum recharged rate of 11.0 $ft^3$/sec and a flow through rate of 1.5 $ft^3$/sec.

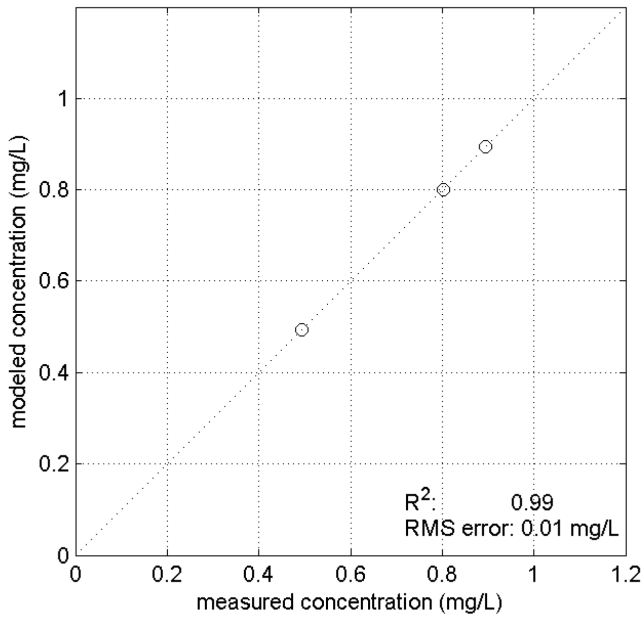



Figure VI-8. Model pond TN target values are plotted against measured concentrations, together with the unity line, for the simulation period from July through September 2003. RMS error for this model verification run is 0.01 mg/L and the $R^2$ correlation coefficient is 0.99.

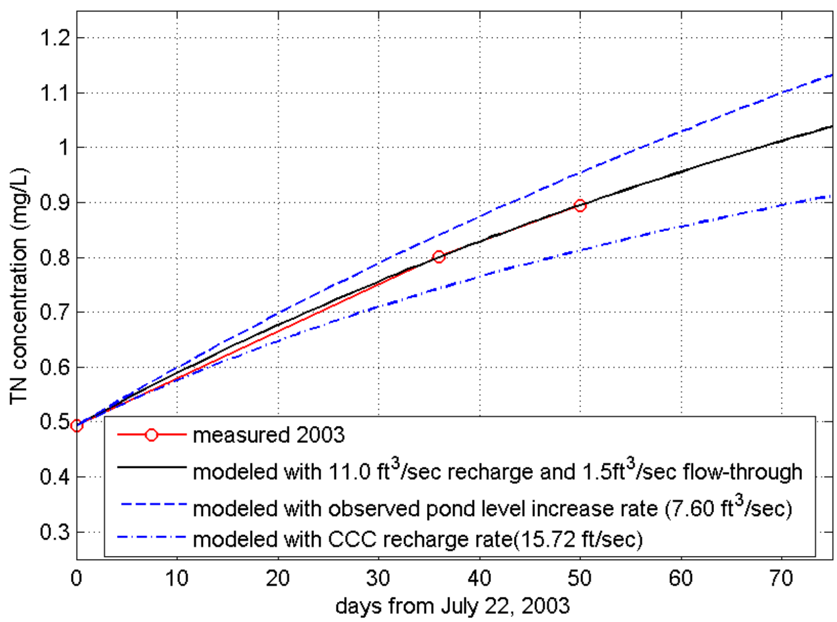



Figure VI-9. Comparison of measured (black line) and modeled (red line with circle markers) TN concentrations through the summer of 2003, from after the June breaching of an inlet to the Atlantic Ocean. This period through the summer was simulated using the mass balance model. Results of the sensitivity analysis are also presented, showing model output using recharge rate reported by the Cape Cod Commission (CCC) and the rate determined using only the measured surface elevation increase of the pond during this same period.

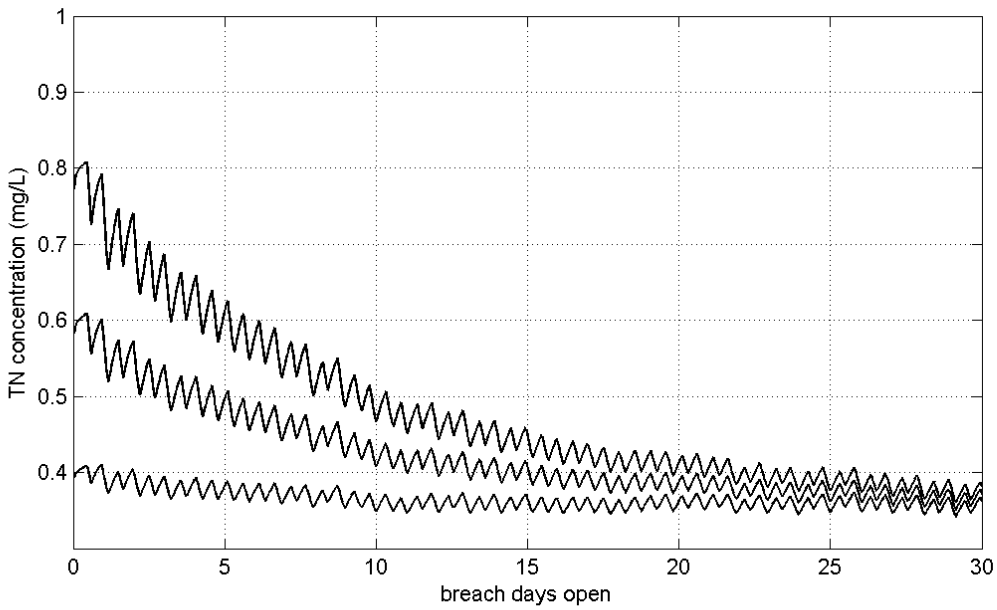



Figure VI-10. RMA-4 model output for Edgartown Great Pond present (2003) loading conditions (Table VI-1), showing how pond averaged TN concentrations vary as a function of initial TN concentration (here for 0.80, 0.60 and 0.40 mg/L) and number of days open for the breach. Model results based on minimum recharge rate of 11.0 $ft^3$/sec with 1.5 $ft^3$/sec flow through. Model results also assume a fully open breach for the complete simulation period.

### VI.2.5 Present 2007 Load Scenarios

The watershed load to Great Pond has decreased since 2003, as the reduced load from the upgraded WWTF has reached the pond (Table VI-5).

Table VI-5. Sub-embayment and surface water loads used for total nitrogen modeling of Edgartown Great Pond, with total watershed N loads, atmospheric N loads, and benthic flux. These loads represent 2007 present loading conditions for the listed sub-embayments (lower load results from newer WWTF Plume).

| sub-embayment | watershed load (kg/day) | direct atmospheric deposition (kg/day) | benthic flux net (kg/day) |
|---|---|---|---|
| Edgartown Great Pond | 25.608 | 11.445 | 20.445 |

### VI.2.6 2007, Build-Out and No Anthropogenic Load Scenarios

To assess the influence of nitrogen loading on total nitrogen concentrations in Great Pond, the standard “build-out” and “no-load” water quality modeling scenarios were run. These runs included two “build-out” scenarios, based on potential development (described in more detail in Section IV), and a “no anthropogenic load” or “no load” scenario assuming only atmospheric deposition on the watershed and sub-embayment, as well as a natural forest within each watershed. An alternate 2007 scenario was also run to determine how conditions have changed in the Pond since the reduced WWTF load has reached the Pond. Comparisons of the alternate watershed loading analyses are shown in Table VI-6. Loads are presented in kilograms per day (kg/day) in this Section, since it is inappropriate to show benthic flux loads in kilograms per year due to seasonal variability.

Table VI-6. Comparison of sub-embayment watershed loads used for modeling of present (2003), present 2007, build-out, and no-anthropogenic ("no-load") loading scenarios of Edgartown Great Pond. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

| sub-embayment | Present 2003 load (kg/day) | Present 2007 (kg/day) | Present 2007 change | build-out (kg/day) | build-out change | no load (kg/day) | no load % change |
|---|---|---|---|---|---|---|---|
| Edgartown Great Pond | 30.292 | 25.608 | -15.5% | 48.666 | +60.7% | 2.759 | -90.9 |

### VI.2.6.1 2007 Loading

The watershed load to Great Pond has decreased since 2003, as the reduced load from the upgraded WWTF has reached the pond. The load breakdown is presented in Table VI-7. The benthic flux for all scenarios is assumed to vary proportional to the watershed load, where an increase in watershed load will result in an increase in benthic flux (i.e., a positive change in the absolute value of the flux), and *vise versa*.

Projected benthic fluxes (for both the build-out and no load scenarios) are based upon projected PON concentrations and watershed loads, determined as:

$$(\textit{Projected N flux}) = (\textit{Present N flux}) * [PON_{projected}]/[PON_{present}]$$

where the projected PON concentration is calculated by,

$$[PON_{projected}] = R_{load} * \Delta PON + [PON_{(present\ offshore)}],$$

using the watershed load ratio,

$$R_{load} = (\textit{Projected N load}) / (\textit{Present N load}),$$

and the present PON concentration above background,

$$\Delta PON = [PON_{(present\ flux\ core)}] - [PON_{(present\ offshore)}].$$

Table VI-7. Sub-embayment and surface water loads used for total nitrogen modeling of Edgartown Great Pond, with total watershed N loads, atmospheric N loads, and benthic flux. These loads represent 2007 present loading conditions for the listed sub-embayments (Loading in 2007 less than 2003 due to "new" WWTF Plume.).

| sub-embayment | watershed load (kg/day) | direct atmospheric deposition (kg/day) | benthic flux net (kg/day) |
|---|---|---|---|
| Edgartown Great Pond | 25.608 | 11.445 | 18.133 |

Using these 2007 loads, the RMA-4 model was run to determine the TN concentration after a 12-day breach, which is a typical opening time span from the available record of openings. Using a starting concentration of 0.60 mg/L, at the end of 12-days, the model shows that the pond averaged TN concentration is 0.41 mg/L. Using this as an input to the mass balance model to simulate the closed summer period after the breach, the TN concentration rises to 0.761 mg/L at 45 days, and 0.994 at 90 days post breach. For each scenario, total nitrogen concentrations in the receiving waters (i.e., the Atlantic Ocean) remained identical to the existing conditions modeling scenario.

### VI.2.6.2 Build-Out

A breakdown of the total nitrogen load entering the Pond for the modeled Build-out scenario is shown in Table VI-8.

Table VI-8. **Build-out scenario** sub-embayment and surface water loads used for total nitrogen modeling of the Edgartown Great Pond system, with total watershed N loads, atmospheric N loads, and benthic flux.

| sub-embayment | watershed load (kg/day) | direct atmospheric deposition (kg/day) | benthic flux net (kg/day) |
|---|---|---|---|
| Edgartown Great Pond | 48.666 | 11.145 | 29.511 |

For the modeled build-out scenario (given an initial concentration of 0.60 mg/L), modeled TN concentrations drop to 0.45 mg/L at the end of the RMA-4 12-day breach simulation. Using the mass balance model to extend the build-out simulation through the summer, the concentration is computed to be 1.069 mg/L 45 days after the closure of the breach, and 1.478 mg/L 90 days after closure of the breach.

### VI.2.6.3 No Anthropogenic Load

A breakdown of the total nitrogen load entering the Pond sub for the no anthropogenic load (“no load”) scenarios is shown in Table VI-9. The benthic flux input to each embayment was reduced (toward zero) based on the reduction in the watershed load (as discussed in §VI.2.6.1). Compared to the modeled present conditions and build-out scenario, atmospheric deposition directly to each sub-embayment becomes a greater percentage of the total nitrogen load as the watershed load and related benthic flux decrease.

Table VI-9. “**No anthropogenic loading**” (“no load”) sub-embayment and surface water loads used for total nitrogen modeling of the Great Pond system, with total watershed N loads, atmospheric N loads, and benthic flux

| sub-embayment | watershed load (kg/day) | direct atmospheric deposition (kg/day) | benthic flux net (kg/day) |
|---|---|---|---|
| Edgartown Great Pond | 2.759 | 11.145 | 6.861 |

Following development of the nitrogen loading estimates for the no load scenario, the water quality model was run to determine nitrogen concentrations in the Pond. Again, total nitrogen concentrations in the receiving waters (i.e., Atlantic Ocean) remained identical to the existing conditions modeling scenarios.

For the modeled no-anthropogenic scenario (given an initial starting concentration of 0.60 mg/L), modeled TN concentrations decreased to 0.35 mg/L at the end of the RMA-4 12-day breach simulation. Using the mass balance model to extend the no anthropogenic load simulation through the summer, the concentration is computed to be 0.441 mg/L 45 days after the closure of the breach, and 0.501 mg/L 90 days after closure of the breach.

# VII. ASSESSMENT OF EMBAYMENT NUTRIENT RELATED ECOLOGICAL HEALTH

The nutrient related ecological health of an estuary can be gauged by the nutrient, chlorophyll, and oxygen levels of its waters and the plant (eelgrass, macroalgae) and animal communities (fish, shellfish, infauna) which it supports. For the Edgartown Great Pond embayment system in the Town of Edgartown, Martha's Vineyard, MA, our assessment is based upon data from the water quality monitoring database (1999-2006) developed by the Martha's Vineyard Commission (MVC) and MEP surveys of eelgrass distribution, benthic animal communities, sediment characteristics and dissolved oxygen records conducted during the summer and fall of 2002. These data form the basis of an assessment of this system's present health, and when coupled with a full water quality synthesis and projections of future conditions based upon the water quality modeling effort, will support complete nitrogen threshold development for these systems (Chapter VIII).

It should be noted that Edgartown Great Pond is in a somewhat different watershed nitrogen loading situation than many embayment systems in southeastern Massachusetts. While land-use continues to change due to residential development similar to other systems, the single largest N source within the watershed has recently been significantly reduced. The Edgartown WWTF, which discharged to the groundwater regime of the Edgartown Great Pond watershed, was upgraded in 1996 to remove nitrogen. Since that date the facility has been showing a high degree of nitrogen removal, with the resultant lowering of nitrogen discharges from this source (greater than two-thirds lowering since the upgrade). However, due to groundwater travel times, the "old' effluent plume is not slated to "wash out" of the aquifer until after 2007-2010 (at the earliest). Therefore, even though the WWTF has been upgraded, the habitat quality of Edgartown Great Pond is still influenced by historical discharge from the "old" facility. The future effect of the upgraded WWTF effluent is assessed by the MEP as part of the future "Build-Out" scenario,

## VII.1 OVERVIEW OF BIOLOGICAL HEALTH INDICATORS

There are a variety of indicators that can be used in concert with water quality monitoring data for evaluating the ecological health of embayment systems. The best biological indicators are those species which are non-mobile and which persist over relatively long periods, if environmental conditions remain constant. The concept is to use species which integrate environmental conditions over seasonal to annual intervals. The approach is particularly useful in environments where high-frequency variations in structuring parameters (e.g. light, nutrients, dissolved oxygen, etc.) are common, making adequate field sampling difficult.

As a basis for a nitrogen thresholds determination, MEP focused on major habitat quality indicators: (1) bottom water dissolved oxygen and chlorophyll a (Section VII.2), (2) eelgrass distribution over time (Section VII.3) and (3) benthic animal communities (Section VII.4). Dissolved oxygen depletion is frequently the proximate cause of habitat quality decline in coastal embayments (the ultimate cause being nitrogen loading). However, oxygen conditions can change rapidly and frequently show strong tidal and diurnal patterns. Even severe levels of oxygen depletion may occur only infrequently, yet have important effects on system health. To capture this variation, the MEP Technical Team deployed dissolved oxygen sensors within the upper portion of the Edgartown Great Pond system (Wintucket station), as well as in the lower main basin (Swan Neck and West End stations). The lower basin locations are to the east and west of the temporary inlet that is formed during the occasional management breaching of the barrier beach separating the pond from the ocean. In this manner a time-series record of the frequency and duration of low oxygen conditions during the critical summer period was obtained. The MEP habitat analysis uses eelgrass as a sentinel species for indicating nitrogen over-loading to coastal embayments. Eelgrass is a fundamentally important species in the ecology of shallow coastal systems, providing both habitat structure and sediment stabilization. Mapping of the eelgrass beds within the Edgartown Great Pond System was conducted for comparison to historic records (MASSDEP Eelgrass Mapping Program, C. Costello) and previous studies. Temporal trends in the distribution of eelgrass beds are used by the MEP to assess the stability of the habitat and to determine trends potentially related to water quality. Eelgrass beds can decrease within embayments in response to a variety of causes, but throughout almost all of the embayments within southeastern Massachusetts, the primary cause appears to be related to increases in embayment nitrogen levels. Within the Edgartown Great Pond System, temporal changes in eelgrass distribution provides a strong basis for evaluating recent increases (nitrogen loading) or decreases (increased flushing-more frequent inlet openings) in nutrient enrichment.

In areas that do not support eelgrass beds, benthic animal indicators were used to assess the level of habitat health from "healthy" (low organic matter loading, high D.O.) to "highly stressed" (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of their habitat. Benthic animal species from sediment samples were identified and the environments ranked based upon the fraction of healthy, transitional, and stressed indicator species. The analysis is based upon life-history information on the species and a wide variety of field studies within southeastern Massachusetts waters, including the Wild Harbor oil spill, benthic population studies in Buzzards Bay (Woods Hole Oceanographic Institution) and New Bedford (SMAST), and more recently the Woods Hole Oceanographic Institution Nantucket Harbor Study (Howes *et al.* 1997). These data are coupled with the level of diversity (H') and evenness (E) of the benthic community and the total number of individuals to determine the infaunal habitat quality.

## VII.2 BOTTOM WATER DISSOLVED OXYGEN

Dissolved oxygen levels near atmospheric equilibration are important for maintaining healthy animal and plant communities. Short-duration oxygen depletions can significantly affect communities even if they are relatively rare on an annual basis. For example, for the Chesapeake Bay it was determined that restoration of nutrient degraded habitat requires that instantaneous oxygen levels not drop below 3.8 mg $L^{-1}$. Massachusetts State Water Quality Classification indicates that SA (high quality) waters maintain oxygen levels above 6 mg $L^{-1}$. The tidal waters (during barrier beach breach events) of the Edgartown Great Pond System are currently listed under this Classification as SA. It should be noted that the Classification system represents the water quality that the embayment should support, not the existing level of water quality. It is through the MEP and TMDL processes that management actions are developed and implemented to keep or bring the existing conditions in line with the Classification.

Dissolved oxygen levels in temperate embayments vary seasonally, due to changes in oxygen solubility, which varies inversely with temperature. In addition, biological processes that consume oxygen from the water column (water column respiration) vary directly with temperature, with several fold higher rates in summer than winter (see Figure VII-1 as an example). It is not surprising that the largest levels of oxygen depletion (departure from atmospheric equilibrium) and lowest absolute levels (mg $L^{-1}$) are found during the summer in southeastern Massachusetts embayments when water column respiration rates are greatest. Since oxygen levels can change rapidly, several mg $L^{-1}$ in a few hours, traditional grab sampling programs typically underestimate the frequency and duration of low oxygen conditions within shallow embayments (Taylor and Howes, 1994). To more accurately capture the degree of bottom water dissolved oxygen depletion during the critical summer period, autonomously recording oxygen sensors were moored 30 cm above the embayment bottom within key regions of the Edgartown Great Pond System (Figure VII-2). The sensors (YSI 6600) were first calibrated in the laboratory and then checked with standard oxygen mixtures at the time of initial instrument mooring deployment. In addition periodic calibration samples were collected at the sensor depth and assayed by Winkler titration (potentiometric analysis, Radiometer) during each deployment. Each instrument mooring was serviced and calibration samples collected at least biweekly and sometimes weekly during a minimum deployment of 30 days within the interval from July through mid-September. All of the mooring data from the Edgartown Great Pond embayment system was collected during the summer of 2002.

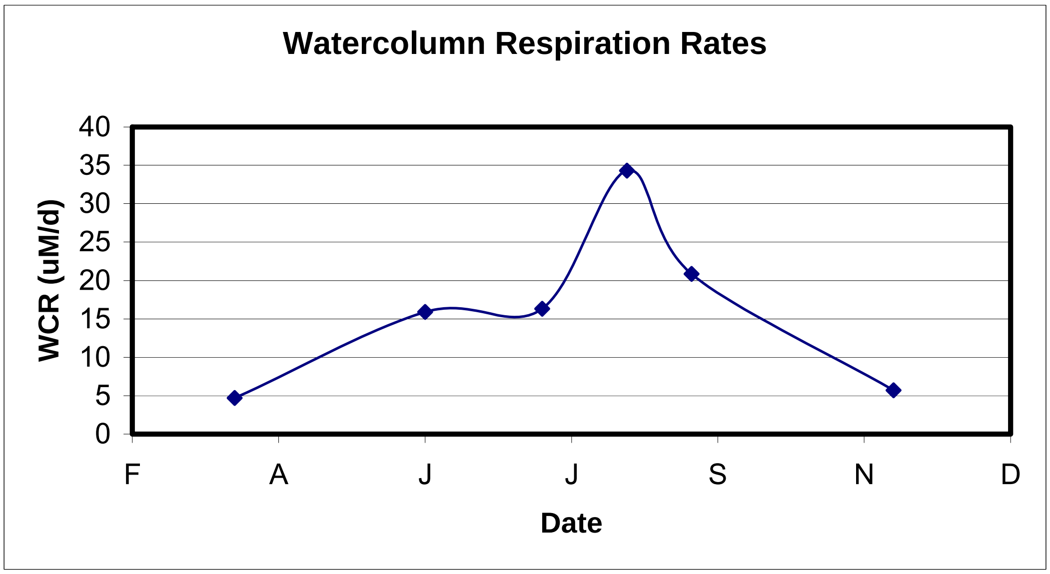



Figure VII-1. Average watercolumn respiration rates (micro-Molar/day) from water collected throughout the Popponesset Bay System (Schlezinger and Howes, unpublished data). Rates vary ~7 fold from winter to summer as a result of variations in temperature and organic matter availability.

Similar to other embayments in southeastern Massachusetts, the Edgartown Great Pond system evaluated in this assessment showed high frequency variation, apparently related to diurnal and sometimes tidal influences. Nitrogen enrichment of embayment waters generally manifests itself in the dissolved oxygen record, both through oxygen depletion and through the magnitude of the daily excursion. The high degree of temporal variation in bottom water dissolved oxygen concentration at each mooring site, underscores the need for continuous monitoring within these systems.

Dissolved oxygen and chlorophyll a records were examined both for temporal trends and to determine the percent of the 42-44 day deployment period that these parameters were below/above various benchmark concentrations (Tables VII-1, VII-2). These data indicate both the temporal pattern of minimum or maximum levels of these critical nutrient related constituents, as well as the intensity of the oxygen depletion events and phytoplankton blooms. However, it should be noted that the frequency of oxygen depletion needs to be integrated with the actual temporal pattern of oxygen levels, specifically as it relates to daily oxygen excursions.

The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate moderately nutrient enriched waters and impaired habitat quality within the upper and lower basins (Figures VII-3 through VII-8). The oxygen data is consistent with organic matter enrichment, primarily from phytoplankton production as seen from the parallel measurements of chlorophyll a. However, there is a clear difference in the extent of response to enrichment, with the upper basin supporting only moderate oxygen depletion and chlorophyll a enhancement and the lower basin supporting moderate-high chlorophyll a enrichment and moderate oxygen depletion. In all cases the oxygen and chlorophyll a levels show patterns consistent with nitrogen enrichment and there was only a small west to east gradient across the lower basin. It is interesting to note that the eastern end of the lower basin supported slightly better habitat quality in the region of the 1951 eelgrass bed, although both ends of the basin were found to have sparse eelgrass patches during the mooring deployments.

Oxygen depletion is not the only indicator of nitrogen enrichment and habitat impairment. While the effect of nitrogen enrichment is to cause oxygen depletion, at high levels of nutrient enrichment and increased phytoplankton (or epibenthic algae) production, oxygen levels can also rise during daylight hours to above atmospheric equilibration levels in shallow systems (generally ~7-8 mg $L^{-1}$ at the mooring sites). The periodic elevated oxygen levels observed in Edgartown Great Pond provides additional evidence that this system is presently receiving nitrogen inputs above the threshold required to maintain high quality estuarine habitat.

The measured levels of oxygen depletion in the bottom waters of Wintucket Cove and the lower main basin to Edgartown Great Pond indicate that this Great Salt Pond is currently organic matter enriched, primarily through in situ production by phytoplankton and periodically experiences moderate levels of oxygen stress, consistent with nitrogen enrichment (Table VII-1). While the levels of oxygen depletion are relatively modest, the phytoplankton blooms in the lower basin are moderate to high (chlorophyll a, >15 µg/L 1%, 49% and 54% of the time) for the east and west regions, respectively (Table VII-2). Edgartown Great Pond was not open to the ocean during the deployment and oxygen and chlorophyll a levels showed poorer habitat quality in the lower versus upper basin, a condition that is likely reversed around the periods of breaching of the barrier beach. However, except for 3 brief (few hours) depletion events at the western site, oxygen conditions were generally >5 mg $L^{-1}$ indicating only a moderate level of oxygen related habitat impairment within this system. This was consistent with the grab sample data from the Water Quality Monitoring Program for Wintucket Cove and also for the upper main basin, Janes Cove , and Slough Cove. The lack of tidal influence during the deployment and salinity values averaging 17 ppt throughout the embayment were important considerations in the interpretation of the mooring records. The mooring specific results are as follows:

***Edgartown Great Pond – Wintucket Cove Mooring Location* (Figures VII-3 and VII-6):**
Located in the northern most portion of the estuary, Wintucket Cove was selected as a mooring station to be representative of the upper basin and its tributary coves. The instrument was located in 1.1m of water (Figure VII-2). Oxygen concentrations showed a diurnal variation of 1-4 mg $L^{-1}$. Dissolved oxygen levels generally were supportive of a high to moderately impaired habitat, only occasionally dropping below the benchmark of 6 mg $L^{-1}$ (one instance below 5 mg $L^{-1}$ for 30 minutes, Table VII-1) or less than 2 mg $L^{-1}$ below air equilibration during the beginning of the deployment. Periodic short temperature stratification events and wind driven mixing appeared to exert control over bottom water oxygen and chlorophyll a levels in this basin. Water temperatures dropped nearly 5$^{o}$C between August 18 and August 23. Prior to this time the bottom water oxygen was consistently showing moderate oxygen depletion.. Following the temperature drop, a pond-wide phytoplankton bloom occurred, although it was more intense in the open lower basin. Chlorophyll a levels were low to moderate, generally less than 10 ug $L^{-1}$,

with bloom concentrations averaging 15 ug $L^{-1}$ . These values were consistently lower than seen at the lower basin sites. Secchi depths at all three locations rarely reached the bottom. The pattern of chlorophyll a was reflected in the distribution of sediment oxygen demand and ammonium flux which were 20% and 70% lower at the Cove versus lower basin stations, most likely the result of lower phytoplankton deposition rates due to lower concentrations and shallower water. Oxygen and chlorophyll a records at the Wintucket station show moderate nutrient enrichment and slight habitat impairment.

***Edgartown Great Pond – Swan Neck Mooring Location* (Figures VII-4 and VII-7):**
The Swan Neck station was located in the south west portion of Edgartown Great Pond at a depth of 1.6 m, within the large main lagoonal basin. As for this portion of the system in general, oxygen depletions were moderate. Oxygen concentrations dropped below the benchmark level of 6 mg $L^{-1}$ only 8 % of the time and below 5 mg $L^{-1}$ only 1% of the time (Table VII-1). Following the temperature decline and coincident phytoplankton bloom discussed above, oxygen values were consistently above air equilibration. The bloom was much larger in the lower basin than upper basin, with chlorophyll a concentrations >15 ug $L^{-1}$ for 49% of the time and >20 ug $L^{-1}$ for 18% of the time (Table VII-2). The level of chlorophyll is relatively high compared to other embayments in the MEP study region, for example Lewis Bay (<12 ug L-1) or East Bay (<10 ug $L^{-1}$) on the Nantucket Sound shore of the Town of Barnstable. The larger bloom in the lower basin may be related to the higher rates of nitrogen release from the sediments in this versus the Wintucket Cove basin (Section IV.3). Oxygen records at the Swan Neck station indicate moderate nutrient enrichment and habitat impairment with respect to dissolved oxygen and chlorophyll a.

***Edgartown Great Pond – West Point Station* (Figures VII-5 and VII-8):**
The West Point station was located in the south eastern portion of Edgartown Great Pond at a depth of 2.3 m, also within the large main lagoonal basin. In general, dissolved oxygen levels were similar to other stations, falling below benchmark levels of 6 and 5 mg $L^{-1}$ for 9% and 3% of the time. There were 3 exceptional events, each of a few hours duration, where oxygen levels dropped below 4 mg $L^{-1}$. It is not clear if these were sub-basin events or the result of temporary bio-fouling of the meters. The lack of simultaneous occurrences at the other 2 mooring locations suggests cautious use of these event data. Chlorophyll a data at this site were similar to the Swan Neck site, suggesting that the phytoplankton bloom was significant and relatively well distributed throughout the lower basin. Chlorophyll a levels were >15, >20 and >25 ug $L^{-1}$, 54%, 34%, and 24% of the time. Similar to the other stations, a rapid temperature decline preceded the increase in chlorophyll a. The magnitude of both the temperature drop and chlorophyll increases were similar to those at Swan Neck (again suggesting that the 3 oxygen depletion events may have been spurious). This location was found to support sediment nitrogen release similar to Swan Neck, consistent with the hypothesis that the larger phytoplankton bloom in the southern part of the estuary may have been related to higher nutrient availability in the lower basin than upper basin. The West Point station showed moderate nutrient enrichment with respect to oxygen and chlorophyll a and moderate habitat impairment.


Figure VII-2. Aerial Photograph of the Edgartown Great Pond system on Martha's Vineyard showing locations of Dissolved Oxygen mooring deployments conducted in the Summer of 2002.

Overall, Edgartown Great Pond is showing a moderate level of habitat impairment from summer oxygen depletion and organic enrichment primarily from phytoplankton production, parameters directly resulting from nutrient inputs.

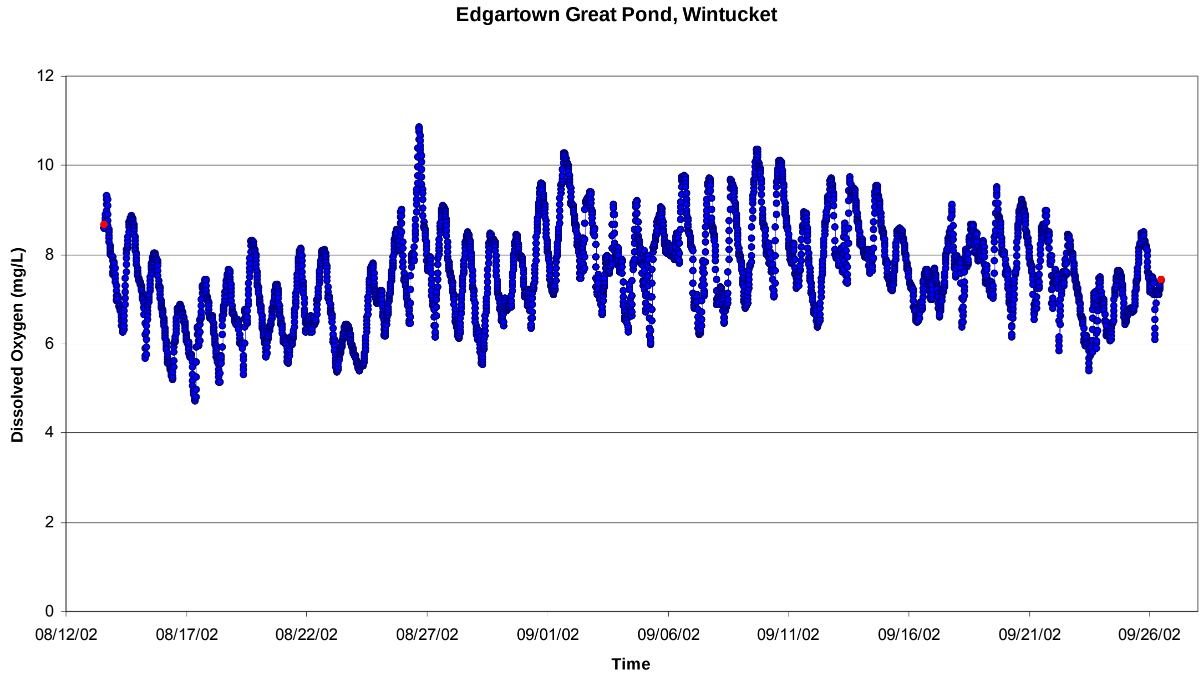



Figure VII-3. Bottom water record of dissolved oxygen at the Edgartown Great Pond - Wintucket station, Summer 2002.

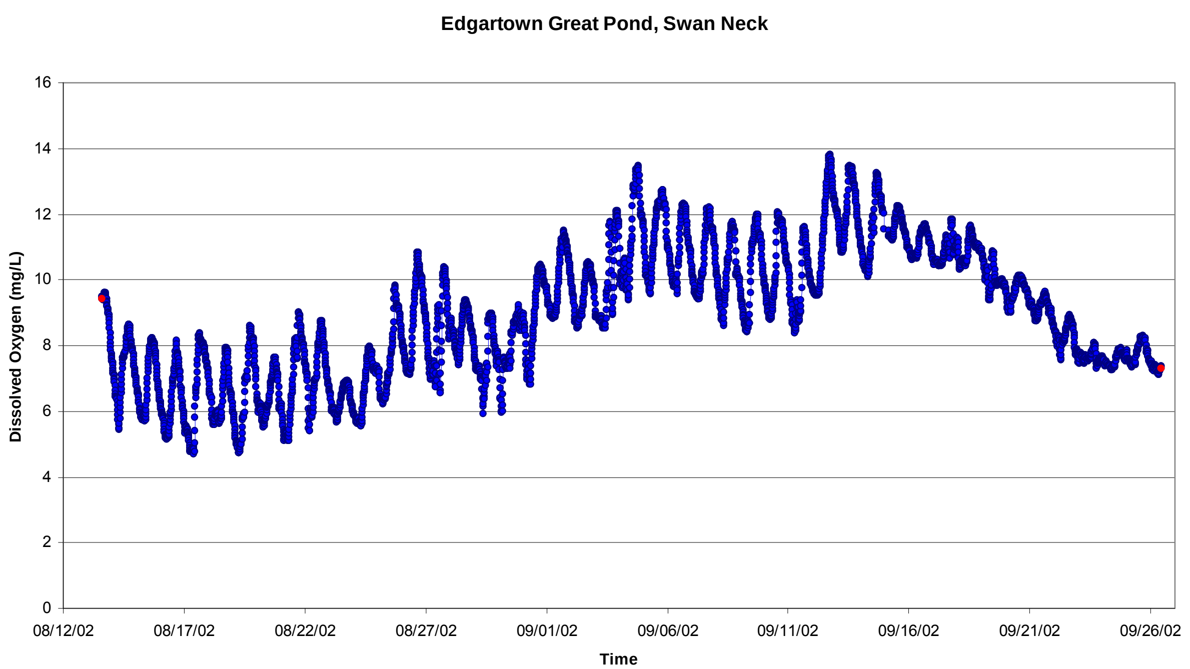



Figure VII-4. Bottom water record of dissolved oxygen at the Edgartown Great Pond Swan Neck station, Summer 2002. Calibration samples represented as red dots.

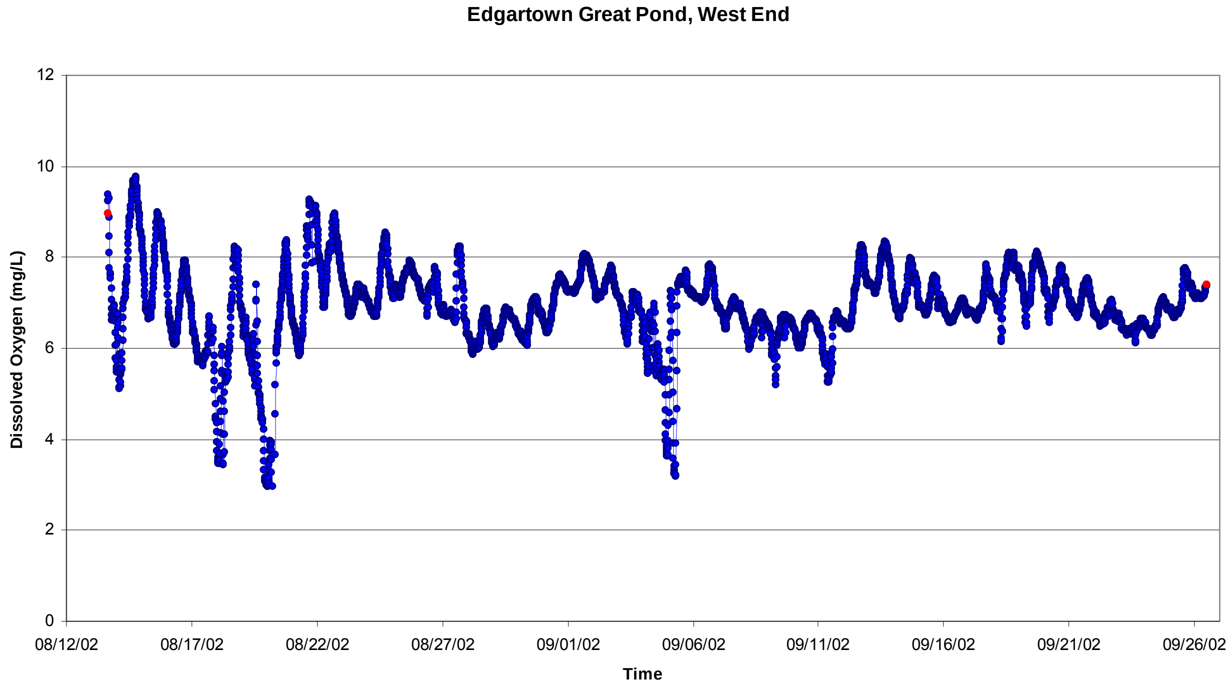



Figure VII-5. Bottom water record of dissolved oxygen at the Edgartown Great Pond – West End station, Summer 2002. Calibration samples represented as red dots.

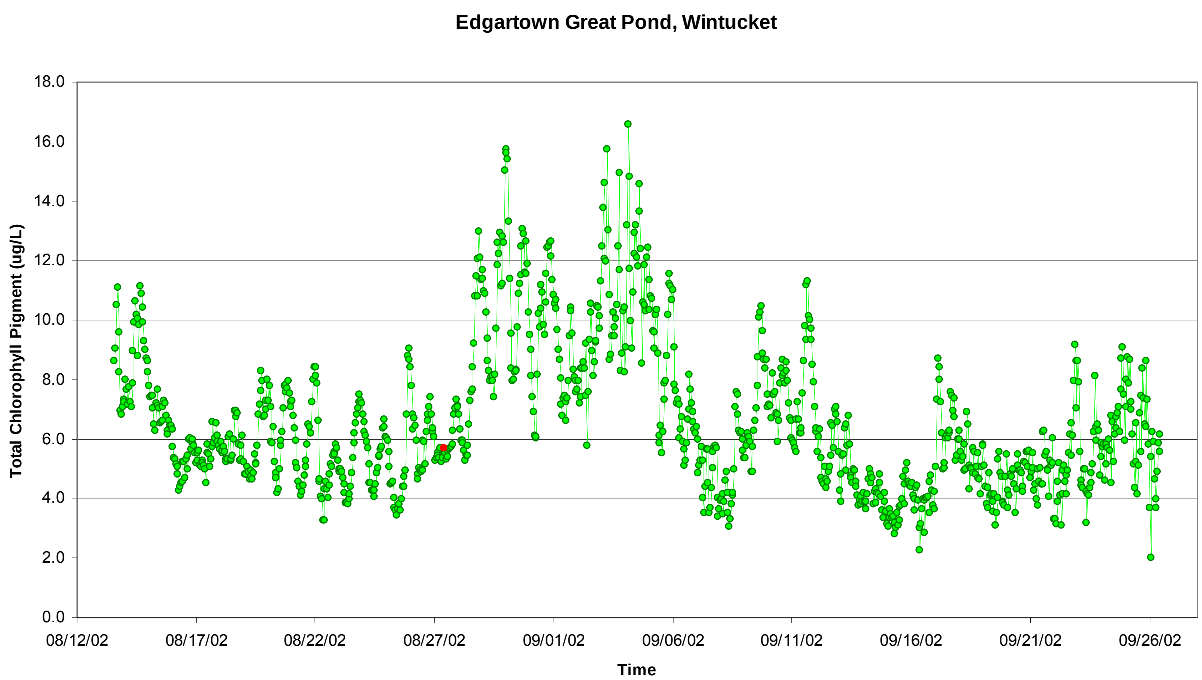



Figure VII-6. Bottom water record of Chlorophyll-*a* at the Edgartown Great Pond - Wintucket station, Summer 2002. Calibration samples represented as red dots.

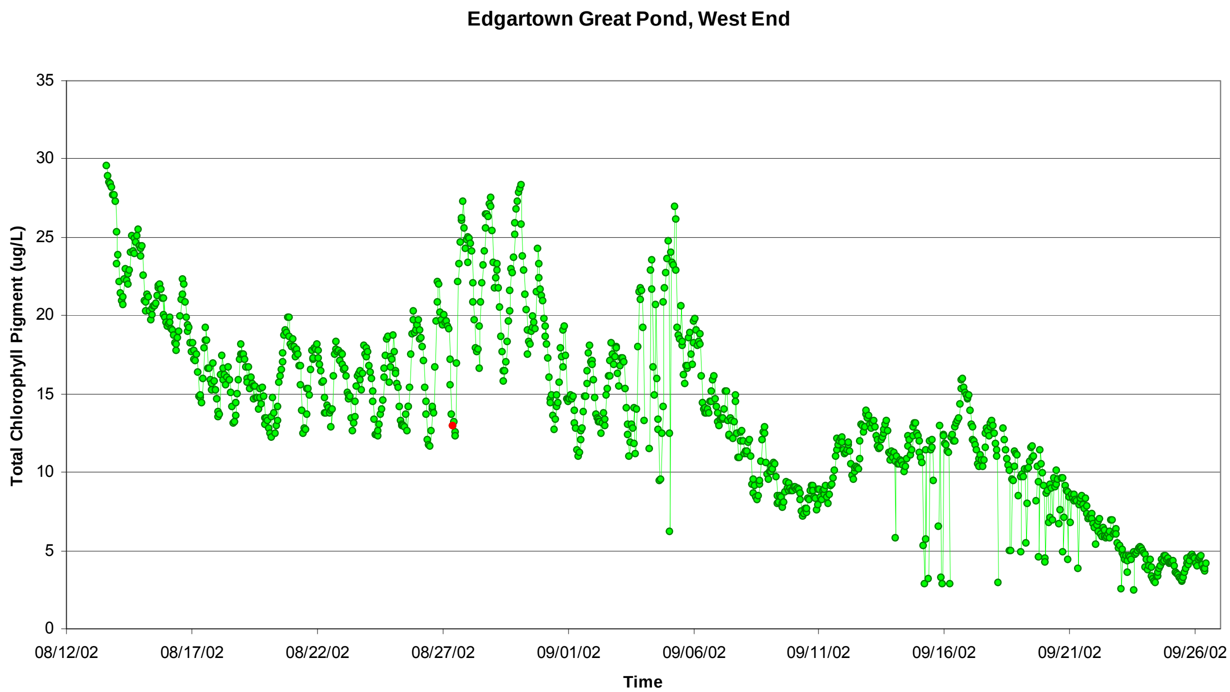



Figure VII-7. Bottom water record of Chlorophyll-*a* at the Edgartown Great Pond – Swan Neck station, Summer 2002. Calibration samples represented as red dots.

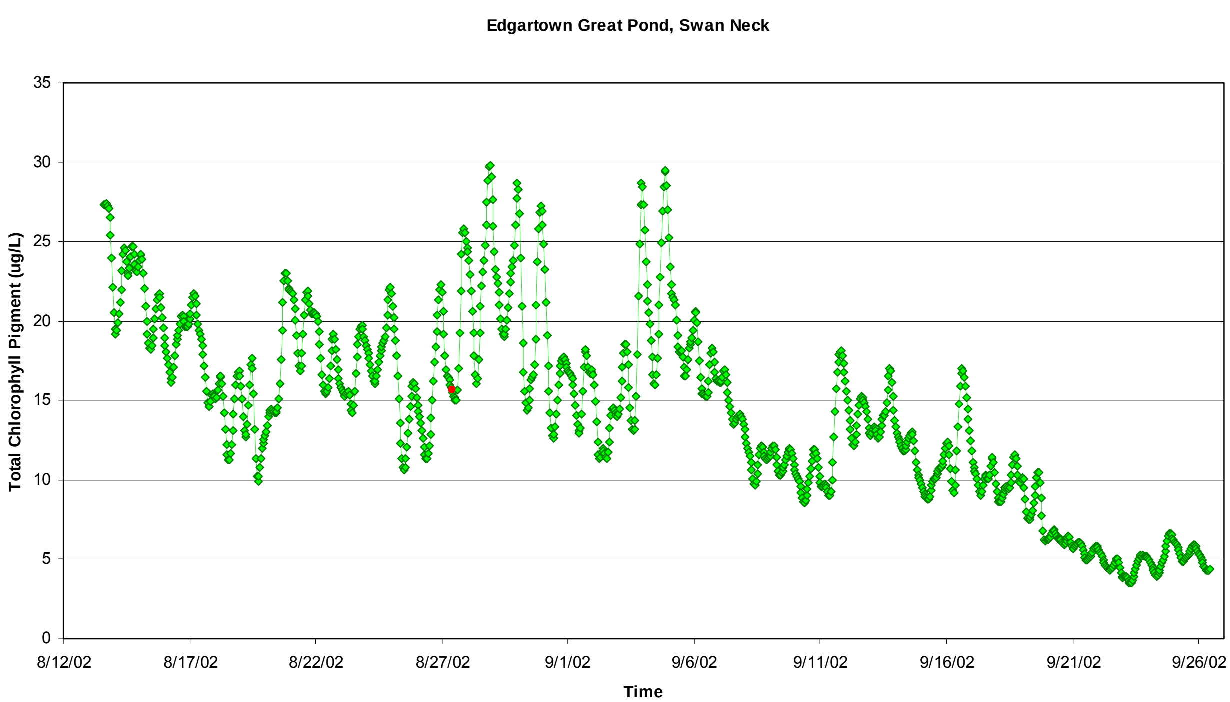



Figure VII-8. Bottom water record of Chlorophyll-*a* at the Edgartown Great Pond – West End station, Summer 2002. Calibration samples represented as red dots.

Table VII-1. Percent of time during deployment of *in situ* sensors that bottom water oxygen levels were below various benchmark oxygen levels.

| Massachusetts Estuaries Project Town of Edgartown: 2002 | Dissolved Oxygen: Continuous Record, Summer 2002 | | | | |
|---|---|---|---|---|---|
| | Deployment Days | < 6 mg/L (% of days) | < 5 mg/L (% of days) | < 4 mg/L (% of days) | < 3 mg/L (% of days) |
| Swan Neck | 42.8 | 8% | 1% | 0% | 0% |
| West End | 43.8 | 9% | 3% | 2% | 0% |
| Wintucket | 43.9 | 6% | 0% | 0% | 0% |

Table VII-2. Duration (% of deployment time) that chlorophyll a levels exceed various benchmark levels within the embayment system. "Mean" represents the average duration of each event over the benchmark level and "S.D." its standard deviation. Data collected by the Coastal Systems Program, SMAST.

| Embayment System | Start Date | End Date | Total Deployment (Days) | > 5 ug/L Duration (Days) | > 10 ug/L Duration (Days) | > 15 ug/L Duration (Days) | > 20 ug/L Duration (Days) | > 25 ug/L Duration (Days) |
|---|---|---|---|---|---|---|---|---|
| Edgartown Great Pond | | | | | | | | |
| Swan Neck | 8/13/2002 | 9/26/2002 | 42.8 | 96% | 79% | 49% | 18% | 4% |
| | | Mean | | 6.88 | 3.07 | 1.16 | 0.47 | 0.24 |
| | | S.D. | | 15.67 | 5.78 | 1.28 | 0.25 | 0.06 |
| West End | 8/13/2002 | 9/26/2002 | 43.8 | 90% | 83% | 54% | 34% | 24% |
| | | Mean | | 2.19 | 1.55 | 0.65 | 0.38 | 0.18 |
| | | S.D. | | 5.43 | 4.62 | 0.92 | 0.43 | 0.14 |
| Wintucket | 8/13/2002 | 9/26/2002 | 43.9 | 71% | 12% | 1% | 0% | 0% |
| | | Mean | | 0.61 | 0.22 | 0.08 | N/A | N/A |
| | | S.D. | | 1.66 | 0.17 | 0.07 | N/A | N/A |

## VII.3 EELGRASS DISTRIBUTION - TEMPORAL ANALYSIS

Eelgrass analysis of historical data was conducted for the Edgartown Great Pond Embayment System by the MASSDEP Eelgrass Mapping Program as part of the MEP. Analysis of available aerial photos from 1951 was used to reconstruct the eelgrass distribution prior to any substantial development of the watershed. The 1951 data were only anecdotally validated. In addition, qualitative field observations of eelgrass have been made by a variety of scientists in 1997 (Pratt and Gaines 1997), MEP Technical Team in 2002, and MVC and Town staff (P. Bagnall and W. Wilcox 2006). While these latter observations do not lend themselves to mapping of eelgrass coverage, they provide critical information on the persistence of eelgrass within this salt pond and its general locations, depths and density. These data form the basis of the MEP eelgrass assessment for this estuary.

The primary use of the MEP eelgrass assessment for an estuary is to indicate (a) if eelgrass once or currently colonizes a basin and (b) if large-scale system-wide shifts have occurred. Integration of these data sets provides a view of temporal trends in eelgrass distribution from 1951 to 2006 (Figure VII-9); the period in which watershed nitrogen loading significantly increased to its present level. This temporal information can be used to determine the stability of the eelgrass community and the potential recoverable acreages should it be determined that habitat loss has occurred.

Over the past decade, eelgrass has existed only in small sparse patches within the lower lagoonal basin of this great salt pond. As tidal exchange only periodically occurs during managed breaches of the barrier beach, the horizontal gradients in water quality typical of tidal estuaries do not structure the eelgrass habitat in the main upper and lower basin of this system. The lack of strong gradients in water quality have been documented from the long-term water quality monitoring data, although periodic short-term gradients in chlorophyll and other parameters do occur (see Section VII.2 for example). All recent observations indicate an absence of dense eelgrass beds within this system. Rather, eelgrass was observed in sparse patches at a variety of locations limited to the lower main lagoonal basin. In the 1997 observations, sparse eelgrass was documented in the nearshore area of Swan Neck, the present "inlet" and near the lower extent of the 1951 coverage area. These observations were similar to those of the system-wide survey (2002) which indicated sparse eelgrass coverage in the eastern and western-most regions off the barrier beach (see Figure IV-6; stations 2 & 8). There is no evidence of eelgrass within the upper main basin or within the major tributary coves.

While water quality parameters, primarily related to nitrogen, chlorophyll and oxygen are the major factors causing shifts in eelgrass habitat quality within this system, water depth is also important in determining potential habitat locations. All of the locations with eelgrass, 1951-2006, are <1.5 meter depth. The more recent field observations suggest eelgrass at depths of 0.5 - 1.0 meters, with the shallower depth potentially related to low stand when the inlet is opened and the deeper depth being determined by light penetration when the inlet is closed. The depth of the upper main basin (above Swan Neck) appears to limit eelgrass habitat in this region of the pond. The absence of eelgrass within the Coves, most likely relates to their shallow depth, organic rich sediments and periodic salinity declines.

The overall results indicate that eelgrass habitat within Edgartown Great Pond is presently impaired and the eelgrass coverage has declined. While it is not possible to determine the density of the eelgrass beds in 1951, it does appear the coverage has declined and that recent eelgrass areas support only sparse colonization by eelgrass plants. The decline of eelgrass beds relative to historical distributions is expected given the elevated nitrogen levels and resulting chlorophyll a and dissolved oxygen depletions within this embayment system. It is also consistent with the persistence of eelgrass within the shallow margins and apparent loss from the deeper regions of the lower basin (1951 versus 1997-2002).

The present impaired eelgrass habitat within the lower main basin of Edgartown Great Pond is consistent with the observed moderate level of nutrient enrichment. Total nitrogen levels (TN) within the lower basin have mean summer time levels of ~0.59 mg N $L^{-1}$ compared to the levels in other southeastern Massachusetts estuaries supporting eelgrass, 0.35-0.45 mg N $L^{-1}$ (range of Cape Cod systems). Other key water quality indicators, dissolved oxygen and chlorophyll a, show similar levels of moderate enrichment with periodic oxygen depletions below 5 mg/L and chlorophyll levels in blooms reaching 10-20 ug/l Given the sensitivity of eelgrass to declining light penetration resulting from nutrient enrichment and secondary effects of organic enrichment and oxygen depletion, impairment of eelgrass habitat is expected within this system.

The observed pattern of loss, from deep areas then shallow areas is consistent with nutrient enrichment. In estuaries on Cape Cod, the general pattern is for highest nitrogen levels to be found within the innermost basins, with concentrations declining moving toward the tidal inlet. This pattern is also observed in nutrient related habitat quality parameters, like phytoplankton, turbidity, oxygen depletion, etc. The consequence is that eelgrass bed decline typically follows a pattern of loss in the innermost basins and from the deeper waters of the outer basins first. The temporal pattern is a “retreat” of beds toward the region of the tidal inlet. It appears from the eelgrass and water quality information that eelgrass beds within Edgartown Great Pond system have declined as a result of nitrogen enrichment and should be the target for restoration and that this habitat would be recovered with appropriate nitrogen management.

Other factors which influence eelgrass bed loss in embayments can also be at play in estuaries like the Edgartown Great Pond Embayment System, though the recent loss appears completely in-line with nitrogen enrichment. However, a brief listing of non-nitrogen related factors is useful. Eelgrass bed loss does not seem to be directly related to mooring density, as there are virtually no moorings (and no marinas) in this "closed" system. Similarly, pier construction and boating pressure may be adding additional stress in nutrient enriched areas, but Edgartown Great Pond, again, does not support these activities. It is not possible at this time to determine the potential effect of shellfishing on eelgrass bed distribution, although it should be noted that shellfish pressure has declined in parallel with the recent changes in eelgrass due to effects of shellfish disease and populations in this system. At present there is no evidence that shell fishing pressure is sufficiently high as to be controlling eelgrass colonization in this estuary.

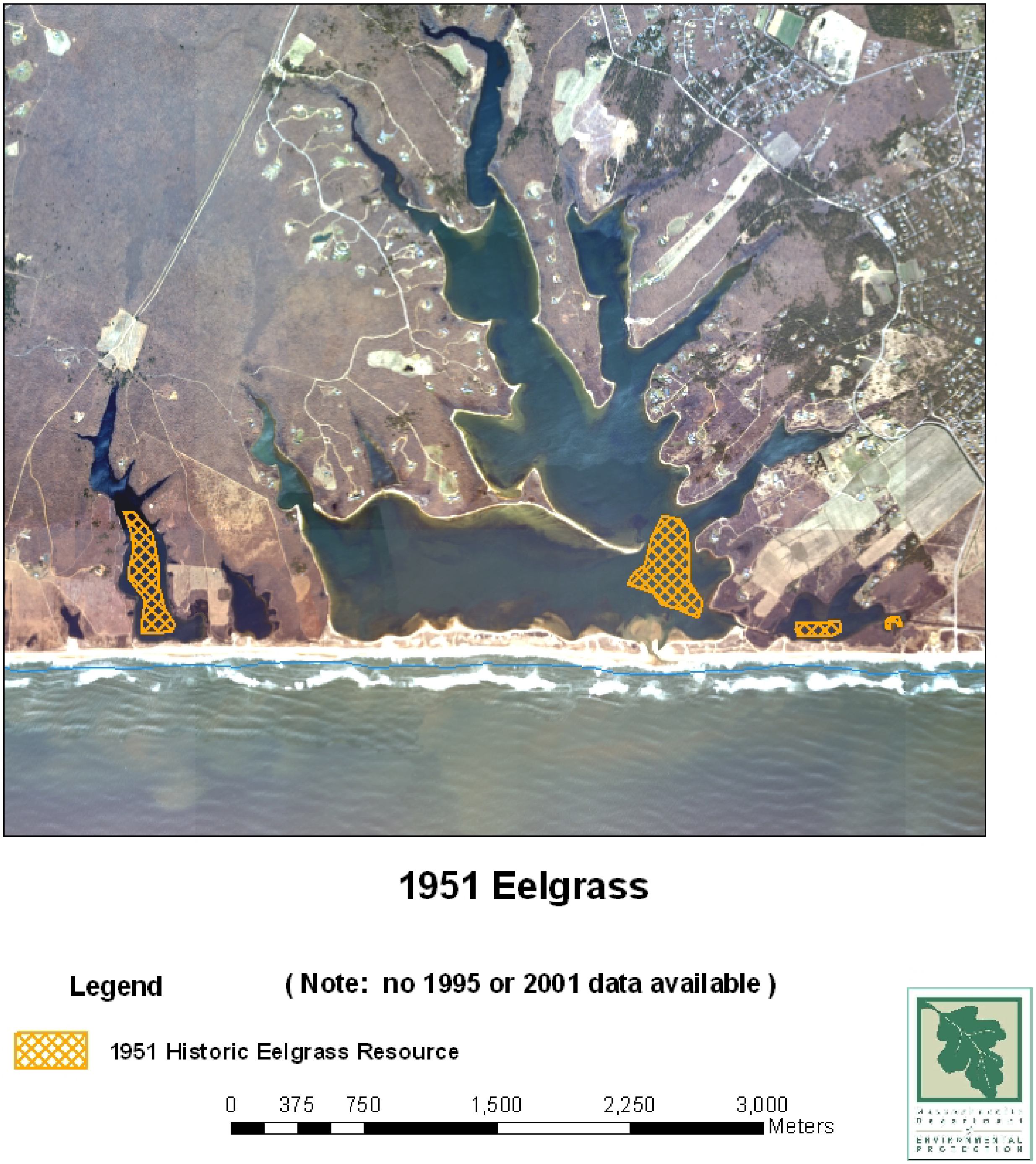



Figure VII-9. Eelgrass distribution within the Edgartown Great Pond Embayment System. The 1951 coverage is depicted by the orange outline (hatched area), which circumscribes the 30.2 acres of eelgrass beds. Very sparse eelgrass patches were observed in 2002-04 by the MEP Technical Team in the region of the 1951 bed and in the western-most region of the lower basin, south of the entrance to Jobs Neck Cove. The separate salt pond to the west is Jobs Neck Pond. The 1951 analysis was provided by the MassDEP Eelgrass Mapping Program.

It is not possible to determine quantitative short- and long-term rates of change in eelgrass coverage from the available data, since there is only limited temporal data with virtually no eelgrass found in the recent surveys. However, it is possible to utilize the 1951 coverage data as an indication of the minimum eelgrass bed area that might be recovered (on the order of 30 acres) if nitrogen management alternatives were implemented (Table VII-3). It is likely that a greater area of eelgrass habitat would be restored, as the 1951 coverage is likely an underestimate as a result of mapping issues and observed consistent records of eelgrass from the western region of the lower basin, not observed in the 1951 analysis. Note that restoration of this eelgrass habitat will necessarily result in restoration of other resources throughout the Edgartown Great Pond Embayment System, specifically the tributary coves, which have traditionally only supported infaunal habitats (see below).

The relative pattern of these data is consistent with the results of the benthic infauna analysis and the observed eelgrass loss is typical of nutrient enriched shallow embayments (see below).

Table VII-3. Changes in eelgrass coverage in the Edgartown Great Pond Embayment System within the Town of Edgartown over the past half century.

| **Edgartown Great Pond<br>Temporal Change in Eelgrass Coverage** | | | | |
|---|---|---|---|---|
| **1951 Acreage** | **1995[1] Acreage** | **2002[1] Acreage** | **2006[1] Acreage** | **%Loss 1951-2002** |
| **30.2** | **sparse[2]** | **sparse[2]** | **sparse[2]** | **~>90%** |
| 1 -- field survey, Gaines 1997; MEP staff 2002; Bagnall & Wilcox, Pers. Comm.<br>2-- very sparse marginal patches within lower basin. | | | | |

## VII.4 BENTHIC INFAUNA ANALYSIS

Quantitative sediment sampling was conducted at 15 locations throughout the Edgartown Great Pond System (Figure VII-10). In some cases multiple assays were conducted. In all areas and particularly those that do not support eelgrass beds, benthic animal indicators can be used to assess the level of habitat health from healthy (low organic matter loading, high D.O.) to highly stressed (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of the habitat in which they live. Benthic animal species from sediment samples are identified and ranked as to their association with nutrient related stresses, such as organic matter loading, anoxia, and dissolved sulfide. The analysis is based upon life-history information and animal-sediment relationships (Rhoads and Germano 1986). Assemblages are classified as representative of healthy conditions, transitional, or stressed conditions. Both the distribution of species and the overall population density are taken into account, as well as the general diversity and evenness of the community. It should be noted that, given the loss of eelgrass beds, the Edgartown Great Pond System is clearly impaired by nutrient overloading. However, to the extent that it can still support healthy infaunal communities, the benthic infauna analysis is important for determining the level of impairment (moderately impaired→significantly impaired→severely degraded). This assessment is also important for the establishment of site-specific nitrogen thresholds (Chapter VIII).

Analysis of the evenness and diversity of the benthic animal communities was also used to support the density data and the natural history information. The evenness statistic can range from 0-1 (one being most even), while the diversity index does not have a theoretical upper limit. The highest quality habitat areas, as shown by the oxygen and chlorophyll records and eelgrass coverage, have the highest diversity (generally >3) and evenness (~0.7). The converse is also true, with poorest habitat quality found where diversity is <1 and evenness is <0.5.

Overall, the Infauna Survey indicated that most areas within Edgartown Great Pond are supporting moderate nutrient related infaunal habitat quality. Also, consistent with the lack of large horizontal gradients in water quality within this mainly non-tidal coastal salt pond, there was only a small spatial variation in infaunal habitat quality. It appears that the upper main basin (above Swan Neck) supports the poorest habitat, moderately-significantly impaired by nitrogen enrichment, with similar impairment in the major tributary coves (Janes Cove, Wintucket Cove, Mashacket Cove). The lower large lagoonal basin and one of the small associated tributary coves (Jobs Neck Cove) supported slightly higher quality habitat, although moderate impairment by nitrogen enrichment was clearly observed in these basins as well. Both of the eastern coves (Turkeyland Cove and Slough Cove) support infaunal animal habitats of intermediate quality between upper and lower basin conditions.

The underlying structure of Edgartown Great Pond and its watershed support the observed spatial variation in infaunal habitat quality. The upper tributary coves receive almost three-quarters of the total watershed nitrogen load to this system, which stimulates organic matter enrichment of the sediments. The upper main basin is deep, creating a depositional environment for organic matter created in situ or entering by transport from its associated basins. In contrast, the semi-separate lower basin created by the formation of Swan Neck, is also moderately impaired by organic enrichment, but receives much less direct input of watershed nitrogen. This pattern can be seen in the bottom sediments of each basin, where the predominance of unconsolidated mud is in the upper basin and more oxidized mud and sand were observed in the lower basin. It should be noted that the pattern observed in the 2002 phytoplankton bloom, as tracked by the moored instruments (Section VII.2) showed slightly lower chlorophyll-a within Wintucket Cove than in the lower basin and generally only moderate oxygen depletions at each station. Unfortunately, mooring data is not available for the deep upper main basin. However, it is nearly certain that the upper deep basin periodically undergoes greater oxygen depletions. As a deep depositional area, it is likely the upper basin receives a greater amount of organic matter to its sediments than reflected by water column chlorophyll a levels with resulting impacts to its benthic habitats. This contention is supported by the Water Quality Monitoring Program oxygen sampling, which showed depletions to <4 mg $L^{-1}$ only in Janes Cove and the upper main basin in 7% and 3% of samples, respectively. The observations of iron accumulations at the sediment surface in the upper main basin also indicate periodic hypoxia. In general, the observed distribution of significantly to moderately impaired infaunal animal habitat in the upper basin and Janes Cove and only moderate impairment in the lower basin compare well with these water quality and sediment data.

The benthic habitats of Edgartown Great Pond generally support moderate to high numbers of individual (120-870 individuals per 0.0625 $m^2$), but show low numbers of species (5-16). The upper basins show moderate to low species diversity (mean = 1.9), while the lower basin shows moderate diversity (mean = 2.5) and moderate to high Eveness (mean = 0.74).

Further evidence of habitat impairment by nitrogen and organic matter enrichment is the dominance of species tolerant of these types of conditions and the absence of species typical of high quality embayment habitats. By example, Janes Cove had high numbers of individuals and species, but two thirds of the species are stress indicator species (e.g. Capitellids) or transitional/disturbance species (amphipods, *Mediomastus*). In addition, the upper reaches, tended to be dominated, by polychaetes, while the lower basin by a mixture of polychaetes, crustaceans and mollusks. The habitat quality within Edgartown Great Pond was similar to other moderately-significantly impaired estuaries (for benthic animals) within the region at similar levels of water column total nitrogen. For example, Hyannis Inner Harbor 0.518-0.574 mg N $L^{-1}$, tidally averaged, North Bay (structured like the upper main basin of Edgartown Great Pond) and Princes Cove, both within the Three Bays System, also show moderate to high habitat impairment at total nitrogen levels of >0.51.

Overall, the infaunal habitat quality was consistent with the gradients in dissolved oxygen, chlorophyll, nutrients and organic matter enrichment in this system. Classification of habitat quality necessarily included the structure of the specific estuarine basin. Based upon this analysis it is clear that the tributary sub-embayment basins are presently supporting moderately to significantly impaired benthic habitat while the lower main basin is generally shows moderate quality. Impairment in these basins is through nitrogen and organic matter enrichment.

The results of the Infauna Survey indicate that the management threshold analysis (Chapter VIII) needs to include a lowering of the level of nitrogen enrichment throughout this salt pond for restoration of nitrogen impaired benthic habitats. However, it is important to note that the non-tidal nature of this embayment and the depositional nature of the upper main basin (deep) make benthic habitat within that region of the system particularly sensitive to nitrogen enrichment.


Figure VII-10. Aerial photograph of the Edgartown Great Pond system showing location of benthic infaunal sampling stations (red symbol).

Table VII-5. Benthic infaunal community data for the Edgartown Great Pond system. Estimates of the number of species adjusted to the number of individuals and diversity (H') and Evenness (E) of the community allow comparison between locations (Samples represent surface area of 0.0625 m2). Stations refer to map in Figure VII-10, (N) is the number of samples per site.

| Location | Sta ID (N) | Total Actual Species | Total Actual Individuals | Species Calculated @75 Indiv. | Weiner Diversity (H') | Evenness (E) |
|---|---|---|---|---|---|---|
| **Edgartown Great Pond - Coves** | | | | | | |
| **Jobs Neck Cove** | Sta. 1 (2) | 10 | 148 | 9 | 2.68 | 0.82 |
| | Sta. 23 (2) | 8 | 476 | 7 | 2.11 | 0.73 |
| **Janes Cove** | Sta. 9 (2) | 16 | 866 | 9 | 2.03 | 0.51 |
| **Wintucket Cove** | Sta. 10 (2) | 9 | 532 | 8 | 2.58 | 0.82 |
| | Sta. 11 (2) | 7 | 576 | 6 | 1.85 | 0.66 |
| **Mashacket Cove** | Sta. 17 (2) | 7 | 157 | 6 | 1.93 | 0.71 |
| **Turkeyland Cove** | Sta. 22 (2) | 8 | 272 | 8 | 2.27 | 0.75 |
| **Slough Cove** | Sta. 21 (2) | 6 | 294 | 5 | 1.03 | 0.42 |
| **Edgartown Great Pond - Main Basin** | | | | | | |
| **Upper Basin** | Sta. 12 (2) | 7 | 119 | 7 | 2.35 | 0.84 |
| | Sta. 13 (2) | 7 | 140 | 6 | 1.69 | 0.70 |
| | Sta. 16 (2) | 6 | 344 | 6 | 2.04 | 0.79 |
| | Sta. 19 (2) | 4 | 240 | 4 | 0.87 | 0.48 |
| **Lower Basin** | Sta. 5 (2) | 8 | 166 | 8 | 2.24 | 0.77 |
| | Sta. 6 (2) | 13 | 296 | 12 | 2.75 | 0.75 |
| | Sta. 7 (2) | 11 | 209 | 10 | 2.18 | 0.63 |

# VIII. CRITICAL NUTRIENT THRESHOLD DETERMINATION AND DEVELOPMENT OF WATER QUALITY TARGETS

## VIII.1 ASSESSMENT OF NITROGEN RELATED HABITAT QUALITY

Determination of site-specific nitrogen thresholds for an embayment requires integration of key habitat parameters (infauna and eelgrass), sediment characteristics, and nutrient related water quality information (particularly dissolved oxygen and chlorophyll-a). Additional information on temporal changes within each sub-embayment and its watershed further strengthens the analysis. These data were collected to support threshold development for the Edgartown Great Pond System by the MEP Technical Team and were discussed in Chapter VII. Nitrogen threshold development builds on this data and links habitat quality to summer water column nitrogen levels obtained from the long-term baseline Water Quality Monitoring Program conducted by the Town of Edgartown and the MV Commission (technical guidance from the Coastal Systems Program at SMAST). At present, the Edgartown Great Pond System is generally showing moderately to significantly impaired habitat for infauna with the lower basin also supporting moderately impaired eelgrass habitat. There is a slight gradient in the infaunal habitat quality with the upper basin and its tributary coves showing greater impairment than he large lagoonal basin running parallel to the barrier beach. All of the habitat indicators are consistent with this evaluation of the whole of system (Chapter VII).

***Eelgrass:***

At present, eelgrass beds are not present in the Edgartown Great Pond System, although sparse patches of eelgrass can still be observed within the lower basin. The current lack of eelgrass beds and the remaining sparse patches are consistent with the elevated chlorophyll-a concentrations, the low dissolved oxygen levels and water column nitrogen concentrations within this system. That the remaining patches are found within the shallow margins versus within the "deeper" regions of the lower basin (1951 versus 1997-2002) also supports the contention that the mechanism of loss is nitrogen enrichment.

Total nitrogen levels (TN) within the lower basin have mean summer time levels of ~0.59 mg N $L^{-1}$ compared to the levels in other southeastern Massachusetts estuaries supporting eelgrass, 0.35-0.45 mg N $L^{-1}$ (range of Cape Cod systems). Other key water quality indicators such as dissolved oxygen and chlorophyll-a show similar levels of moderate enrichment with periodic oxygen depletions below 5 mg/L and chlorophyll levels in blooms reaching 10-20 ug/l. Given the sensitivity of eelgrass to declining light penetration resulting from nutrient enrichment and secondary effects of organic enrichment and oxygen depletion, impairment of eelgrass habitat is expected within this system.

While water quality parameters, primarily related to nitrogen, chlorophyll and oxygen are the major factors causing shifts in eelgrass habitat quality within this system, water depth is also important in determining potential habitat locations for restoration. All of the locations with eelgrass (1951-2006) are <1.5 meter depth. The more recent field observations suggest eelgrass at depths of 0.5 - 1.0 meters, with the shallower depth potentially related to low water stand when the inlet is opened and the deeper depth being determined by light penetration when the inlet is closed. The depth of the upper main basin (above Swan Neck) appears to have historically limited eelgrass colonization of this basin. The absence of eelgrass within the Coves, most likely relates to their shallow depth, organic rich sediments and periodic salinity declines.

Relative to setting a benchmark for restoration, it is unfortunate that the density of the historical 1951 beds have not been quantified. While it is certain that eelgrass habitat at that time was of a higher quality than at present, it was likely not a high quality habitat due to the systems periodic tidal exchange and "naturally" nitrogen enriched condition. Routine opening of this salt pond was initiated in the 1940's and would have been required for habitat maintenance at that time, as well as today. Therefore, habitat restoration in this nutrient enriched system should focus on improving eelgrass habitat within the lower main basin, and on full restoration of infaunal habitat quality pond-wide. It should be noted that there is no evidence of eelgrass within the upper main basin or within the major tributary coves.

The overall results indicate that eelgrass habitat within Edgartown Great Pond is presently impaired and the eelgrass coverage has declined. While it is not possible to determine the density of the eelgrass beds in 1951, it does appear the coverage has declined and that recent eelgrass areas support only sparse colonization by eelgrass plants. The decline of eelgrass beds relative to historical distributions is expected given the elevated nitrogen levels and resulting chlorophyll a and dissolved oxygen depletions within this embayment system.

Based upon the 1951 eelgrass coverage data it appears that on the order of 30 acres of eelgrass habitat might be recovered if nitrogen management alternatives were implemented (Table VII-3). It is likely that a greater area of eelgrass habitat would be restored, as the 1951 coverage is likely an underestimate as a result of mapping issues and observed, consistent records of eelgrass from the western region of the lower basin, not observed in the 1951 analysis. Note that restoration of this eelgrass habitat will necessarily result in restoration of other resources throughout the Edgartown Great Pond Embayment System, specifically the tributary coves which have traditionally only supported infaunal habitats (see below). However, given the uncertainty in the quality of the 1951 eelgrass habitat (e.g. eelgrass density), improvement of eelgrass habitat within the lower basin, coupled to embayment-wide restoration of infaunal habitat, should be used to set the nitrogen threshold for management of this salt pond.

***Water Quality:***

Overall, Edgartown Great Pond is showing a moderate level of habitat impairment (eelgrass and infaunal animals) from summer oxygen depletion and organic enrichment primarily from phytoplankton production, parameters directly related to nutrient inputs. The level of oxygen depletion and the magnitude of daily oxygen excursions and chlorophyll-a levels indicate moderately nutrient enriched waters and impaired habitat quality within the upper and lower basins (Figures VII-3 through VII-8). The oxygen data is consistent with organic matter enrichment, primarily from phytoplankton production as seen from the parallel measurements of chlorophyll-a. The periodic elevated oxygen levels observed in Edgartown Great Pond provides additional evidence that this system is presently receiving nitrogen inputs above the threshold required to maintain high quality estuarine habitat.

The measured levels of oxygen depletion in the bottom waters of Wintucket Cove and the lower main basin to Edgartown Great Pond indicate that this Great Salt Pond is currently organic matter enriched, primarily through in situ production by phytoplankton. Moreover, the system periodically experiences moderate levels of oxygen stress, consistent with nitrogen enrichment (Table VII-1). While the levels of oxygen depletion are relatively modest, the phytoplankton blooms in the lower basin are moderate to high (chlorophyll-a, >15 µg/L 1%, 49% and 54% of the time) for the east and west regions, respectively (Table VII-2). The level of chlorophyll is relatively high compared to other embayments in the MEP study region, for example Lewis Bay (<12 ug L-1) or East Bay (<10 ug $L^{-1}$) on the Nantucket Sound shore of the

Town of Barnstable. The larger bloom in the lower basin may be related to the higher rates of nitrogen release from the sediments in this versus the Wintucket Cove basin (Section IV.3). Except for 3 brief (few hours) depletion events at the western site (lower basin), oxygen conditions were generally >5 mg $L^{-1}$ indicating only a moderate level of oxygen related habitat impairment within this system. This was consistent with the grab sample data from the Water Quality Monitoring Program for Wintucket Cove and also for the upper main basin, Janes Cove, and Slough Cove.

The relatively uniform moderate level of habitat impairment is consistent with the small range in observed total nitrogen levels throughout this estuary, 0.582 mg N $L^{-1}$ in the lower basin to 0.650 mg N $L^{-1}$ in upper Mashacket Cove. The relative uniformity of total nitrogen results from the non-tidal nature of this system, the lack of major surface water discharges and the absence of major restrictions separating the coves from the main basin. As discussed below, the level of water column TN during summer has been documented to cause moderate (0.5 - 0.6 mg N $L^{-1}$) to significant (>0.6 mg N $L^{-1}$) impairment of infaunal animal communities in southeastern Massachusetts estuaries.

***Infaunal Communities:***

Overall, the infauna survey indicated that most areas within Edgartown Great Pond are supporting moderate nutrient related infaunal habitat quality. Also, consistent with the lack of large horizontal gradients in water quality within this mainly non-tidal coastal salt pond, there was only a relatively small spatial variation in infaunal habitat quality. It appears that the upper main basin (above Swan Neck) supports the poorest habitat, moderately to significantly impaired, with similar impairment in the major tributary coves (Janes Cove, Wintucket Cove, Mashacket Cove). The lower large lagoonal basin and one of the small associated tributary coves (Jobs Neck Cove) supported slightly higher quality habitat, although moderate impairment by nitrogen and organic enrichment was clearly observed in these basins as well. Both of the lower eastern coves (Turkeyland Cove and Slough Cove) support infaunal animal habitats of intermediate quality between upper and lower basin conditions (Table VIII-1).

The underlying structure of Edgartown Great Pond and its watershed supports the observed spatial variation in infaunal habitat quality. The upper tributary coves receive almost three-quarters of the total watershed nitrogen load to this system, which stimulates organic matter enrichment of the sediments. The upper main basin is deep, creating a depositional environment for organic matter created in situ or entering by transport from its associated basins. The semi-separate lower basin is moderately impaired by organic enrichment, but receives much less direct input of watershed nitrogen. This pattern is reflected in the bottom sediments of each basin, with the predominance of unconsolidated mud in the upper basin and more oxidized mud and sand in the lower basin. While data is limited, it is nearly certain that the upper deep basin periodically undergoes oxygen depletion. As a deep depositional area, the upper basin sediments are enriched in fine organic matter with resulting impacts to its benthic habitats. This contention is supported by the pond-wide oxygen sampling data from the Water Quality Monitoring Program, which showed depletions to <4 mg $L^{-1}$ only in Janes Cove and the upper main basin (7% and 3% of samples, respectively). The observations of iron accumulation at the sediment surface in the upper main basin also indicate periodic hypoxia. In general, the observed distribution of significantly to moderately impaired infaunal animal habitat in the upper basin and Janes Cove and only moderate impairment in the lower basin compares well with these water quality and sediment data.

Table VIII-1. Summary of Nutrient Related Habitat Health within the Edgartown Great Pond Embayment System (Town of Edgartown, MA.), based upon assessment data presented in Chapter VII. The main basin of Edgartown Great Pond and its major tributary sub-embayments (Coves) experience only periodic tidal exchange with ocean waters during managed breaching of the barrier beach. Some basins were approximated using monitoring data coupled to instrument mooring data.

| Health Indicator | Edgartown Great Pond Embayment System | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Main Basin | | Tributary Coves | | | | | |
| | Upper[1] | Lower | Jobs Neck Cove | Janes Cove | Wintucket Cove | Mashacket Cove | Turkeyland Cove | Slough Cove |
| Dissolved Oxygen | H-MI[2,3a] | MI[2,3] | --[10] | MI[3a] | H-MI[2] | H-MI[5a] | --[10] | H[2a] |
| Chlorophyll | MI[5,6] | MI[5] | MI[5] | --[10] | H-MI[6] | --[10] | --[10] | MI[5] |
| Macroalgae | --[7] | --[7] | --[7] | --[7] | --[7] | --[7] | --[7] | --[7] |
| Eelgrass | --[9] | MI[8] | --[9] | --[9] | --[9] | --[9] | --[9] | --[9] |
| Infaunal Animals | SI-MI[11] | MI[12] | MI[12] | SI-MI[14] | SI-MI[14] | SI-MI[13] | MI[12] | MI[12] |
| **Overall:** | **SI-MI[15]** | **MI[16]** | **MI** | **SI-MI** | **SI-MI** | **SI-MI** | **MI** | **MI** |

a -- analysis of Water Quality Monitoring Program data
1 -- monitoring data and Wintucket Cove & Lower Basin moored instruments, as appropriate.
2 – oxygen levels generally >6 mg/L, with periodic depletions 6-5 mg/L.
3 – oxygen levels generally >6 mg/L, with oxygen depletions rarely 4-3 mg/L.
4 -- oxygen levels generally >6 mg/L, with periodic depletions 5-4 mg/L..
5 – moderate to high chlorophyll a levels generally 10-25 ug/L, generally >15 ug/L
6 – moderate chlorophyll a levels 2-12 ug/L, generally <8 ug/L.
7 -- drift algae sparse or absent, little surface microphyte mat, no visible accumulations
8 -- eelgrass beds (1951); now very sparse eelgrass in easternmost & westernmost lower main basin (2002), observed during MEP surveys, also in 2006 by MVC and Edgartown Shellfish.
9 – no evidence this basin is supportive of eelgrass.
10 -- insufficient data for assessment on this Health Indicator
11 -- low - # species, moderate # individuals, mainly polychaetes, some amphipods, moderate-low diversity and Eveness, organic enrichment indicators
12 -- moderate # species, moderate # individuals, moderate diversity and Eveness, dominated by polychaetes and crustaceans
13 -- low # species, moderate # individuals, dominated by disturbance species (e.g. Ampelisca).
14 -- moderate # species, high # individuals, dominated by organic enrichment species (Streplospio) with Capitella, Mediomastus, Ampelisca.
15 -- regions of basin significantly impaired infaunal habitat, other areas only moderately impaired, eelgrass habitat not used in assessment based upon historical data and MassDEP analysis.
16 -- eelgrass has declined since 1951 and between 1995 - 2003, but evidence of historically dense eelgrass beds is lacking. The decline in eelgrass patches indicates moderate impairment and that nitrogen management to improve this key habitat type should be undertaken.

H = Healthy habitat conditions; MI = Moderate Impairment; SI = Significant Impairment;
SD = Severe Degradation; -- = not applicable to this estuarine reach

Overall, the infaunal habitat quality was consistent with the gradients in dissolved oxygen, chlorophyll, nutrients and organic matter enrichment in this system. Classification of habitat quality necessarily included the structure of the specific estuarine basin. Based upon this analysis it is clear that the tributary sub-embayment basins are presently supporting moderately to significantly impaired benthic habitat while the lower main basin generally shows moderate quality. Impairment in these basins is through nitrogen and organic matter enrichment. These results indicate that the nitrogen management threshold analysis (see below) needs to include a lowering of the level of nitrogen enrichment throughout this salt pond for restoration of nitrogen impaired benthic habitats. However, it is important to note that the non-tidal nature of this embayment and the depositional nature of the upper main basin (deep) make benthic habitat within that region of the system particularly sensitive to nitrogen enrichment.

## VIII.2 THRESHOLD NITROGEN CONCENTRATIONS

The approach for determining nitrogen loading rates that will maintain acceptable habitat quality throughout an embayment system, is to first identify the critical spatial distribution and secondly, to determine the nitrogen concentration within the water column which will restore specific locations to a desired habitat quality. The sentinel location(s) are selected such that their restoration will necessarily bring the other regions of the system to acceptable habitat quality levels. Once the sentinel site(s) and the target nitrogen level are determined, the Linked Watershed-Embayment Model is used to sequentially adjust nitrogen loads until the targeted nitrogen concentration is achieved.

Since the Edgartown Great Pond System does not support strong horizontal gradients (range in total nitrogen levels from 0.58 mg N $L^{-1}$ in the lower basin to <0.63 mg N $L^{-1}$ in the coves, with 0.65 mg N $L^{-1}$ in upper Mashacket Cove), the MEP Technical Team decided to use the average of the five long-term water quality stations to determine a pond-wide threshold (EGP 2,3,5,6,9). This distributed "location" for the threshold stems from the variability at individual sites and the non-tidal nature of this system. These stations are presently showing an average TN level of 0.596 mg N $L^{-1}$ (range = 0.587-0.613 mg N $L^{-1}$). As noted in previous sections, the average concentrations at these stations approximate concentrations throughout the pond waters (i.e. it is representative of other pond locations).

Relative to setting a benchmark for restoration, it is unfortunate that the density of the historical 1951 beds has not been quantified. While it is certain that eelgrass habitat at that time was of a higher quality than at present, it was likely not a high quality habitat due to the systems periodic tidal exchange and "naturally" nitrogen enriched condition. Routine opening of this salt pond was initiated in the 1940's and would have been required for habitat maintenance at that time as well as today. Therefore, habitat restoration in this nutrient enriched system should focus on improving eelgrass habitat within the lower main basin and on full restoration of infaunal habitat quality pond-wide. It should be noted that there is no evidence of eelgrass within the upper main basin or within the major tributary coves.

Since the infaunal community at all sites with the Pond are either dominated by organic matter enrichment species or are depleted, comparisons to the muddy basins of other estuarine systems in the MEP study region were relied upon. This type of comparative analysis suggests that a healthy infaunal habitat would clearly be achieved at an average nitrogen level of TN <0.5 mg TN $L^{-1}$. This level was found for Popponesset Bay, where based upon the infaunal analysis coupled with the nitrogen data (measured and modeled), nitrogen levels on the order of 0.4 to 0.5 mg TN $L^{-1}$ were found to be supportive of high infaunal habitat quality in that system. Similarly, in the deeper basins of Three Bays System, healthy infaunal areas are found at nitrogen levels of TN <0.42 mg TN $L^{-1}$ (Cotuit Bay and West Bay) and in Eel Pond (Bourne) at a TN level of 0.45 mg TN $L^{-1}$. Conversely, moderate impairment of infaunal habitat has routinely been documented by the MEP in areas where nitrogen levels of TN >0.5 mg TN $L^{-1}$ were observed. By example, the moderately impaired infaunal habitat in Hyannis Inner Harbor (Barnstable) was found at concentrations of 0.518-0.574 mg N $L^{-1}$ and in Bournes Pond and Great Pond (Falmouth) at concentrations >0.6 mg N $L^{-1}$.

Based on the line of evidence provided above, the MEP Technical Team determined that infaunal habitat quality within Edgartown Great Pond is responding to nitrogen levels in a manner consistent with other embayments within the MEP study region, as seen by the present TN level of ~0.6 mg TN $L^{-1}$ supporting a moderately impaired infaunal community. The integration of all information available clearly supports a nitrogen threshold for restoration of healthy infaunal habitat within Edgartown Great Pond of 0.5 mg N $L^{-1}$ (time averaged). The modeling simulations in Section VIII-3 targeted the 0.5 mg TN $L^{-1}$ for healthy habitat. This significant lowering of average TN levels within the lower basin of Edgartown Great Pond will also improve eelgrass habitat within the historic 1951 coverage area and likely in the western portion of the lower basin as well.

### VIII.3 DEVELOPMENT OF TARGET NITROGEN LOADS

After developing the dispersion-mass balance model of Edgartown Great Pond to accurately simulate the nitrogen conditions that exist under present nitrogen loadings and periodic openings to tidal exchange, various management alternatives were examined as to their efficacy in restoring the observed nitrogen related habitat impairments (Section VIII.1). In addition, the model was used to simulate a modified management approach that could be followed to improve water quality conditions in the pond year-round.

The effect of alterations to nitrogen loads and/or pond-opening practices on habitat quality was gauged from predicted changes in water quality conditions pond-wide (Stations EGP 2,3,5,6,9 Chapter VI). The main goal of this proposed management scenario is to prevent time averaged pond-wide TN concentrations in the pond from rising above 0.50 mg/L during the summer months, when benthic regeneration and algae production is greatest. One effective alternative to achieving these goals was found to be to reduce the watershed loading to the pond, together with an additional mid-summer breach. This potential mid-summer breach would be in addition to the present 2 successful breachings per year.

Watershed loading was reduced from present (2007) conditions until time averaged pond-wide TN concentrations would remain below 0.50 mg/L during a 45-day period[1]. The threshold modeling assumptions include 1) a successful early summer breach, which lowers the average pond TN concentration to 0.35 mg/L; 2) a successful mid-summer breach that remains open for 11-days, and which again lowers pond-averaged TN concentrations to 0.35 mg/L; 3) the mid-summer breach is in addition to the current practice of 2 successful breaches per year; and 4) a combined freshwater input rate (groundwater + precipitation) of 11.0 $ft^3$/sec, which is the lower range of summertime groundwater flow rates to the pond. Though it is true that the period between the fall breach and the spring breach is a bit longer than the period between the others, it is not significant in the sense that this longer period occurs during the winter time when there are extremely low rates of N-regeneration and therefore little N would be accumulating in the watercolumn. Moreover, it is not likely that much N is accumulating over the sediments during that 2 month "gap" in the winter time as the accumulation would typically be occurring through the settling of particulate organic N out of the water column to the sediments. The

[1] The time-averaged total nitrogen level of 0.5 mg $L^{-1}$, means that the average total nitrogen level from just after the tidal inlet closes until the next inlet is opened equals 0.5 mg N $L^{-1}$ across the 6 long-term water quality monitoring stations within Edgartown Great Pond (EGP 1-6; Chapter VI). In the alternative, a 45 day period was used in the average.

winter time is when water quality is typically at its best and when there is the least paticulate in the water column available to settle out to the sediments. Additionally, it should be noted that the rate of freshwater recharge was only used to predict changes in pond elevation. In addition, it appears that the concentration (0.35 mg/L) after the spring breach is reasonable, given the breach modeling of an 11 day opening (Figure VI-1) and the most likely TN level prior to the breach in the year following the implantation of a mid-summer breach. During the late 1990's the top 25% of spring TN concentrations averaged ~0.70 mg/L. However, in the year following a mid-summer breach, these highest levels would be 0.2 mg/L lower (figure VIII-1) or ~0.50 mg/L. It should be noted further that these measured highest quartile values were during years generally with only 1 successful breach.

One of the MEP management alternatives which resulted in a lowering of the nitrogen levels within Edgartown Great Pond to meet the nitrogen threshold for improving eelgrass habitat and restoring high quality infaunal animal habitat combines watershed nitrogen management and a modification of the present opening regimen. This alternative can be further modified by increasing nitrogen reduction and lengthening the period between pond openings, or doing less nitrogen management with a shorter interval between pond openings. The intermediate alternative was based upon the history of successful pond openings and a moderate level of watershed nitrogen management. The resulting threshold septic loading is presented in Table VIII-2. A 30% reduction in the present (2003-06) septic load to the pond, in combination with the plume of treated effluent from the "new" WWTF replacing the historical N load from the "old" WWTF discharge (pre-1996) was sufficient to achieve the threshold requirements. This septic load change results in a 17.8% change in the total watershed load to the pond, as shown in Table VIII-3. A tabulation of all the loads to the pond is provided in Table VIII-4. The benthic loading term is effected by the change in watershed load. The same method described in section VI.2.5.1 was used to adjust the benthic regeneration load to the pond for threshold conditions. The 30% reduction in present septic loading coupled with a mid-summer pond opening, 45 days after the late spring opening, achieved the target of a time averaged pond-wide TN concentrations below 0.50 mg $L^{-1}$ over the summer period.

Table VIII-2. Comparison of sub-embayment septic loads used for modeling of present 2003-06 and modeled threshold loading scenarios of Edgartown Great Pond. Septic loads are from existing residential and commercial properties. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

| sub-embayment | Present Septic N Load (kg/day) | Threshold (kg/day) | Threshold change |
|---|---|---|---|
| Edgartown Great Pond | 15.167 | 10.617 | -30.0% |

| Table VIII-3. Comparison of sub-embayment watershed loads used for modeling of present 2007 and modeled threshold loading scenarios of Edgartown Great Pond. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms. The threshold level reflects the lowered septic loading (threshold) in Table VIII-2 and the "new" WWTF nitrogen load (2007). (Loading in 2007 less than 2003 due to "new" WWTF Plume.) | | | |
|---|---|---|---|
| sub-embayment | Present N Load (kg/day) | Threshold (kg/day) | Threshold Change |
| Edgartown Great Pond | 25.608 | 21.058 | -17.8% |

| Table VIII-4. Sub-embayment and surface water loads used for total nitrogen modeling of threshold conditions for Edgartown Great Pond, with total watershed N loads, atmospheric N loads, and benthic flux. | | | |
|---|---|---|---|
| sub-embayment | Threshold N Load (kg/day) | direct atmospheric deposition (kg/day) | benthic flux net (kg/day) |
| Edgartown Great Pond | 21.058 | 11.445 | 13.559 |

Through the course of the summer, the effect on TN concentrations of the threshold management scenario suggested for Edgartown Great Pond is presented in Figure VIII-1. For the 101-day period shown in Figure VIII-1, the time averaged TN concentration is 0.50 mg/L. A similar plot of salinities is presented in Figure VIII-2. In each plot, results are also shown for the case where the first, early summer breach is made, but the mid-summer one is not. The average salinity during the course of this 101-day simulation is 25.5 ppt.

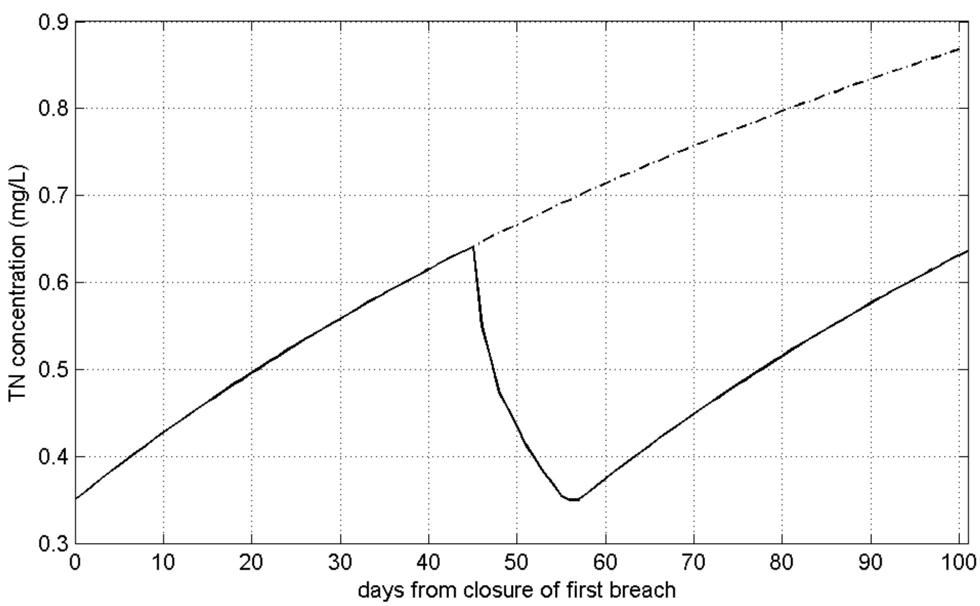



Figure VIII-1. Comparison of modeled pond-averaged TN concentrations for case where the pond is breached only in the early summer (thick black dot-dashed line) and also when it is breached an additional time mid-summer.

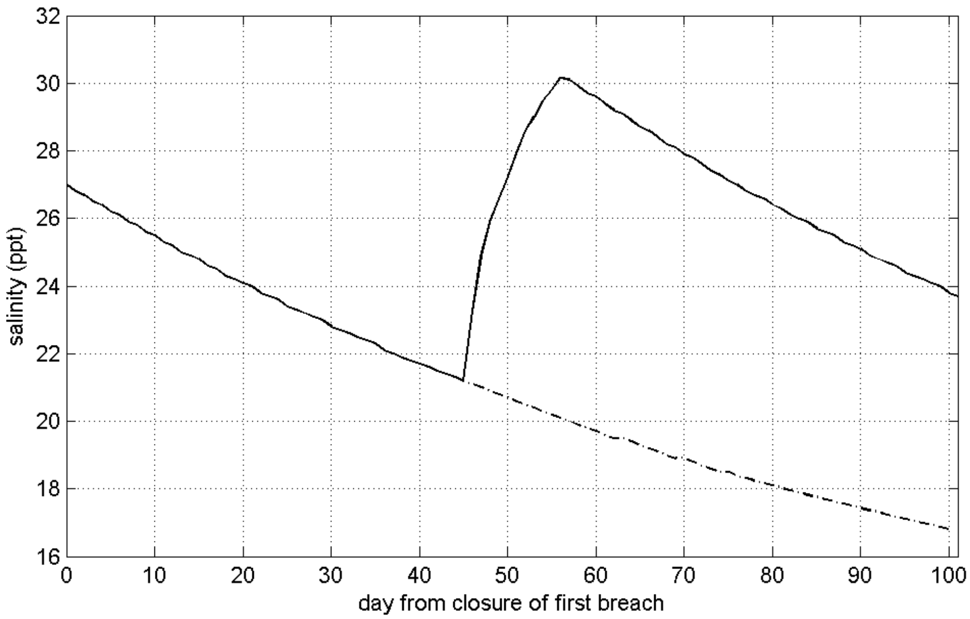



Figure VIII-2. Comparison of modeled pond-averaged salinities for case where the pond is breached only in the early summer (thick black dot-dashed line) and also when it is breached an additional time mid-summer.

# IX. REFERENCES


Anderson Nichols & Co., Edgartown Water Resource Protection Program (1984)

Brigham Young University (1998). "User's Manual, Surfacewater Modeling System."

Cambareri, T.C. and E.M. Eichner. 1998. Watershed Delineation and Ground Water Discharge to a Coastal Embayment. *Ground Water*. 36(4): 626-634.

Cape Cod Commission, (1998). "Cape Cod Coastal Embayment Project." Barnstable, MA.

Cape Cod Commission Water Resources Office, 1991. Technical Bulletin 91-001, Nitrogen Loading.

Cape Cod Commission Water Resources Office, 1998. Cape Cod Coastal Embayment Project Interim Final Report.

Cape Cod Commission. 2000. "Coastal Nitrogen Loading Project".

Delaney, D.F. 1980. Ground-Water Hydrology of Martha's Vineyard, Massachusetts. US Geological Survey Hydrologic Investigations Atlas HA-618.

Dyer, K.R. (1997). Estuaries, A Physical Introduction, 2nd Edition, John Wiley & Sons, NY, 195 pp.

Earth Tech (1998) Preliminary Data: Meeting House Golf LLC

Earth Tech Inc., Groundwater Modeling for the Delineation of the Watershed to Edgartown Great Pond.

Eichner, E.M. and T.C. Cambareri. 1992. Technical Bulletin 91-001: Nitrogen Loading. Cape Cod Commission, Water Resources Office, Barnstable, MA. Available at: http://www.capecodcommission.org/regulatory/NitrogenLoadTechbulletin.pdf

Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA.

Eichner, E.M., T.C. Cambareri, K. Livingston, C. Lawrence, B. Smith, and G. Prahm. 1998. Cape Coastal Embayment Project: Interim Final Report. Cape Cod Commission, Barnstable, MA.

Gaines, A. 1993, Coastal Resources Planning and Management: Edgartown Great Pond. WHOI, Woods Hole, MA

Gaines, A. (1996) An Artificial Inlet for Application on a Seasonally High Energy Barrier Beach. Proposal to Boldwater Homeowners by Coast & Harbor Consultants

Henderson, F. M. (1966). *Open Channel Flow*. Macmillan Publishing Company, New York. pp. 96-101.

Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, J. Wood, E. Eichner (2004). Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Popponesset Bay, Mashpee and Barnstable, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2003). Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Stage Harbor, Sulphur Springs, Taylors Pond, Bassing Harbor and Muddy Creek, Chatham, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

Horsley & Witten Inc, Herring Creek Farm Study

King, Ian P. (1990). "Program Documentation - RMA2 - A Two Dimensional Finite Element Model for Flow in Estuaries and Streams." Resource Management Associates, Lafayette, CA.

Lindeburg, Michael R. (1992). *Civil Engineering Reference Manual, Sixth Edition*. Professional Publications, Inc., Belmont, CA.

Llewellyn-Smith, The Hydrogeology of Martha's Vineyard, Mass. MS Thesis, UMASS Dept. Geology and Geography, 1987.

Main Engineers, Geohydrologic Study For the Edgartown Water Pollution Control Facility (1986)

Martha's Vineyard Commission (1998) Data Report, Dukes County, MA. 1998

Martha’s Vineyard Commission. 1999. Edgartown Great Pond: Nutrient Loading and Recommended Management Program, 1996-1998. W. Wilcox, principal author. MassDEP Grant # 96-04/604.

Martha's Vineyard Commission, 1999, "Edgartown Great Pond: Nutrient Loading and Recommended Management Program 1996-1998”

Massachusetts Division of Water pollution Control (1977) Martha's Vineyard Water Quality Study

Massachusetts Department of Environmental Protection. 1999. DEP Nitrogen Loading Computer Model Guidance. Bureau of Resource Protection. Boston, MA. Available at: http://www.state.ma.us/dep/brp/dws/techtool.htm

Massachusetts Department of Revenue. November, 2002. Property Type Classification Codes.

Michael T. Hoover, Ph.D. 1997. A Framework for Site Evaluation, Design, and Engineering of On-Site Technologies Within a Management Context".

Millham, N.P. and B.L. Howes, (1994a). Freshwater flow into a coastal embayment: groundwater and surface water inputs. Limnology and Oceanography 39: 1928-1944.

Millham, N.P. and B.L. Howes (1994b). Patterns of groundwater discharge to a shallow coastal embayment. Marine Ecology Progress Series 112:155-167.

Norton, W.R., I.P. King and G.T. Orlob (1973). "A Finite Element Model for Lower Granite Reservoir", prepared for the Walla Walla District, U.S. Army Corps of Engineers, Walla Walla, WA.

Pratt, S.D. and A. Gaines, An Environmental Status Report on Edgartown Great Pond: Bottom Habits and their Flora and Fauna, 1997.

Ramsey, J.S., B.L. Howes, S.W. Kelley, and F. Li (2000). “Water Quality Analysis and Implications of Future Nitrogen Loading Management for Great, Green, and Bournes Ponds, Falmouth, Massachusetts.” Environment Cape Cod, Volume 3, Number 1. Barnstable County, Barnstable, MA. pp. 1-20.

Ramsey, John S., Jon D. Wood, and Sean W. Kelley, (1999). “Two Dimensional Hydrodynamic Modeling of Great, Green, and Bournes Ponds, Falmouth, MA.” Applied Coastal Research and Engineering, Inc. report prepared for the Town of Falmouth and Horsley & Witten, Inc. 41 pp.

Saunders Associates (1989) Martha’s Vineyard Landfill Monitoring Well Sampling Program: Final Report

Shepard, F.C. Waquoit Bay National Estuarine Research Reserve. 1996. "Managing Wastewater: Prospects in Massachusetts for a Decentralized Approach".

Shepard, F.C. Waquoit Bay National Estuarine Research Reserve. 1996. "A Massachusetts Guide to Needs Assessment and Evaluation of Decentralized Wastewater Treatment Alternatives".

Skomal, G.B. (1998) Finfish Survey: Edgartown Great Pond. Third Quarterly Report: Massachusetts Division of Marine Fisheries

Smith and Mahoney (1991) Martha’s Vineyard Landfill Groundwater Quality Monitoring Program: Final Report

Smith, K.N. and B.L. Howes, 2006. Attenuation of watershed nitrogen by a small New England salt marsh. Manuscript in review

Taylor, C.D. and B.L. Howes, 1994. Effect of sampling frequency on measurements of seasonal primary production and oxygen status in near-shore coastal ecosystems. Marine Ecology Progress Series 108: 193-203.

USGS web site for groundwater data for Massachusetts and Rhode Island: http://ma.water.usgs.gov/ground_water/ground-water_data.htm

Van de Kreeke, J. (1988). “Chapter 3: Dispersion in Shallow Estuaries.” In: Hydrodynamics of Estuaries, Volume I, Estuarine Physics, (B.J. Kjerfve, ed.). CRC Press, Inc. pp. 27-39.

Whitman & Howard (1994) A Numerical Groundwater Flow Model and Zone II Delineation for the Farm Neck Well, Oak Bluffs, Mass., Wellesley, Ma.

Whitman & Howard (1996) Letter Report on Second Phase of Nitrate Plume Investigation

Wilcox, W.M. (1998) Island Coastal Ponds Water Quality Survey, 1995-1996: Great Ponds Report. MV Shellfish, MV Commission, UMASS Extension

Wilcox, W.M. (1986) Vineyard Farm Survey. Unpublished Survey.

Wood, J.D., J.S. Ramsey, and S. W. Kelley, (1999). "Two-Dimensional Hydrodynamic Modeling of Barnstable Harbor and Great Marsh, Barnstable, MA." Applied Coastal Research and Engineering, Inc. report prepared for the Town of Barnstable. 28 pp.

Zimmerman, J.T.F. (1988). "Chapter 6: Estuarine Residence Times." In: Hydrodynamics of Estuaries, Volume I, Estuarine Physics, (B.J. Kjerfve, ed.). CRC Press, Inc. pp. 75-84.