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.

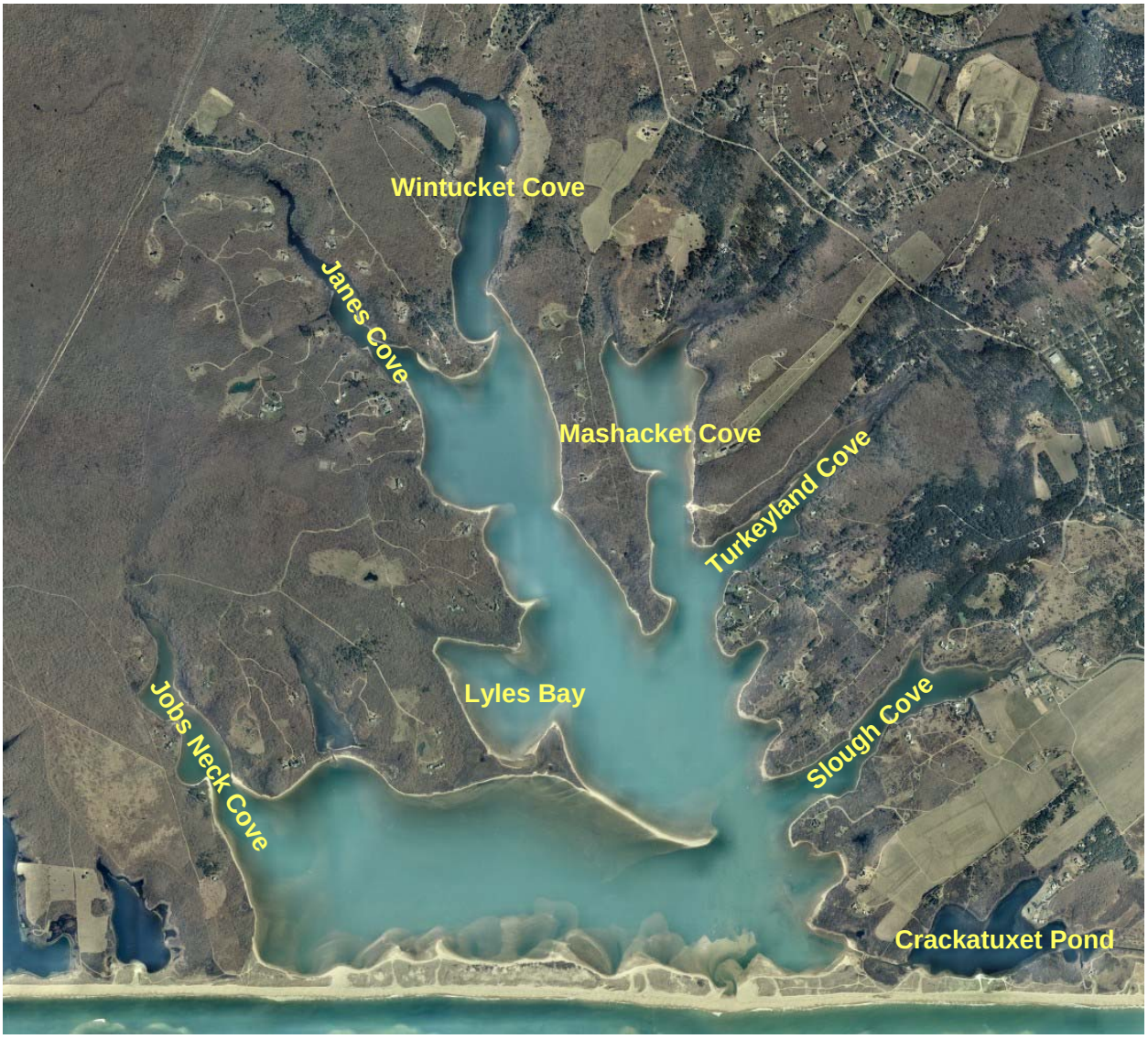

Figure I-2. Study region for the Massachusetts Estuaries Project analysis of the Edgartown Great Pond Embayment System. Tidal waters enter the Pond through periodic breaching of the barrier beach and flow in from the Atlantic Ocean. Freshwaters enter from the watershed primarily through direct groundwater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

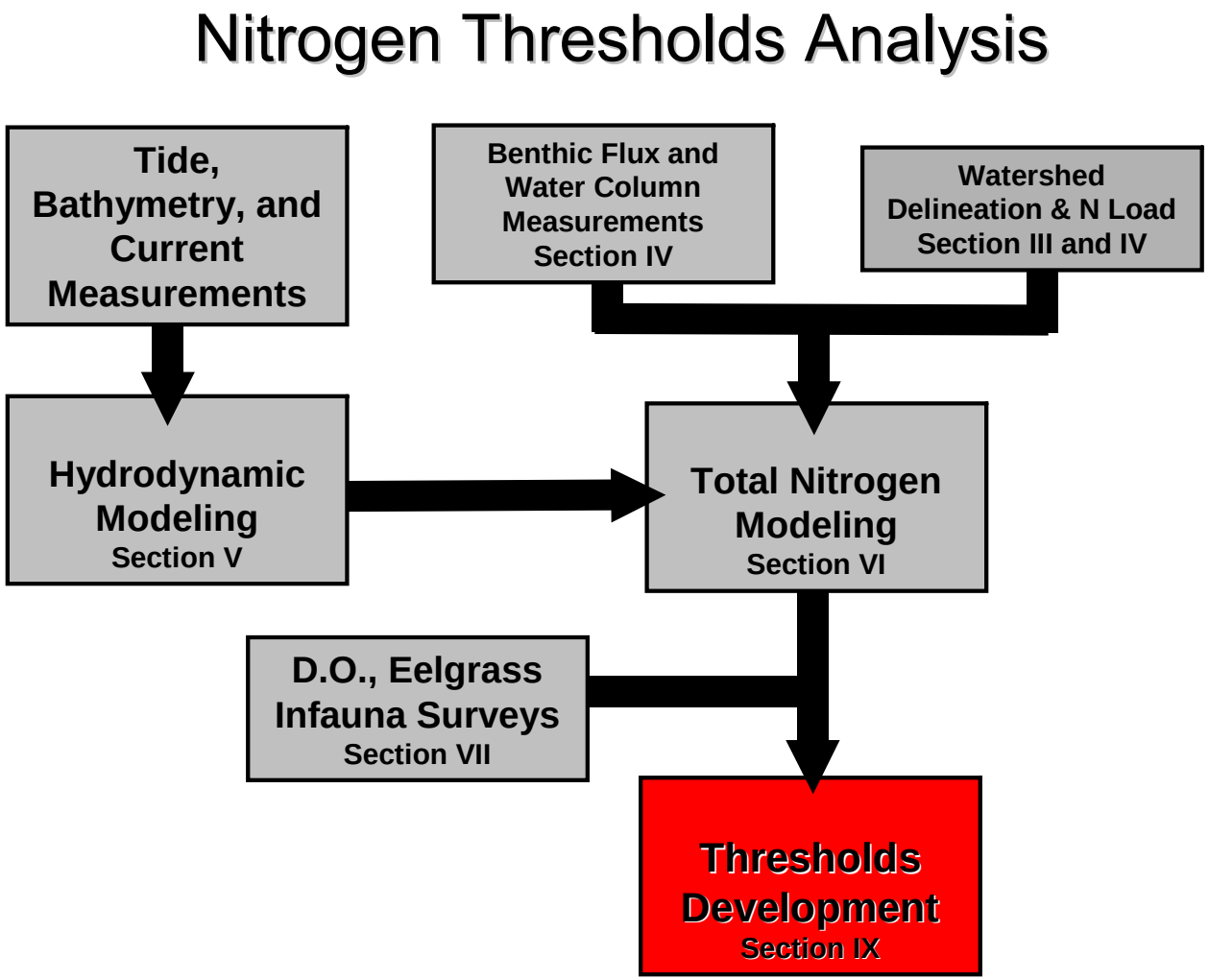

Figure I-3. Massachusetts Estuaries Project Critical Nutrient Threshold Analytical Approach

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.