I. INTRODUCTION

The Centerville River Embayment System is a complex estuary located within the Town of Barnstable on Cape Cod, Massachusetts with a southern shore bounded by water from Nantucket Sound (Figure I -1). The estuary is composed of a lagoon formed behind a barrier spit and running parallel to the shoreline, comprised of the Centerville River and East Bay, and a drowned river valley estuary, Bumps River/Scudder Bay. The Bay's watershed is distributed entirely within the Town of Barnstable. A large portion of the overall watershed includes the sub-watersheds contributing direct groundwater discharge to the estuary and contributing to the four surface water discharges flowing with to the estuarine reach of the Bumps River (Skunknett River, Bumps River) or directly into Centerville River (stream from Long Pond, stream from Lake Elizabeth). Although 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 Centerville River System, will require the Town of Barnstable to be active in nutrient management throughout the watershed to the overall system. This will be made easier by virtue of the fact that the watershed to the Centerville River System resides entirely within the boundary of the Town of Barnstable.

The number of sub-embayments (East Bay, Centerville River, Bumps River, Scudder Bay, Centerville River marshes) to the Centerville River 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. 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. In particular, the Centerville River system and its sub-embayments along the Barnstable shores are at risk of eutrophication (over enrichment) from high nitrogen loads in the groundwater and runoff from their watersheds.

The Centerville River Embayment System is a complex estuary with one inlet connecting Centerville Harbor-Nantucket Sound to Centerville River and a number of sub-embayments (East Bay, Centerville River, Bumps River, Scudder Bay, Centerville River marshes) as depicted in Figure I-1. Centerville Harbor abuts Nantucket Sound and is bounded to the west by Dowes Beach in the vicinity of the inlet to the estuary and Halls Creek Salt Marsh located along the most eastern boundary of the Harbor. The Centerville River Estuary receives tidal waters from Nantucket Sound which flow into a single lower basin (East Bay) located on the western end of Centerville River. East Bay and Centerville River are separated from Centerville Harbor by a barrier beach. The barrier beach is commonly known as Dowes Beach to the west of the inlet to Centerville River, Long Beach immediately to the east of the inlet and then Long beach transitions into Craigville Beach. Moving east from Craigville Beach is Coville Beach which terminates in a small tidal inlet which allows Nantucket Sound flood waters to enter the Halls Creek Salt Marsh system (Figure I-2). The inlet connecting Centerville Harbor and East Bay – Centerville River is a feature that has very likely migrated along the barrier beach as a function of longshore transport of sediments and coastal storms. Currently, the inlet is armored and stable and the Town of Barnstable periodically dredges the inlet channel to keep the inlet and East Bay navigable. Centerville River runs west to east behind the barrier beach and terminates in a salt marsh system commonly referred to as the Centerville Marshes. Midway along the west-east axis of the Centerville River, the Centerville River is joined with the Bumps River flowing south from the up reaches of the estuarine system. The confluence of the

estuarine Bumps River with Centerville River is a very shallow area of the Centerville River reach and has periodically been dredged to keep the waterway navigable as described in Section II. At the uppermost end of the estuarine reach of Bumps River is located Scudder Bay, a terminal sub-embayment that receives direct fresh surfacewater inflow from the watershed via the Bumps River. The estuarine reach of the Bumps River also receives fresh surfacewater inflow from the watershed via the Skunknett River. Unlike the more upland habitat that characterizes the shores of Scudder Bay, salt marsh dominates the shoreline at the eastern most end of the Centerville River estuarine reach. Centerville River proceeds in a northeasterly direction upwards towards Long Pond and receives direct fresh surface water discharge from Long Pond and Lake Wequaquet. Lower in the salt marsh system is located another fresh surface water input that discharge from Lake Elizabeth to the east. These smaller sub-embayments (including Bumps River and Scudder Bay) constitute important components of the Town's natural and cultural resources.

Figure I-1. Study region for the Massachusetts Estuaries Project analysis of the Centerville River Embayment System. Tidal waters enter the Bay through one inlet from Nantucket Sound. Freshwaters enter from the watershed primarily through 4 surface water discharges (Skunknett River, Bumps River, a stream from Long Pond and a stream from Lake Elizabeth) and direct groundwater discharge.

Figure I-2. Topographic Map of the Centerville River System depicting major geographic features.

The present Centerville River system results from tidal flooding of drowned river valleys formed primarily by the Bumps River discharging to Scudder Bay and Skunknett River discharging to estuarine reach of the Bumps River. In the northeast portion of the Centerville River system, the stream flowing from Long Pond likely contributed to the morphology of this portion of the system as would also be so for the small stream flowing from Lake Elizabeth (a small coastal kettle pond). Drowning of the river valleys occurred gradually as a result of rising sea level following the last glaciation approximately 18,000 years BP. Coastal processes, including the formation of a barrier spit (beach and dune deposits) have altered the positions of the tidal inlet(s) to the Centerville River system and affecting tidal exchange between the open water Centerville Harbor and the enclosed Centerville River. Most of the estuarine reach of the Centerville River and East Bay comprise a lagoon formed behind a barrier spit (Long Beach - Craigville Beach), which separates the estuary from Centerville Harbor and Nantucket Sound. The barrier spit grew from the southeastern shore, and is a very dynamic geomorphic feature.

The primary ecological threat to the Centerville River System as a coastal resource is degradation resulting from nutrient enrichment. Although the enclosed estuarine system has some bacterial contamination issues related to stormwater run-off from the watershed, these do not appear to be having large system-wide impacts. Bacterial contamination causes closures of shellfish harvest areas within the East Bay and Bumps River sub-embayments as well as portions of Centerville River. In contrast, loading of the critical eutrophying nutrient, nitrogen, to the Centerville River System has been greatly increased over the past few decades with further increases certain unless nitrogen management is implemented. The nitrogen loading to the Centerville River Estuary, like almost all embayments in southeastern Massachusetts, results primarily from on-site disposal of wastewater.

The Town of Barnstable has been among the fastest growing towns in the Commonwealth over the past two decades and does have a centralized wastewater treatment system located in Hyannis. Even so, the vast majority of the Centerville River System watershed is not connected to any municipal sewerage system and wastewater treatment and disposal is primarily based on privately maintained septic systems. As existing and probable increasing levels of nutrients impact Barnstable's coastal embayments, water quality degradation will accelerate, with further harm to invaluable environmental resources.

As the primary stakeholder to the Centerville River System, the Town of Barnstable was among the first communities to become concerned over perceived degradation of Bay waters. The concern over declining habitat quality led directly to the establishment of a comprehensive water quality monitoring program aimed at determining the degree to which waters of the Town's embayments maybe be impaired. The Town of Barnstable Water Quality Monitoring Program was provided technical assistance by the Coastal Systems Program at SMAST-UMD and over the past several years has had the Water Quality Monitoring Program of the Three Bays Preservation Trust merged into Barnstable's Town-wide embayment monitoring program. This effort provides the quantitative watercolumn nitrogen data (1999-2004) required for the implementation of the MEP's Linked Watershed-Embayment Approach used in the present study.

The common focus of the Barnstable Water Quality Monitoring effort has been to gather site-specific data on the current nitrogen related water quality throughout the Centerville River 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 conducted in support of an Environmental Impact Report for the Centerville River Dredging Project that got underway in the early part of 2002. The details of the EIR are presented in Section II. The MEP approach 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 Barnstable. 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 local non-governmental organization (NGO) Three Bays Preservation. The modeling tools developed as part of this program provide the quantitative information necessary for the Town of Barnstable 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 Centerville River System has been significantly altered by human activities over the past ~100 years or more (see Section I.2, below). As a result, the present nitrogen "overloading" appears to result partly from alterations to the geomorphology and ecological systems. These alterations subsequently affect nitrogen loading and transport 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 Barnstable) 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 Cape Cod Commission (CCC) have undertaken the task of providing a quantitative tool for watershed-embayment management for communities throughout Southeastern Massachusetts.

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 DEP 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 DEP 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, DEP 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.

In appropriate estuaries, bacterial technical reports will be developed in support of a Cape Cod wide TMDL for bacterial contamination. As possible, these analyses of bacterial contamination will be conducted in concert with the nutrient effort (particularly if there is a 303d listing), as was the case for the Prince's Cove sub-embayment to the Three Bays system. Currently, the MEP (through SMAST) has not been tasked with a technical assessment of bacterial contamination in the Centerville River System for inclusion of this system into the Cape Cod wide bacterial TMDL that the MassDEP is in the process of producing.

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 23 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 Centerville River Embayment System exchanges tidal water with Nantucket Sound through one inlet at the west end of a barrier beach referred to as Long – Craigville Beach. The inlet connecting Centerville Harbor to East Bay was opened by dredging in the early 1900's and is armored on the west side (Dowes Beach) and remains in a "natural" un-stabilized state on the east side (Long Beach). For the MEP analysis, the Centerville River Estuarine System has been partitioned into four general sub-embayment groups: the 1) East Bay 2) Centerville River West 3) Centerville River East, including the marshes northeast of bridge, and 4) Bumps River (inclusive of Scudder Bay) as depicted in Figure I-1.

Within the overall Centerville River System is seen a diversity of estuarine habitats, including the tidal portion of East Bay and Centerville River which operates as an embayment, the Bumps River and Scudder Bay with associated fringing wetlands and the large salt marsh area at the eastern end of the Centerville River. Most of the System's salt marsh area is to the east and associated with Bumps River and has shallow tidal flats and large salinity fluctuations. In contrast, East Bay and Centerville River show more typical embayment characteristics with a mixture of open water areas and channels, small fringing salt marshes and relatively stable salinity gradients. Although the upper sub-embayment system of Bumps River and Scudder Bay up-gradient of Centerville River exhibit different hydrologic characteristics (river dominated versus tidally dominated), the tidal forcing for these systems is generated from Nantucket Sound. Nantucket Sound exhibits a moderate to low tide range, with a mean range of about 2.5 ft. Since the water elevation difference between Nantucket Sound and the Centerville River System is the primary driving force for tidal exchange, the local tide range naturally limits the volume of water flushed during a tidal cycle (note the tide range off Stage Harbor Chatham is ~4.5 ft, Wellfleet Harbor is ~10 ft).

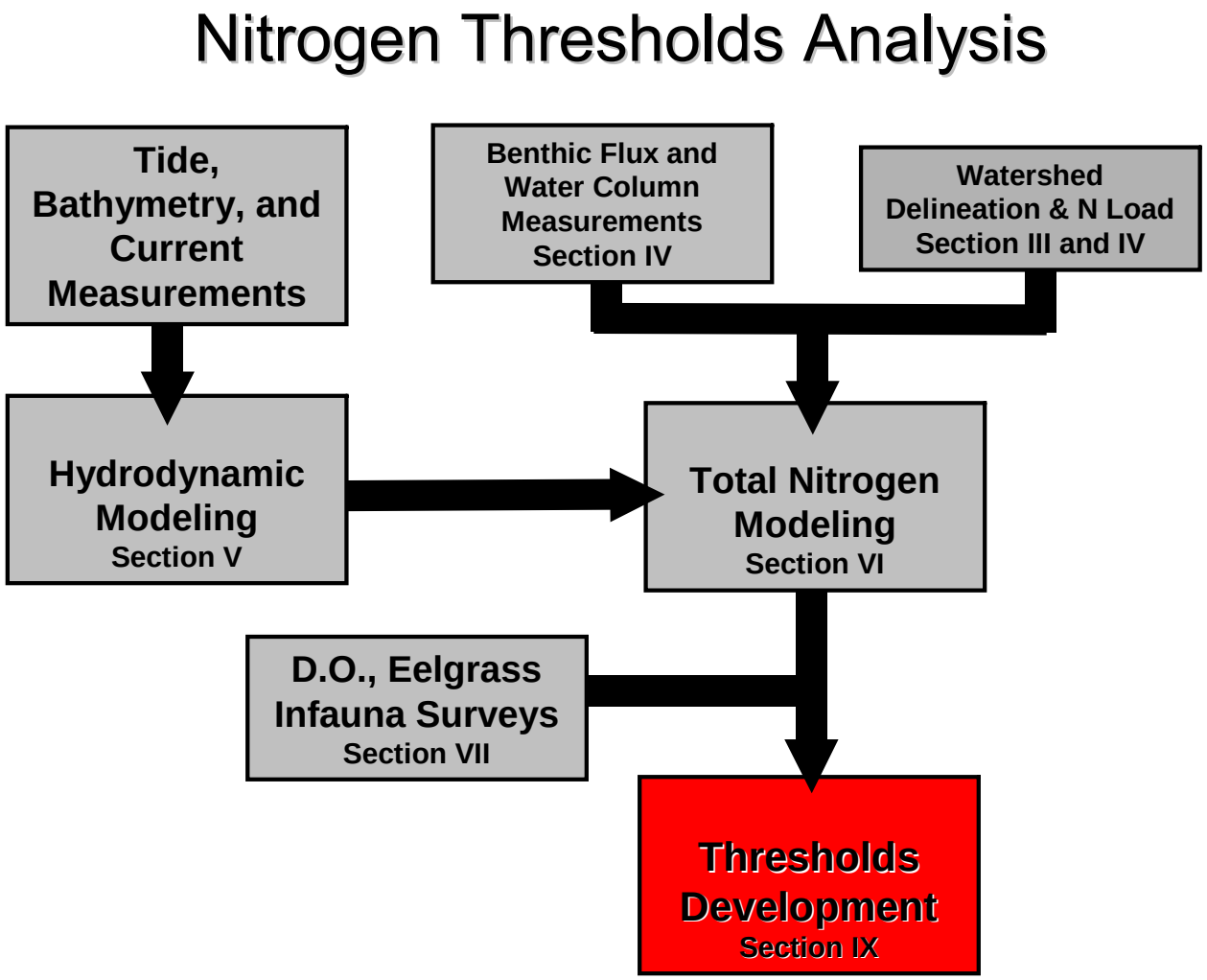

Figure I-3. Massachusetts Estuaries Project Critical Nutrient Threshold Analytical Approach

Tidal damping (reduction in tidal amplitude) through an embayment can range from negligible, indicating "well-flushed" conditions, or show tidal attenuation caused by constricted channels and marsh plains, indicating a "restrictive" system, where tidal flow and the associated flushing are inhibited. Tidal data indicate only minimal tidal damping through the inlet into the East Bay – Centerville River. It appears that the tidal inlet is operating efficiently having recently been dredged in the 2002 to 2003 time frame during the most recent Centerville River Dredging Project. Within the Bumps River and Centerville Marshes portion of the System, the tide propagates to the sub-embayments with negligible attenuation, consistent with generally well-flushed conditions throughout.

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 Centerville River System, phosphorus is highly retained during groundwater transport as a result of sorption to aquifer minerals (Weiskel and Howes 1992). Since even 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). 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). Tidal reaches within the Centerville River Estuary 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 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). 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 Centerville River System monitored by the Town of Barnstable/Three Bays Preservation. Data from the Water Quality Monitoring Program combined 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 Centerville River System are near or beyond their ability to assimilate additional nutrients without impacting their ecological health. Nitrogen levels are elevated throughout the System and eelgrass beds have not been observed within the Centerville system for over a decade. Nitrogen related habitat impairment within the Centerville River Estuary shows a gradient of high to low moving from the inland reaches to the tidal inlet. The result is that nitrogen management of the primary sub-embayments to the Centerville River 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, it is sometimes possible that eutrophication within the Centerville River sub-embayments (e.g. Scudder Bay) could potentially occur without human influence and must be considered in the nutrient threshold analysis. While this finding would not change the need for restoration, it would change the approach and potential targets for management. 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 Centerville System; however, a thorough understanding of estuarine circulation is required to accurately determine nitrogen concentrations within each component of the 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 Centerville River System, including the tributary sub-embayments of East Bay, Centerville

River, Bumps River, Scudder Bay and the Centerville River Marshes. A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents 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 watershed delineations by USGS using a modification of the West Cape model for sub-watershed areas designated by MEP. Almost all watershed sourced nitrogen entering the Centerville River System is transported by freshwater, predominantly groundwater. Concentrations of total nitrogen and salinity of Nantucket Sound source waters and throughout the Centerville River system were provided by the Town of Barnstable/Three Bays Water Quality Monitoring Program (a coordinated effort between the Town of Barnstable, Three Bays Preservation and the Coastal Systems Program at SMAST). Measurements of the salinity and nitrogen distributions throughout estuarine waters of the Centerville River System (2000-2005) 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 Centerville River System for the Town of Barnstable. 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-watershed surrounding the estuary were derived from Cape Cod Commission data and offshore water column nitrogen values were derived from an analysis of monitoring stations in Nantucket Sound (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/protection of the River in Section VIII. Additional modeling is conducted to produce an example of the type of watershed nitrogen reduction required to meet the determined system threshold for restoration or protection. 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 Centerville River System were undertaken relative to potential alterations of circulation and flushing, including an analysis to identify hydrodynamic restrictions and an examination of

dredging options to improve nitrogen related water quality. The results of the nitrogen modeling for each scenario have been presented in Section IX.