

I. INTRODUCTION

The Popponesset Bay System is located within the Towns of Mashpee (north & west) and Barnstable (east), on Cape Cod Massachusetts with a southern shore bounded by water from Nantucket Sound (Figure I-1). The Bay's watershed is distributed among the Towns of Mashpee, Barnstable and Sandwich. It should be noted that Town of Sandwich does have jurisdiction over land and associated land uses in the uppermost portions of the overall watershed to Popponesset Bay. Specifically, portions of the Popponesset Bay watershed that exist within the Town of Sandwich are generally situated above the Mashpee-Wakeby Pond system with the exception of a small area immediately above Wakeby Pond that lies within the Town of Mashpee. As such, in order to achieve effective restoration of Popponesset Bay, it is critical that all three towns (Barnstable, Mashpee, and Sandwich) constituting the total Popponesset Bay watershed be involved in nutrient management discussions. Land uses closest to the embayment are likely to 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.

The present Bay results from tidal flooding of drowned river valleys formed primarily by the Mashpee and Santuit Rivers as a result of rising sea level. The Bay is separated from Nantucket Sound by a barrier spit, which grew from the southwestern shore. The spit, Popponesset Beach, as a barrier spit, is a very dynamic geomorphic feature. The Bay exchanges tidal water with Nantucket Sound through a single maintained inlet. The shore to the north of the inlet has been stabilized with riprap, as is the heavily residential southern portion of Popponesset Beach. The current spit is significantly shorter than seen in 1880 Barnstable County or 1938 USGS topographic maps, where the tip of the spit extended north to Rushy Marsh.

The estuarine region of the Popponesset Bay System is composed of a large lower basin, Popponesset Bay, and multiple tributary sub-embayments (Ockway Bay, Pinquickset Cove, Shoestring Bay, Mashpee River, Popponesset Creek). These sub-embayments constitute important components of the Town's natural and cultural resources. In addition, the large number of sub-embayments greatly increases the System's shoreline and decreases the travel time of groundwater 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 Popponesset Bay system and its sub-embayments along the Mashpee and Barnstable shores are at risk of eutrophication (over enrichment) from high nitrogen loads in the groundwater and runoff from their watersheds.

The primary ecological threat to Popponesset Bay embayment system as a coastal resource is degradation resulting from nutrient enrichment. Although the watershed and the Bay have some organic contamination and bacterial contamination issues, these do not appear to be having large System-wide impacts. Organic contamination has been identified associated with an abandoned junkyard in Forestdale (J. Braden Thompson site) where a groundwater plume containing trichloroethylene and tetrachloroethylene is discharging to the surface waters of Mashpee-Wakeby Pond in the upper watershed to the Bay. In addition, a small volatile organic compound plume associated with the former Augat site (on Rt. 28) is discharging



Figure I-1. Study region for the Massachusetts Estuaries Project analysis of the Popponeset Bay System. Tidal waters enter the Bay through the single inlet from Nantucket Sound. Freshwaters enter from the watershed primarily through 3 surface water discharges (Mashpee River, Santuit River, Quaker Run) and direct groundwater discharge. Rushy Marsh is a separate embayment with a direct tidal connection to Nantucket Sound.

directly to Shoestring Bay. Bacterial contamination causes closures of shellfish harvest areas periodically within the Bay System. In contrast, loading of the critical eutrophying nutrient, nitrogen, to the Bay waters has been greatly increased over the past few decades with further increases certain unless nitrogen management is implemented. The nitrogen loading to the Bay, like almost all embayments in southeastern Massachusetts, results primarily from on-site disposal of wastewater. The Town of Mashpee has been among the fastest growing towns in the Commonwealth over the past two decades and does not have centralized wastewater treatment; although several small privately operated facilities operate within the Popponeset Bay watershed. As existing and probable increasing levels of nutrients impact Mashpee's coastal embayments, water quality degradation will accelerate, with further harm to invaluable environmental resources.

As the primary stakeholder to the Popponeset Bay System, the Town of Mashpee was the first community to become concerned over perceived degradation of Bay waters. The concern over declining habitat quality followed significant on-going efforts to preserve open space within the Mashpee River sub-watershed, most recently related to the Mashpee National Wildlife Refuge (1995). This concern led to one of the first ecological studies of contamination within the estuary, by KV Associates completed in 1991. This effort attempted to develop a plan for managing contamination in the Mashpee and Shoestring Bay estuaries. By the mid-1990's phytoplankton and macroalgal blooms had raised the declining quality of the Bay into the realm of general discussion. The Town of Mashpee through its Board of Selectman, Watershed Management Committee, Waterways Commission and Shellfish Department began the Popponeset Bay Water Quality Monitoring Program in July 1997, in concert with the Cotuit Waders of the Town of Barnstable and SMAST (then the Center for Marine Science and Technology). Initial results from 1997 and 1998, indicated nutrient, chlorophyll a and dissolved oxygen conditions were consistent with significant eutrophication within the Mashpee River, Ockway Bay and Shoestring Bay (Howes and Schlezinger 1998).

The Monitoring Program was then expanded (in recent years with formal Town of Barnstable participation) and has continued through summer 2003 to provide baseline water quality data for the MEP. Preliminary land-use analysis of the watershed to the Popponeset Bay embayment system supported the view that the habitat decline within this large estuarine system was being caused by increased nitrogen inputs from the surrounding watershed due to expanding commercial and residential development (Cape Cod Commission 1998). In 1998 and 1999 the Town of Mashpee allocated funds for a project to quantitatively assess nutrient sources and model nitrogen levels within the System with SMAST scientists. Since it was becoming clear that nitrogen restoration of the Bay would likely require some traditional wastewater treatment approaches, the on-going ecological assessment and modeling project was wrapped into the Town's Wastewater Facilities Planning effort by the Mashpee Sewer Commission. Under the direction of the Mashpee Sewer Commission and the Town of Barnstable DPW, the Popponeset Bay System was included in the first round prioritization of the Massachusetts Estuaries Project to provide state-of-the-art analysis and modeling. However, given that the MEP was able to fully integrate the Towns' on-going data collection and modeling effort, no additional municipal funds were required for MEP tasks.

The common focus of the Mashpee and Barnstable effort has been to gather site-specific data on the current nitrogen related water quality throughout the Popponeset Bay System and determine its relationship to watershed nitrogen loads. This seven-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 master planning and nitrogen management alternatives development needed by the Towns of Mashpee and 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. The modeling tools developed as part of this program provide the quantitative information necessary for the Towns of Mashpee and 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.

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. At its higher levels, enhanced 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 related to changes in land-use as watershed 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 Towns of Mashpee and 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 (MA DEP), the University of Massachusetts – Dartmouth School of Marine Science and Technology (SMASST), 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, TMDL's for bacterial contamination will also be conducted in concert with the nutrient effort (particularly if there is a 303d listing). However, the goal of the bacterial program is to provide information to guide targeted sampling for specific source identification and remediation. As part of the overall effort, the evaluation and modeling approach will be used to assess available options for meeting selected nitrogen goals, protective of embayment health.

The major Project 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 15 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 fully field validated and unlike many approaches, accounts for nutrient sources, attenuation, and recycling and variations in tidal hydrodynamics (Figure I-2). This methodology integrates a variety of field data and models, specifically:

- 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 Popponeset Bay embayment system exchanges tidal water with Nantucket Sound through a single maintained inlet at the tip of Popponeset Beach. For the MEP analysis, the Popponeset Bay estuarine system has been partitioned into five general sub-embayment groups: the 1) Popponeset (main) Bay, 2) Pinguickset Cove, 3) Ockway Bay, 4) Mashpee River (lower or tidal region) and 5) Shoestring Bay (see Figure I-1). Popponeset Creek was considered as part of the Popponeset (main) Bay in the modeling and thresholds analysis.

Within the Popponeset Bay System, the tidal portion of the Mashpee River shows the clearest estuarine characteristics, with extensive salt marsh area, tidal flats and large salinity fluctuations. In contrast, Popponeset Bay, Shoestring Bay and Ockway Bay show more typical embayment characteristics dominated by open water areas, having only fringing salt marshes, relatively stable salinity gradients and relatively large basin volumes relative to tidal prism. Although the four sub-embayment systems bounding the main open water portion of Popponeset Bay (Pinguickset Cove, Ockway Bay, Mashpee River lower, and Shoestring Bay) exhibit different hydrologic characteristics (river dominated versus tidally dominated), the tidal forcing for these systems is generated from Nantucket Sound. Nantucket Sound, adjacent Popponeset Beach, 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 Popponeset Bay 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).

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 Popponeset Bay inlet. It appears that the tidal inlet is operating efficiently, possibly due to the active inlet maintenance program. Similarly, within the Popponeset Bay System, the tide propagates to the sub-embayments with negligible attenuation, consistent with generally well-flushed conditions throughout.

Given the present hydrodynamic characteristics of the Popponeset Bay System, it appears that estuarine habitat quality is more dependent on nutrient loading to bay waters than tidal characteristics within the component sub-embayments.

Nitrogen loading to the Popponeset Bay System was determined relative to five (5) sub-embayments: Pinguickset Cove, Ockway Bay, Mashpee River (lower or tidal region), Shoestring Bay, and Popponeset Bay. The watershed for this estuarine system contains approximately 13,000 acres, dominated by single-family residences. Commercial and residential land-uses primarily in the southern portion of Mashpee and in the Barnstable region create a large nutrient load to the Popponeset Bay System. The nitrogen loading from the more heavily populated areas of the Town of Mashpee is focused on the northern reaches of the estuarine system.

Nitrogen Thresholds Analysis

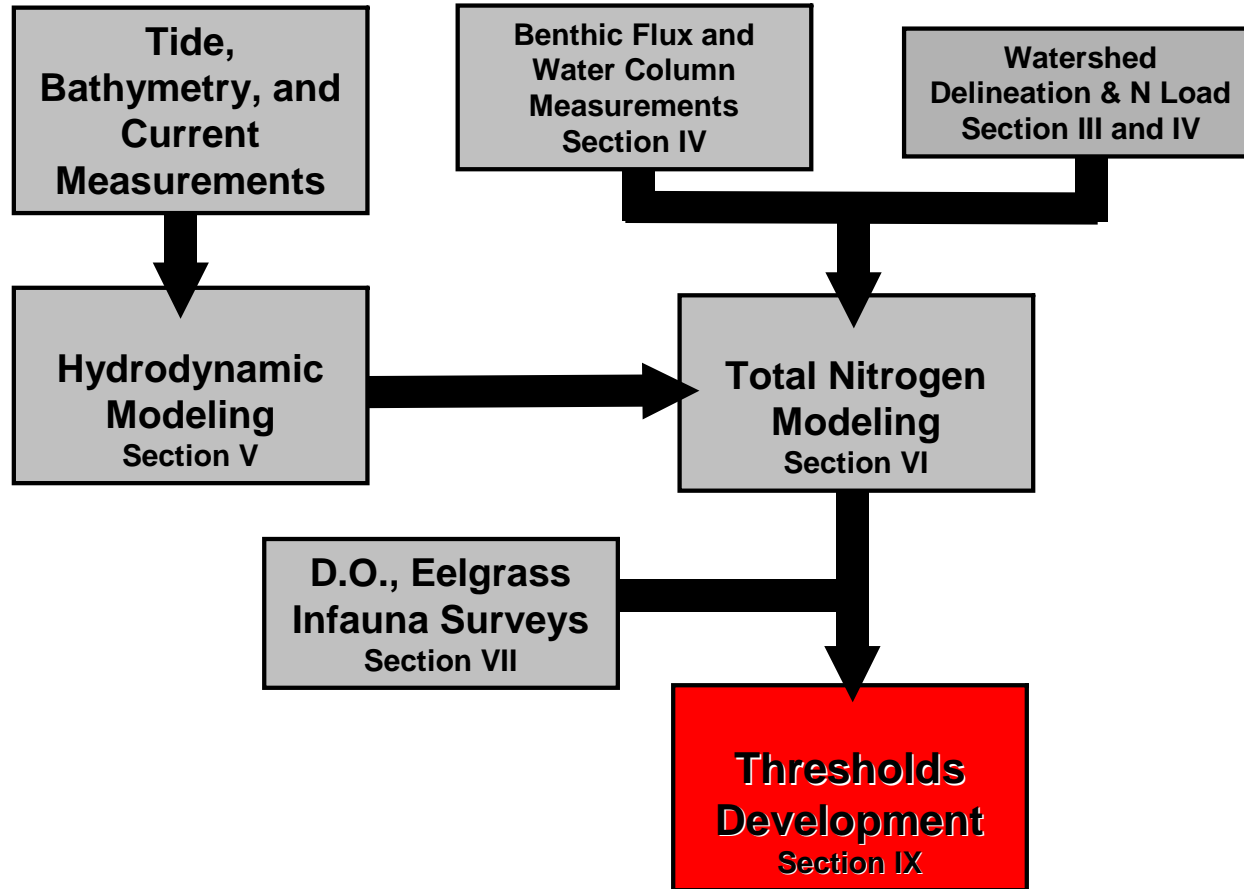


Figure I-2. Massachusetts Estuaries Project Critical Nutrient Threshold Analytical Approach

System wide, approximately three quarters of the nitrogen load from single-family dwellings enters the Shoestring Bay sub-embayment as well as the tidally influenced lower reach of the Mashpee River.

As management alternatives are being developed and evaluated, it is important to note that Popponeset Bay is a relatively dynamic system. The spit forming Popponeset Beach is continually expanding and eroding, once nearly reaching the inlet channel to the Three Bays System to the north. The spit frequently experiences periodic over wash (Aubrey and Gaines 1982). The present inlet position is relatively new, resulting from a breach of the spit in the hurricanes of 1954. Similarly, within the main Bay, several islands apparent 50 -100 years ago have been incorporated into other landforms with unquantified effects on the circulation of Bay waters. Thatch Island and Little Thatch Island within the lower main Bay have “joined” with the spit, most likely due to a combination of the natural processes of overwash of the barrier beach and shoreline retreat. Daniels Island, at the entrance to Ockway Bay, has been joined to the mainland by filled causeways, apparently filling salt marshes and changing the local circulation pattern.

Hydrodynamics have also been altered within Popponeset Creek due to dredging and channelization of wetlands. Within the watershed there have been changes to the freshwater systems which attenuate nitrogen during transport to bay waters. Most notable have been the modification to riparian zones either through channelization, restriction, or filling of freshwater wetlands and, in some cases, transformation to cranberry agriculture. Most of the alterations have reduced the nutrient buffering capacity of these systems, magnifying the nitrogen loading to the bay. However, the predominant watershed alteration has been the shifting of fields and pine-oak forest to residential and commercial development, with its resultant increasing nitrogen input to the watershed, aquifer and ultimately bay waters. This recent shift in land-use has likely resulted in this estuary receiving its highest rates of nitrogen loading than at any period over the past 400 years. Previous large shifts in land-use, primarily from forest to agriculture did not have the same resultant enhancement in nitrogen loading as agriculture generally recycled nitrogen (as opposed to commercial fertilizers) and the population was <10% of today. The present year-round population per square mile is greater than the entire town population of 50 years ago (total population based on 2000 census for Towns of Mashpee, Sandwich, and Barnstable are 12,946, 20,136 and 47,821 respectively). It appears that the nitrogen attenuation capacity of the freshwater systems may have been reduced, as the need to intercept the nitrogen loading to the watershed has increased. While this may be a partial cause of the present estuarine decline, it may also represent a potential opportunity for restoration of bay systems.

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 Popponeset Bay 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 Popponeset Bay 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. 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 Popponeset Bay System monitored by the Popponeset Bay Water Quality Monitoring Program with site-specific habitat quality data (D.O., eelgrass, phytoplankton blooms, benthic animals) 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 Popponeset Bay System (including Popponeset Bay) are near or beyond their ability to assimilate additional nutrients without impacting their ecological health. Nitrogen levels are elevated throughout the System and eelgrass has not been observed for over a decade. The result is that nitrogen management of the primary sub-embayments is aimed at restoration, not protection or maintenance of existing conditions. In general, nutrient over-fertilization is termed “eutrophication” and when the nutrient loading is primarily from human activities, “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 Popponeset Bay’s sub-embayments could potentially occur without man’s 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 Popponeset Bay Systems; 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 Popponeset Bay System, including the tributary sub-embayments of Mashpee River, Ockway Bay, Shoestring Bay, Pinquickset Cove and the Popponeset Bay central basin. 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 nitrogen entering Popponeset Bay is transported by freshwater, predominantly groundwater. Concentrations of total nitrogen and salinity of Nantucket Sound source waters and throughout the Popponeset Bay System were taken from the Popponeset Bay Water Quality Monitoring Program (supported by the Towns of Mashpee and Barnstable, associated with the Coastal Systems Program at SMAST). Measurements of current salinity and nitrogen and salinity distributions throughout estuarine waters of the System 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 Popponeset Bay System for the Towns of Mashpee (lead) and 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 of the Bay in Section VIII. Additional modeling is conducted to produce an example of the type of watershed nitrogen reduction required to meet the determined Bay threshold for restoration. 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 Popponesset Bay System was 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 (Section IX).