

## I. INTRODUCTION

The Three Bays Embayment System is a complex estuary located entirely within the Town of Barnstable on Cape Cod, Massachusetts with a southern shore bounded by water from Nantucket Sound (Figure I -1). The Bay's watershed is distributed primarily among the Towns of Barnstable and Sandwich, with a small region adjacent Santuit Pond (<1% of the watershed) within the Town of Mashpee and comprised primarily "protected" forest land. The Town of Sandwich has jurisdiction over land and associated land uses in the uppermost portions of the overall watershed to The Three Bays system. Specifically, portions of the Three Bays watershed that exist within the Town of Sandwich are generally situated above the Spectacle Pond, Lawrence Pond and Triangle Pond system and within the contributing area to the upper and mid reaches of the Marstons Mills River. However, the majority of the watershed falls within the Town of Barnstable, which includes the watershed contributing direct groundwater discharge to the estuary and contributing to the lower Marstons Mills River and to the Little River. 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 Three Bays System, will require both the Towns of Barnstable and Sandwich to be active in nutrient management and restoration discussions and planning.

The large number of sub-embayments to the Three Bays 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 Three Bays 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 Three Bays Embayment System is a complex estuary, with multiple inlets and sub-embayments (Cotuit Bay, West Bay, North Bay, Prince's's/Warren's Cove). The estuary receives tidal waters from Nantucket Sound into its two large lower basins, Cotuit Bay to the west of Osterville Grand Island, and West Bay to the east of Grand Island. Floodwaters from Nantucket Sound enter the two large lower basins of the Three Bays system through 2 tidal inlets and flow through the Seapuit River (Figure I-1). Both Cotuit Bay and West Bay exchange tidal waters with upgradient North Bay through "natural" channels. A third tidal passage apparently once existed through the salt marsh between Little Island and Grand Island, but this no longer exists, due to the causeway supporting the roadway from the mainland to Grand Island. Further upgradient of North Bay are two smaller sub-embayments (Prince's's Cove and Warren's Cove). These smaller sub-embayments (including Tim's Cove adjacent to Cotuit Bay, Eel River adjacent to West Bay and Seapuit River connecting Cotuit Bay to West Bay) constitute important components of the Town's natural and cultural resources.

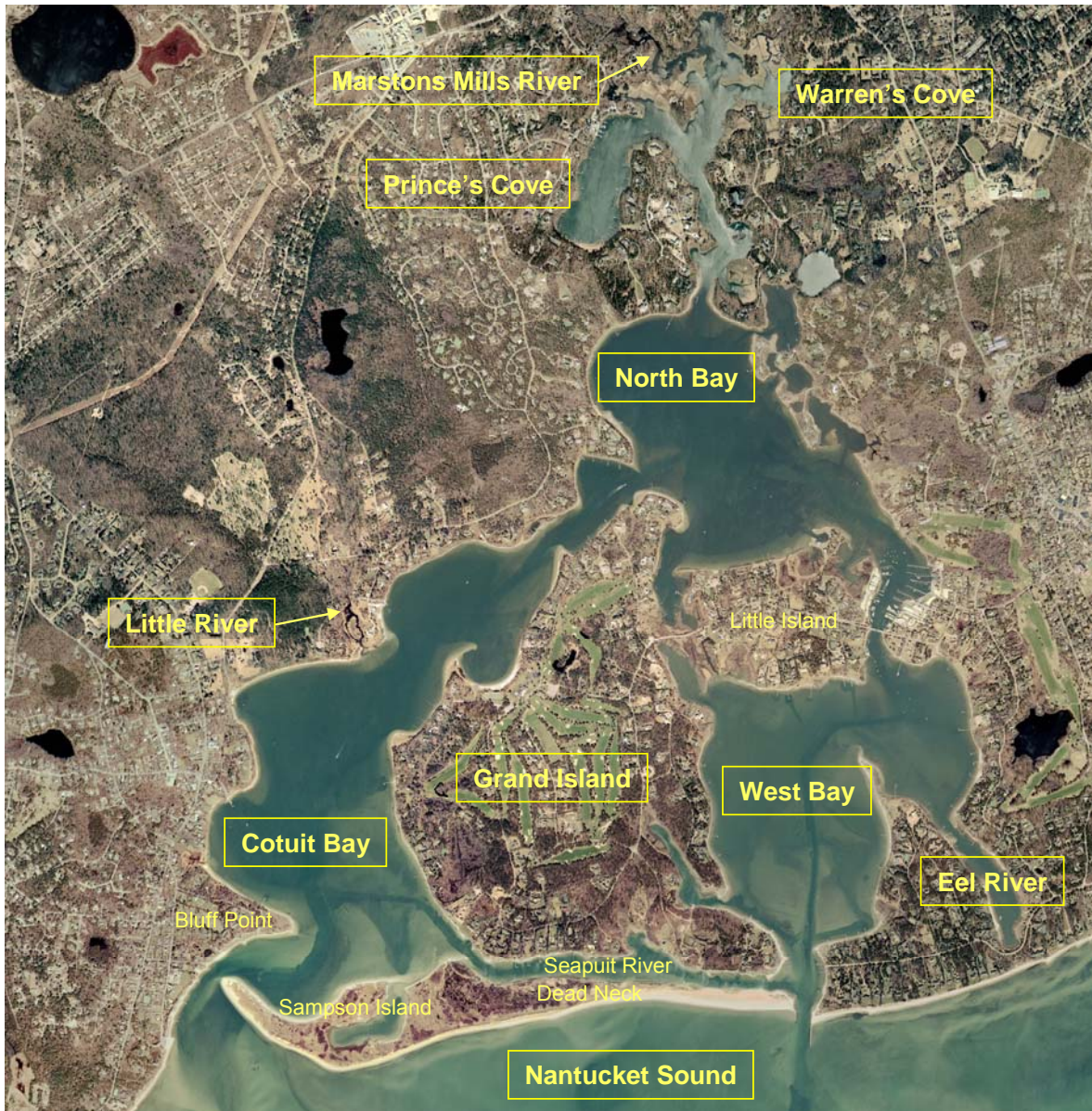


Figure I-1. Study region for the Massachusetts Estuaries Project analysis of the Three Bays Embayment System. Tidal waters enter the Bay through two inlets from Nantucket Sound. Freshwaters enter from the watershed primarily through 2 surface water discharges (Marston's Mills River and Little River) and direct groundwater discharge.

The present Three Bays system results from tidal flooding of drowned river valleys formed primarily by the Marston's Mills River discharging to the Prince's Cove/Warren's Cove sub-embayment upgradient of North Bay as well as incorporated ancient kettle ponds. Little River may also have contributed slightly to the formation, discharging to the head of Cotuit Bay, although the upper reach of Little River is primarily man-made for herring production. Drowning of the river valleys occurred gradually as a result of rising sea level following the last glaciation approximately 18,000 years before present (BP). It appears that the Three Bays system has had multiple inlet positions as an estuary. Coastal processes, including the formation of a barrier spit (beach and dune deposits) have altered the positions of the tidal inlet(s) to the Three

Bays system, affected tidal exchange and are responsible for enclosing Cotuit Bay and West Bay from Nantucket Sound as sea level rose. The Bay is presently separated from Nantucket Sound by a barrier spit (Dead Neck/Sampson Island), which grew from the southeastern shore, and is a very dynamic geomorphic feature. The Bay presently exchanges tidal water with Nantucket Sound through two maintained inlets. The smaller man-made eastern inlet has been stabilized with riprap where as the larger western inlet flowing into Cotuit Bay remains unarmored and is maintained by infrequent dredging.

The primary ecological threat to the Three Bays 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 (Howes et al. MEP Bacterial Tech Report 2004). Bacterial contamination causes closures of shellfish harvest areas regularly within the Prince's's Cove and Warren's Cove sub-embayments as well as portions of North Bay. In contrast, loading of the critical eutrophying nutrient, nitrogen, to the Three Bays System 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 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, however, the vast majority of the Three Bays watershed is not connected to any municipal sewerage system, but rather, rely on privately maintained septic systems for treatment and disposal of wastewater. 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 Three Bays 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 followed significant on-going efforts to preserve open space within the Marstons Mills River and Little River sub-watersheds. This local concern also led to the conduct of several studies (see Chapter II) of nitrogen loading to the system (Cape Cod Commission 1998) and the formation of a citizens organization, Three Bays Preservation Inc., to provide local stewardship of the Three Bays system and to assist in advancing restoration of the System within the Town. One of the initial projects of Three Bays Preservation was to establish, in 1999, a nitrogen related water quality monitoring program throughout the Three Bays system to support restoration efforts. The Three Bays Water Quality Monitoring Program was provided technical assistance by the Coastal Systems Program at SMAST-UMD and over the past several years have been incorporated 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.

Since the initial results of the Water Quality Monitoring Program and the land-use studies indicated that parts of the Three Bays system were presently impaired by land-derived nitrogen inputs, the Town of Barnstable and Three Bays Preservation undertook additional site-specific data collection to support MEP's ecological assessment and modeling project. The effort was part of the Town's Wastewater Facilities Planning effort and was aimed at restoration of the resources within the Three Bays system. Under the direction of the Town of Barnstable DPW, the Three Bays System was included in the second tier of the Massachusetts Estuaries Project (rank #15).

The common focus of the Barnstable effort has been to gather site-specific data on the current nitrogen related water quality throughout the Three Bays 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 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 Three Bays System has been significantly altered by human activities over the past ~400 years (see Section 1.2, 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 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’s Cove sub-embayment to the Three Bays system. The MEP (through SMAST) has already completed the Technical Analysis and Report to support the inclusion of this system in the Cape Cod wide bacterial TMDL that the MASSDEP is in the process of producing. The goal of the bacterial program is to provide information to guide targeted sampling for specific source identification and remediation.

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 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 both calibrated and 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:

- 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 Three Bays embayment system exchanges tidal water with Nantucket Sound through two inlets at the east and west ends of a barrier beach referred to as Dead Neck/Sampson Island. The eastern most inlet connecting Nantucket Sound to West Bay was opened by dredging in 1900 and is armored on both the Oyster Harbors Beach/Dead Neck side as well as the Wianno Beach side. For the MEP analysis, the Three Bays estuarine system has been partitioned into five general sub-embayment groups: the 1) Cotuit Bay, 2) West Bay/Eel River, 3) North Bay, 4) Prince's's Cove and 5) Warren's Cove (see Figure I-1). The estuarine reach of the Marstons Mills River was considered as part of the Prince's's Cove / Warren's Cove sub-embayment system flowing into the head of North Bay in the modeling and thresholds analysis.

Within the Three Bays System, the tidal portion of the Prince's's Cove and Warren's Cove sub-embayment system (Marstons Mills River) including the upper portion of North Bay show the greatest diversity of estuarine habitats, with most of the System's salt marsh area, shallow tidal flats and large salinity fluctuations being present in this area. In contrast, Cotuit Bay and West Bay show more typical embayment characteristics dominated by open water areas, small fringing salt marshes, relatively stable salinity gradients and relatively large basin volumes relative to tidal prism. Although the upper two sub-embayment systems up-gradient of North Bay and the open water portions of Cotuit Bay and West Bay exhibit different hydrologic characteristics (river dominated versus tidally dominated), the tidal forcing for these systems is generated from Nantucket Sound. Nantucket Sound, adjacent Dead Neck (Oyster Harbors 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 the Three Bays 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).

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 two inlets into the Three Bays system. It appears that both the tidal inlets are operating efficiently, possibly due to the active inlet maintenance program. Similarly, within the Three Bays System, the tide propagates to the sub-embayments with negligible attenuation, consistent with generally well-flushed conditions throughout.

# Nitrogen Thresholds Analysis

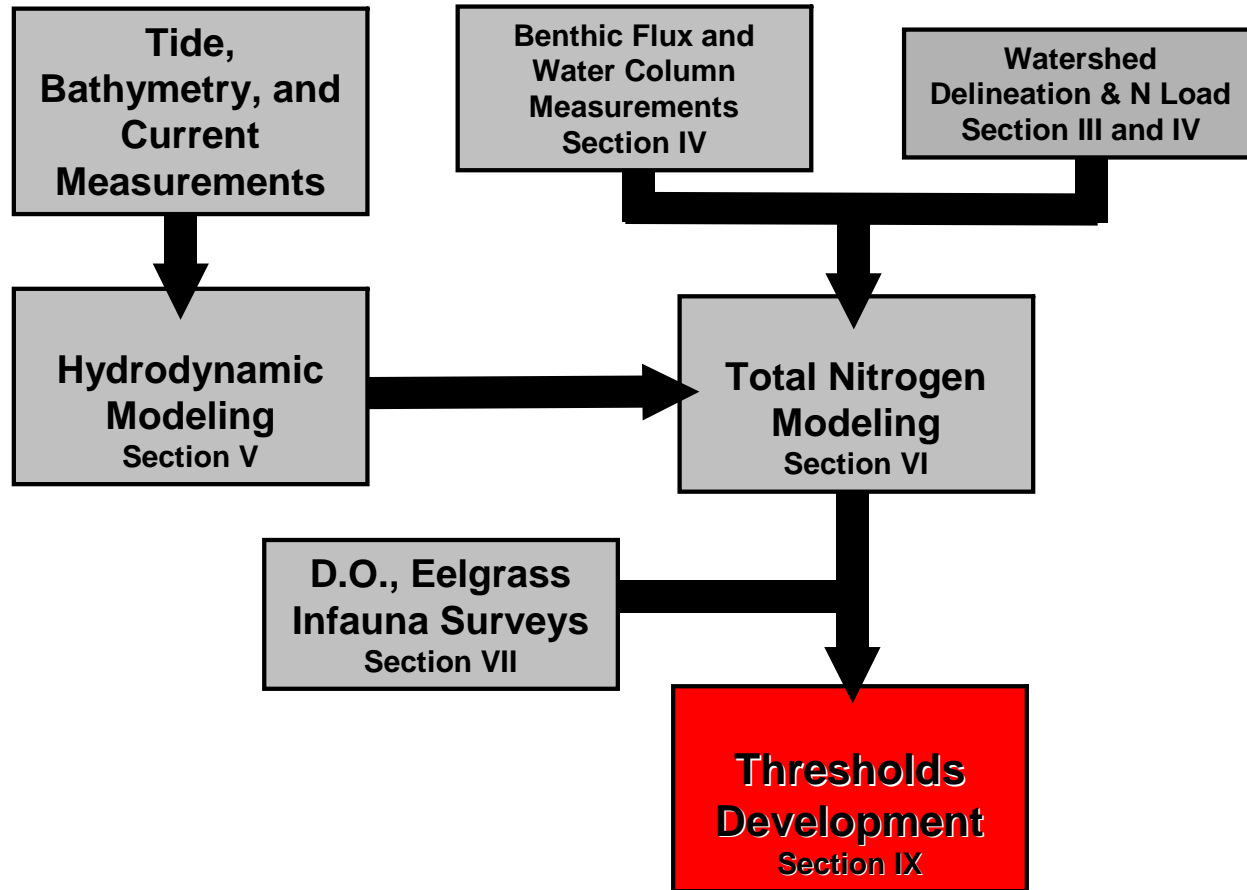


Figure I-2. Massachusetts Estuaries Project Critical Nutrient Threshold Analytical Approach

## ***History of Change***

As management alternatives are being developed and evaluated, it is important to note that the Three Bays System is naturally a relatively dynamic system. Equally important is the recognition that it has been significantly altered by man's activities over the past ~300 years and particularly over the past century.

Management of coastal systems requires not only an understanding of both present conditions, but also of the history of physical and environmental alteration. In addition, within degraded or partially degraded systems, an evaluation of the system's "maximum level of sustainable environmental health" is also needed. It is clear that there has been significant alteration of the Three Bays hydrologic and biological systems over the past several centuries since the early days of the mills along Goodspeeds River. What follows is a brief description of the Three Bays system focusing on major upland or embayment alterations relating to present system health (Howes and Hampson 2000).

While the nutrient related health of the Three Bays System as it exists today is very much linked to changes wrought by human activities, it is the physical structure of the system laid down by the retreat of the Laurentide Ice Sheet that still controls much of the Bays' tolerance to nutrient inputs. The physical structure, shape and depth of a coastal embayment plays a major role in its susceptibility to ecological impacts from nutrient loading. Physical structure (geomorphology), which includes embayment bathymetry, inlet configuration and saltwater reaches, when coupled with the tidal range of the adjacent open waters, determines the system's rate of flushing. System flushing rate is generally the primary factor for removing nutrients from active cycling within coastal bays and harbors like the Three Bays system. As a result maximizing system flushing is one of the standard approaches for controlling the nutrient related health of coastal embayments.

As the Cape Cod Bay and Buzzards Bay Lobes of the Ice Sheet retreated, the sandy outwash plain that now holds the Three Bays watershed was formed. This sandy outwash produced the highly permeable soils found throughout upper Cape Cod. It is the permeability of the soils which has resulted in the importance of groundwater flow as a major pathway for nutrient transfers from sub-watersheds to adjacent coastal waters in this region. The presence of both groundwater and surface water pathways for input of nutrients into the present estuary has significant impact on its response to changing nutrient loadings with the surrounding watershed from changing land-uses.

As sea level rose and flooded the present basins of the Three Bays system, salt marshes began to form and an estuarine ecosystem began to function. At present it is not clear to what extent the basins of the embayment were formed from flooding kettle ponds versus merely flooding erosional valleys. However, given the shape and depth of the basins compared to other non-kettle systems on the southern shore of the upper Cape, it seems likely that kettle ponds with freshwater stream inflows and outflow were incorporated. With further sea-level rise the present marine beach deposits of Dead Neck, Sampson's Island, Bluff Point, northern tip of Grand Island and near the bridge to Little Island began to develop. The result was a complex estuarine system with a single inlet to Nantucket Sound through Cotuit Bay and major freshwater inputs through the Marstons Mills River and to a lesser extent, Little River.

Based upon studies from other regions of Cape Cod, it is likely that Native Americans utilized the resources of the Three Bays System for several thousand years before ceding the region to Captain Miles Standish in 1648. Native Americans likely used both the upland and

estuarine resources. The marine food sources of the system would provide both shellfish (scallops, oysters and quahogs) and fish, particularly herring. According to James Otis, the name Mystic was the Native American term for small streams and ponds, particularly where herring and trout abounded. The largest lake within the watershed is still called Mystic Lake reputedly from this early term.

In 1653 when Roger Goodspeed, the first European to settle within the Three Bay watershed, settled by the Marstons Mills River (for a while named Goodspeeds River), the Three Bays system was different from the present system in both its circulation and water quality. The upland was largely forested with some open lands, the Marstons Mills River was free flowing (no dams) and had more extensive freshwater marshes within its lower reaches and the embayment was connected to Nantucket Sound via a single inlet. While this single inlet almost certainly reduced the tidal exchange with high quality Nantucket Sound waters, the much lower terrestrial input of nutrients suggests a high quality estuarine system. However, it is also likely that, similar to today, within the region of the estuarine reach of the Marstons Mills River and associated salt marshes the sediments and bay waters were among the most nutrient and organic matter rich within the Three Bays System. However, the aquatic and upland components of this System began to change rapidly. By 1689 a fulling mill was constructed on the Marstons Mills River. In 1704-5 the dam was constructed thus altering the pathway of surface water transport and associated nutrients to the estuary. Town records indicating the leasing of herring rights and the requirement that all mills maintain fishways is testament to the magnitude of the herring population supported by this system. An active herring run within the Marstons Mills River continues to this day.

During the 1800's utilization of the estuary and its watershed continued to increase. Regions of the watershed were cleared for agricultural land and the Grist Mill at Marstons Mills continued operations past 1842. Within the watershed were changes to the freshwater systems which attenuate nitrogen during transport to bay waters. Most notable were the modification of riparian zones either through channelization, restriction, or filling of freshwater wetlands and, in some cases, transformation to cranberry agriculture. Most of the alterations reduced the nutrient buffering capacity of these systems, magnifying the nitrogen loading to the bay which greatly increased in the next century. Land clearing was accelerated by the development of salt works on the shores of the Bay which used fire to fuel evaporation for salt production. This activity peaked in 1812 and then declined.

Direct use of marine resources focused on oyster production, where oysters were initially pickled and shipped in barrels to market. In these earlier centuries, as today, oysters were cultured on the Bays' bottom. One of the first growers, Captain George Fisher who was granted a large section of Cotuit Bay shipped oysters to widespread U.S. markets. With the demand for oysters, the natural beds surrounding Grand Island became depleted and spat were imported from Long Island for grow out. However, at least for awhile, seed could be collected at the mouth of nearby Popponesset Bay on deployed scallop shells to supply the grow out needs. During this period, scallops were harvested within the Three Bays system in quantity and even at the turn of the century scallops represented a major economic resource. This record of substantial scallop harvest indicates that eelgrass beds were likely prevalent throughout the Bays. This suggests that the water was clearer (greater transparency due to less phytoplankton), hence less nutrient loading from the watershed was occurring. During this period the population was still small, for example there were only 36 homes in Santuit, Little River and Cotuit combined. Throughout the 1800's the residents relied heavily on coastal resources as salt making, oyster production, fishing, farming, ship-building and coastal trading.

By far the greatest changes to the Three Bays watershed and estuary have occurred during the last 100 years. The most obvious change has been the dramatic shift in land-use to residential housing during the last half of the 1900's. With this shift and the advent of fertilized lawns, has come a dramatic increase in the amount of nitrogen, which enters the Three Bays system. The previous large shifts in land-use, primarily from forest to agriculture did not have the same resultant increase in nitrogen loading, as the historic 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). Unfortunately previous reductions in the capacity of the freshwater systems to attenuate nitrogen prior to its entry into the Three Bays system has accelerated the rate of nitrogen impairment as land-use changed. While this may be a partial cause of the present estuarine decline, it may also represent a potential opportunity for restoration of bay systems.

It is the recent increase in nitrogen load which is responsible for the observed declines in estuarine habitat quality throughout most of the Three Bays Estuary. In addition to this multi-decadal shift in watershed nitrogen loading, there were likely pulses of nutrients to the system during the 1940's associated with the military training areas within the Bays. The associated barracks, warehouses and storage tanks installed during WWII would result in a "new" source of nitrogen loading and the paving of the beach from Baxters Neck to Point Isabella (western shore of North Bay) may have also increased bacterial contamination in the adjacent waters.

In the late 1800's there was another major change to the Three Bays Estuarine System. Until this time, tidal exchange with Nantucket Sound was restricted to a single inlet to Cotuit Bay. However, a second inlet was opened which likely increased the flushing of West Bay, which previously had exchanged estuarine waters via the Seapuit River and through North Bay. Regardless of the extent to which this second inlet increased the flushing out of nutrient rich estuarine waters, it will have helped to buffer the Bays against the coming nutrient increases in the latter part of the century. Recent efforts to maintain the Bays for navigation may have also helped to maintain tidal exchanges, but the extent that this may have helped lessen the effects of increased watershed loadings has not been determined. Dredging of the Marstons Mills River from Prince's Cove to North Bay in 1957 and the inlet to Cotuit Bay (most recently in the late 1990's) are two of the more notable examples of recent efforts.

Unfortunately while nutrient related decline in environmental health of the Three Bays System will be reduced by maximizing tidal exchange with the high quality waters of Nantucket Sound, the growing watershed nutrient loading and the structure of the system will require watershed management to restore the estuarine habitats within the Three Bays system to meet the high level of quality designated by the State Water Quality Standards. Watershed management will likely involve reduction of nitrogen inputs from various sources and possibly the removal of large loads (eg. wastewater) from the watershed. Watershed management targeted at embayment restoration will usher in a new phase in the ever changing Three Bays System to the benefit of both present and future generations.

### **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 Three Bays 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 Three Bays 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 Three Bays System monitored by the Town of Barnstable/Three Bays Preservation. 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 Three Bays System are near or beyond their ability to assimilate additional nutrients without impacting their ecological health. Nitrogen levels are elevated throughout the Systems and eelgrass beds have not been

observed within the Three Bays system for over a decade, although some plants were observed within the shallows of the upper estuary until 1995. Nitrogen related habitat impairment within the Three Bays 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 Three Bays 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 Three Bays sub-embayments 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 Three Bays 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 Three Bays System, including the tributary sub-embayments of Prince’s’s Cove, Warren’s Cove, North Bay, Cotuit Bay and West Bay. 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 the Three Bays System is transported by freshwater, predominantly groundwater. Concentrations of total nitrogen and salinity of Nantucket Sound source waters and throughout the Three Bays system were taken from the 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 current salinity and nitrogen and salinity distributions throughout estuarine waters of the Systems (1999-2004) 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 Three Bays 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-watersheds 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 threshold for restoration of the Bay. 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 Three Bays 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.