I. INTRODUCTION

The Phinneys Harbor Estuarine System (inclusive of Eel Pond, Back River and Phinneys Harbor) is located within the Town of Bourne, on Cape Cod Massachusetts. The system has a western shore bounded by water from Buzzards Bay (Figure I-1). The watershed for this embayment system is also distributed almost entirely within the Town of Bourne with the exception of the very uppermost portions of the watershed which extends inland into the Massachusetts Military Reservation (MMR) within the Town of Sandwich. The Phinneys Harbor System is one of the Town of Bourne's significant marine resources. At a time when many other coastal ponds and bays tributary to Buzzards Bay have been degraded, water quality in Phinneys Harbor has generally remained moderately high with eelgrass beds observed in the early 1990's. However, the tributary sub-embayments to Phinneys Harbor (Eel Pond and Back River) have shown indications of nutrient enrichment, although this may be a natural consequence of the large salt marsh area associated with the estuarine reach of the Back River (Coalition for Buzzards Bay, 1999). Significant in maintaining the water quality within this system is the flushing rate and tidal exchange with the high quality waters of Buzzards Bay.

The Phinneys Harbor System is a moderately complex estuary comprised of 3 principal basins covering 536 acres: a flooded kettle pond, Eel Pond; a wetland dominated portion, Back River; and an artificial large outer basin, Phinneys Harbor (Figure I-1). The present mouth of the Back River (between Rocky Point and Phinneys Point) was the historic seaward terminus of the functional estuarine system until the 1930's, when the causeway to Hog Island and Mashnee Island was constructed. It is this causeway that extended the estuary, by semi-enclosing a basin, now Phinneys Harbor (see Chapter V). In addition, the southern boundary of Phinneys Harbor has also become more enclosed with a causeway to Toby Island. Although Phinneys Harbor now functions as an "artificial" sub-embayment to Buzzards Bay, it previously had supported estuarine habitats as a coastal basin along the shore of the central Buzzards Bay Estuary. Therefore, ecological changes resulting from the enclosure are more associated with nutrient enrichment of a semi-enclosed basin receiving upland inputs than a major change in environmental forcing functions (e.g. estuarine/brackish, tidal/non-tidal, etc).

The Phinneys Harbor basin as it is known today is only about a half century old. The existing peninsula that connects Hog Island and Mashnee Island to the mainland was constructed to gain ready access to the Islands from Agawam Point to support summer residences. The Harbor was originally open water bounded by Agawam Point to the north and Toby Island to the south. The inlet between Rocky Point and Phinneys Point provided shallow access to Back River and Eel Pond from what was historically open water Buzzards Bay. Prior to the formation of Phinneys Harbor, coastal processes associated with the spit (Rocky Point) are likely to have periodically restricted tidal flow to Back River/Eel Pond. At present, neither the inlet to Phinneys Harbor nor to Back River are fixed by jetties. However, the channel into the Back River marshes is currently structured by the western Railroad Bridge, constructed in the late 1800's. The adjacent bridge to the east for Shore Road was constructed more recently with a wider span than the railroad bridge.

Figure I-1 Phinneys Harbor (inclusive of Eel Pond and Back River) study region for the Massachusetts Estuaries Project nutrient analysis. Tidal waters enter the estuarine system through one inlet to Buzzards Bay. Freshwaters enter from the watershed primarily through 1 surface water discharge (stream from Mill Pond to Back River upgradient of County Road) and direct groundwater discharge.

The watershed to Phinneys Harbor is somewhat geologically complex, being composed primarily of Buzzards Bay Plain glacial deposits near the coast, glacial moraine deposits, the Buzzards Bay Glacial Moraine (inland) and Mashpee Outwash Plain deposits in the uppermost regions of the watershed. These formations consist of material deposited after the retreat of the Cape Cod Lobe of the Laurentide Ice sheet ~18,000 years ago. The material is highly permeable and as such, direct rainwater run-off is typically rather low for this type of coastal system. Therefore, most freshwater inflow to the estuarine system is via groundwater discharge or groundwater fed surface water flow. At present, Phinneys Harbor is a tidal embayment with a small groundwater fed stream originating in shallow Mill Pond (upgradient of County Road) and discharging to the headwaters of the Back River sub-estuary. Almost all of the 85 acres of salt marsh in the Phinneys Harbor System is held within the Back River estuarine reach. The other inner tributary sub-embayment, Eel Pond, is a very different functional unit than the wetland dominated Back River. Eel Pond is a drowned kettle pond which is connected to Back River through a narrow tidal channel. Eel Pond receives relatively low amounts of freshwater inflow (Chapter III) and maintains a salinity greater than 27 ppt compared to ~29 ppt within the outer Harbor. However, it appears Eel Pond may infrequently stratify due to its geomorphology, thus increasing its sensitivity to nitrogen enrichment. Phinneys Harbor acts as a mixing zone for terrestrial freshwater inflow and saline tidal flow from Buzzards Bay, however, the salinity characteristics of the system varies with the volume of freshwater inflow as well as the effectiveness of tidal exchange with Buzzards Bay. Overall, the small freshwater contributing area and large tide range result in a relatively high salinity (>27ppt) throughout much of the Phinneys Harbor System.

Similar to other embayments on Cape Cod Phinneys Harbor is a mesotrophic (moderately nutrient impacted) shallow coastal estuarine system. However, eelgrass beds within Phinneys Harbor have historically filled most of the seabed in the northwestern quadrant of the open water portions of the Harbor as can be determined from photo-interpretation of 1951 aerial photographs of the Harbor (MASSDEP Eelgrass Mapping Program, Section VII.3). Eelgrass beds within the southern portion of Phinneys Harbor off Monument Beach have been documented circa. 1980 (Costa 1988). This historical distribution may result from the fine sand and muds within the protected area formed by the Mashnee Island Causeway versus the coarse sand, rock and cobble of the higher energy region adjacent Monument Beach. However, DMF surveys in the early 1990's noted eelgrass decline in the northern portion of the basin, which was documented by the MASSDEP surveys in 1995 and 2001 (Chapter VII). The presence of eelgrass is particularly important to the use of Phinneys Harbor as fish and shellfish habitat. Currently eelgrass beds have retreated to small fringing patches located in the outer areas in the vicinity of Mashnee Island and Toby Island. The Phinneys Harbor System represents an important shellfish resource to the Town of Bourne, primarily for quahogs. However, shellfishing activities are seasonally suspended by the Massachusetts Division of Marine Fisheries as a result of bacterial contamination from watershed run-off and other potential sources. Selectively open DMF segments located in the Phinneys Harbor system include BB:47.1 (Back River mouth, open Nov 1 – April 15), BB:47.2 (Back River and Eel Pond, conditionally closed Jan 20, 2006, exclusive of BB:47.3 of Back River in the vicinity of the boatyard), BB:46.1 (portion of Monument Beach open Nov 1-May 30) and BB:46.3 (portion of Mashnee Island shoreline open Dec 1 – April 30, primarily due to waterfowl). The DMF designated shellfish growing area BB:46.0 (main open water portion of Phinneys Harbor) approved for shellfishing year round. The shellfish closures and documented eelgrass loss has raised public concern over the estuarine resources within this system in recent years. The Town of Bourne has specifically targeted stormwater remediation within the watershed (DPW).

Phinneys Harbor is important for recreational boating and supports approximately 400 moorings. Additionally, the Town of Bourne owns and operates a public marina in the Inner Harbor near the causeway connecting the mainland to Tobys Island. The municipal marina has both a Town Dock, which consists of a pier with floats, and a public boat ramp. Boat fueling activities at the Town Dock are available as is electricity. Pump-out facilities for boat waste are provided by the Town of Bourne. The Monument Beach Marina facilities, off Shore Road, include a dock with 61 slips, a gasoline pump, 35 town moorings, private bathrooms & showers, public bathrooms and a public snack bar. Adjacent to the Marina are a public beach, a permitted parking area associated with the public boat ramp.

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, Phinneys Harbor, specifically the Eel Pond and Back River portions of the overall system, as well as other embayment systems on Cape Cod, is at risk of eutrophication from high nitrogen loads in the groundwater and runoff from their watersheds.

The primary ecological threat to Phinneys Harbor resources is degradation resulting from nutrient enrichment. Loading of the critical eutrophying nutrient, nitrogen, to the embayment waters has been greatly increased over the past few decades with further increases certain unless nitrogen management is implemented. The nitrogen loading to Phinneys Harbor and other Bourne embayments (Red Brook Harbor, Pocasset River, Megansett Harbor, Squeteague), like almost all embayments in southeastern Massachusetts, results primarily from on-site disposal of wastewater. The Town of Bourne has been among the fastest growing towns in the Commonwealth over the past two decades. The Town does not have centralized wastewater treatment and there is presently no WWTF servicing the Phinneys Harbor System watershed. These unsewered areas contribute significantly to the nitrogen loading of Phinneys Harbor System, both through transport in direct groundwater discharges to estuarine waters and through surface water flow to the estuarine reach of the Back River.

The Harbor's watershed includes a variety of nutrient sources, among them the runoff from roads and lawns, as well as effluent from a growing number of residential septic systems. One of the potential sources of nitrogen of public concern has been the Town Landfill which is partially within the upper portion of the Harbor watershed. The MEP Technical Team working with the Town Departments and Landfill staff conducted an investigation to determine the coastal discharge location of nitrogen enriched groundwater, primarily from the historic septage disposal lagoons. The investigation used watershed delineation modeling (Chapter III), groundwater modeling using particle tracking and analysis of the monitoring well network associated with the Landfill site. The analysis indicated that the Landfill is contributing negligible nitrogen to the Phinneys Harbor System and that the flow path for nitrogen enriched groundwater from the historic septage lagoons is to the Cape Cod Canal, between the Railroad and Bournes Bridges (Chapter IV).

Of the watershed derived nitrogen load discharging to the Phinneys Harbor Estuarine System, about half is discharged to the Eel Pond and Back River sub-embayments, with the other half discharging through direct groundwater seepage to the Phinneys Harbor Basin directly. The greatest level of development and residential load is situated in the nearshore regions of the system. Estimates of nitrogen loading to the Harbor from the watershed have been previously conducted by SMAST scientists, the Cape Cod Commission and the Buzzards Bay Project. The bulk of the present nitrogen loading is from residential housing and light

commercial areas, associated sources (roads, driveways, etc.), and the Brookside golf course located within the system watershed. Nitrogen loading from the upper portions of the watershed are very small, as approximately two-thirds of the upper watershed area is composed of forested lands of which nearly 40 percent is within the Massachusetts Military Reservation. Of the available developable land within the watershed nearly two-thirds of that developable land has already been utilized resulting in a watershed that is approaching build-out conditions with residential inputs accounting for the large fraction of nitrogen load to adjacent waters.

At present, Phinneys Harbor (specifically the Eel Pond and Back River tributary sub-embayments to Phinneys Harbor) appear to be beyond their ability to tolerate additional nitrogen inputs. Phinneys Harbor and possibly Eel Pond are presently showing habitat degradation consistent with nitrogen overloading. The Back River estuarine reach is currently functioning primarily as a salt marsh system and as such has a high tolerance for nitrogen inputs and has no signs of degradation. Although the Phinneys Harbor watershed is approaching build-out, nitrogen related degradation will likely increase with further water quality degradation, unless nitrogen management is initiated. Phinneys Harbor nitrogen loads can increase by 34% as build-out is reached, however, as management options are clearly defined and implemented a high degree of certainty for restoration can be attained so long as potential future sources of load are appropriately factored into the nutrient analysis for the watershed and the harbor.

The Town of Bourne, as the primary stakeholder to the Phinneys Harbor embayment system, has been concerned over the resource quality of this significant coastal resource. The community has worked to implement controls on direct stormwater discharges and the Town of Bourne Task Force on Local Pollution has focused on this and other Town embayments for protection and restoration. In addition, the Town of Bourne has supported the Coalition for Buzzards Bay's Water Quality Monitoring Program which has been collecting data on nitrogen related water quality within the Phinneys Harbor System since 1992. The Coalition's BayWatcher Program has collected the principal baseline water quality data necessary for ecological management of Bourne's embayments and harbors. The BayWatchers is a citizen-based water quality monitoring program run by the Coalition for Buzzards Bay (T. Williams, Project Coordination) with technical and analytical assistance from the Coastal Systems Program at SMAST-UMD.

The common focus of the Coalition for Buzzards Bay BayWatcher Water Quality Monitoring Program effort has been to gather site-specific data on the current nitrogen related water quality throughout all the embayments tributary to Buzzards Bay and determine the relationship between observed water quality and habitat health. This multi-year effort was initiated in 1992, with significant support from the Buzzards Bay Project. The BayWatcher Water Quality Monitoring Program in Phinneys Harbor developed a data set that elucidated the long-term water quality of this system. Additionally, as remediation plans for various systems are implemented, the continued monitoring will help satisfy monitoring requirements by State regulatory agencies and provide quantitative information to the Town relative to the efficacy of remediation efforts. The MEP effort builds upon the Coalition for Buzzards Bay water quality monitoring program, and previous hydrodynamic and water quality analyses conducted by Applied Coastal Research and Engineering and SMAST, and includes high order biogeochemical analyses and water quality modeling necessary to develop critical nitrogen targets for the Phinneys Harbor embayment system, and its major sub-embayments (Back River and Eel Pond).

In conjunction with other Town efforts, the Town of Bourne's Planning Office continues to enhance its tools for gauging future nutrient effects from changing land-uses. The GIS database used in the present MEP evaluation is part of that continuing effort. Based on the wealth of information obtained over the many years of study of the Phinneys Harbor System, particularly as relates to the Town Landfill, the Eel Pond and Back River portions of the Phinneys Harbor embayment system were included in the first round prioritization of the Massachusetts Estuaries Project to provide state-of-the-art analysis and modeling. This effort was undertaken as a partnership with the Town Department and Landfill staff. In the interest of maximizing efficiency and rigor of the nutrient analysis for Eel Pond and Back River, it was decided to add Phinneys Harbor in order to complete the overall analysis, even though Phinneys Harbor entered the Massachusetts Estuaries Project in Round 4 of embayment prioritizations. Additionally, given that the MEP was able to fully integrate the Towns' on-going data collection and modeling efforts, minimal additional municipal funds were required for MEP tasks.

The 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 Town of Bourne. 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 Town Bourne to develop and evaluate the most cost effective nitrogen management alternatives to restore the Town's valuable coastal resources 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 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 Bourne) 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 newest 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 MASSDEP 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 implementation plan. That plan must identify, among other things, the required activities to achieve the allowable load to meet the allowable loading target, the time line for those activities to take place, and reasonable assurances that the actions will be taken.

In appropriate estuaries, TMDLs 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:

- 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 model available to address future regulatory 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 ca. 20 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 suggests "solutions" for the protection or restoration of nutrient related water quality and allows testing of "what if" management scenarios to support evaluation of resulting water quality impact versus cost (i.e., "biggest ecological bang for the buck"). In addition, once a model is fully functional it can be "kept alive" and corrected 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

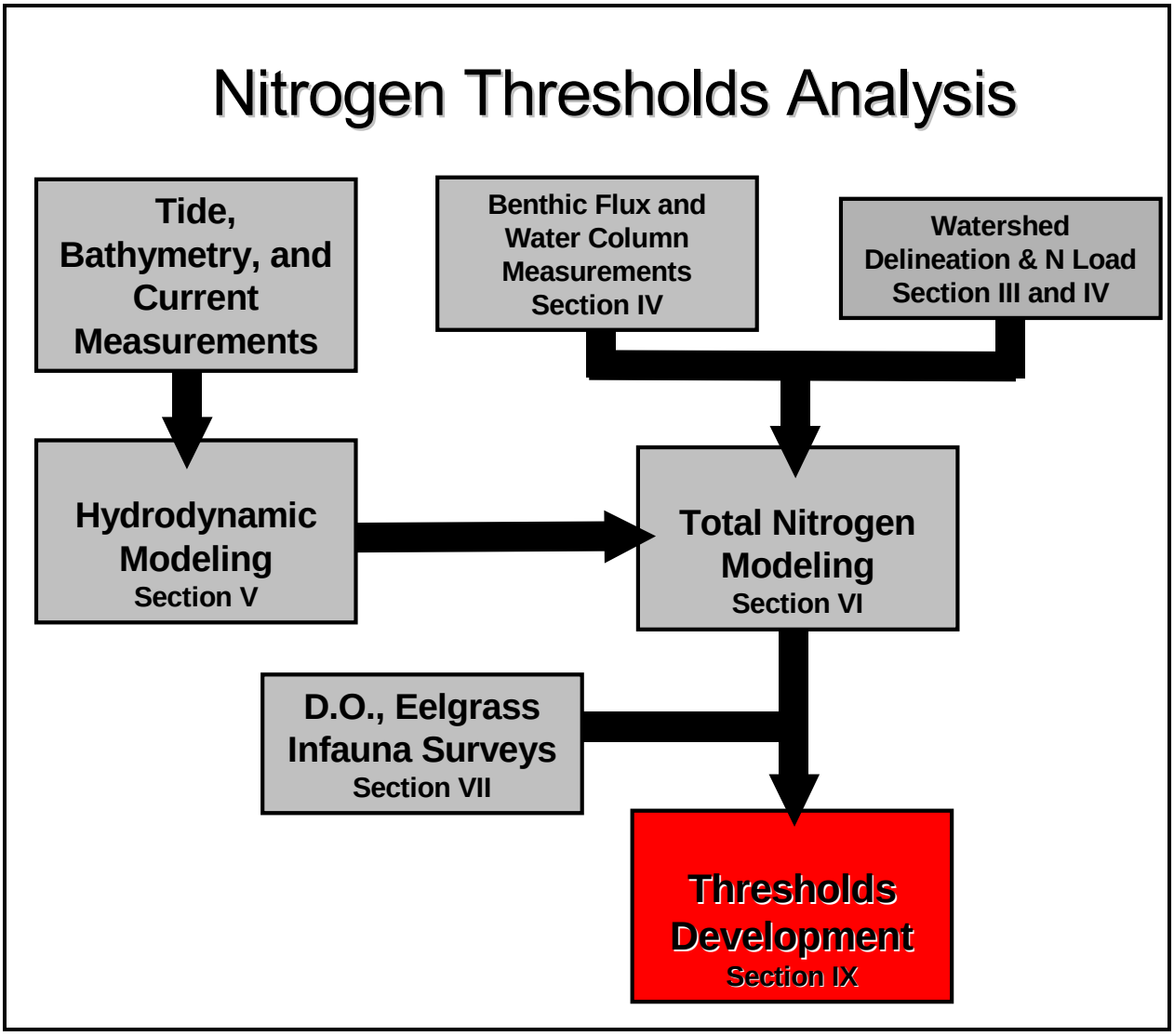

Figure I-2. Massachusetts Estuaries Project Critical Nutrient Threshold Analytical Approach. Section numbers refer to sections in this MEP report where the specified information is provided.

I.2 SITE DESCRIPTION

The coastal salt ponds of Cape Cod tributary to Buzzards Bay tend to be lagoonal estuaries with basins running parallel to the barrier beach and inner tributary basins comprised of salt marsh or drowned kettle basin (e.g. West Falmouth Harbor). The Phinneys Harbor Estuary is a moderately complex estuary formed primarily as an artificial lagoon. Phinneys Harbor, formed by the creation of artificial barrier beaches (causeways) from the upland to Mashnee Island (north) and to Toby Island (south). The inner basins are typical of other complex sub-estuaries in the region containing both a major salt marsh creek system (Back River) and a drowned kettle pond (Eel Pond). While the configuration of the outer basin is only ~75 years old, the inner sub-systems were formed by post-glacial processes and rising sea-levels. The Back River and Eel Pond basins are situated within the Buzzards Bay terminal moraine deposited after the retreat of the Buzzards Bay Lobe of the Laurentide Ice sheet and consisting of glacial till, as opposed to the sandy outwash deposits typical of the eastern shore of Buzzards Bay. As post-glacial sea-level rose, Buzzards Bay and then the Back River/Eel Pond basins became marine systems. The entire Phinneys Harbor Estuary is a relatively recent formation, first requiring inundation with marine waters (4,500-3,000 years B.P.).

The watershed to Phinneys Harbor is somewhat geologically complex, being composed primarily of Buzzards Bay Plain glacial deposits near the coast, glacial moraine deposits, the Buzzards Bay Glacial Moraine (inland) and Mashpee Outwash Plain deposits in the uppermost regions of the watershed. These formations consist of material deposited after the retreat of the Cape Cod Lobe of the Laurentide Ice sheet ~18,000 years ago. The material is highly permeable and as such, direct rainwater run-off is typically rather low for this type of coastal system. Therefore, most freshwater inflow to the estuarine system is via groundwater discharge or groundwater fed surface water flow.

At present, Phinneys Harbor is a tidal embayment with a small groundwater fed stream originating in shallow Mill Pond (upgradient of County Road) and discharging to the headwaters of Back River sub-estuary. Almost all of the 85 acres of salt marsh in the Phinneys Harbor System is held within the Back River estuarine reach. The other inner tributary sub-embayment, Eel Pond, is a very different functional unit than the wetland dominated Back River. Eel Pond is a drowned kettle pond which is connected to Back River through a narrow tidal channel. Eel Pond receives relatively low amounts of freshwater inflow (Chapter III) and maintains a salinity greater than 27 ppt compared to ~29 ppt within the outer Harbor. However, it appears Eel Pond may infrequently stratify due to its geomorphology, thus increasing its sensitivity to nitrogen enrichment. Phinneys Harbor acts as a mixing zone for terrestrial freshwater inflow and saline tidal flow from Buzzards Bay, however, the salinity characteristics of the system varies with the volume of freshwater inflow as well as the effectiveness of tidal exchange with Buzzards Bay. Overall, the small freshwater contributing area and large tide range result in a relatively high salinity (>27ppt) throughout much of the Phinneys Harbor System.

The inlet between Rocky Point and Phinneys Point provided shallow access to Back River and Eel Pond from what was historically open water Buzzards Bay. Prior to the formation of Phinneys Harbor, coastal processes associated with the spit (Rocky Point) is likely to have periodically restricted tidal flow to Back River/Eel Pond. At present, neither the inlet to Phinneys Harbor nor to Back River are fixed by jetties. However, the channel into the Back River marshes is currently structured by the western Railroad Bridge, constructed in the late 1800's. The adjacent bridge to the east for Shore Road was constructed more recently with a wider span than the railroad bridge.

The habitat quality of the Phinneys Harbor System is linked to the level of tidal flushing through its inlet to Buzzards Bay, which exhibits a moderate tide range of about 5 ft. Since the water elevation difference between the Bay and Harbor 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). The inlets to Phinneys Harbor and to Back River are not presently armored with jetties.

Like the Estuary itself, the watershed areas contributing nitrogen to the harbor are distributed fully within the Town of Bourne, although a small portion of inland forested watershed is within the Town of Sandwich/Massachusetts Military Reservation (MMR). The Phinneys Harbor System is one of the Town of Bourne's significant marine resources. At a time when many other coastal ponds and bays in the Town have been degraded, water quality in this estuary has until recently remained fairly high, as pockets of eelgrass in the 1990's demonstrate. However, the Phinneys Harbor System has been undergoing degradation of its resources over the past decades as a result of nutrient overloading from its watershed, primarily resulting from residential development.

Phinneys Harbor is a shallow mesotrophic (moderately nutrient impacted) coastal estuarine system on the eastern shore of Buzzards Bay. For the MEP analysis, the Phinneys Harbor System was analyzed individually as a stand-alone system. Similar to other embayments on Cape Cod (e.g. West Falmouth Harbor) Phinneys Harbor is an estuary with focused freshwater input at the headwaters of the Back River sub-embayment and tidal exchange of marine waters from Buzzards Bay (tide range of approximately 1.5 m) at the mouth. The Phinneys Harbor estuarine system was partitioned into several regions: 1) the main basin commonly considered Phinneys Harbor, 2) outer Back River near the mouth, 3) inner Back River which receives a freshwater stream discharge from an upgradient bog/Mill Pond, 4) Eel Pond (see Figure I-1). Phinneys Harbor and its associated sub-embayments is a true estuary, acting as the mixing zone of terrestrial freshwater inflow and saline tidal waters from Buzzards Bay. Salinity in the harbor ranges from approximately 30 ppt at the Buzzards Bay inlet to less than 10 ppt at the uppermost end of the Back River estuarine reach. However, salinities throughout all of the basins is generally >27 ppt..

Given the present hydrodynamic characteristics of the Phinneys Harbor embayment system, it appears that estuarine habitat quality is mostly dependent on the level of nutrient loading to embayment waters as opposed to tidal characteristics. In Phinneys Harbor, minimal enhancements to tidal flushing may be achieved via inlet or channel modification to Back River thereby resulting in some mediation of the nutrient loading impacts from the watershed. The details of such are a part of the MEP analysis described later in this report.

Nitrogen loading to the Phinneys Harbor embayment system was determined relative to the regions of the estuary as depicted in Figure I-1. Based upon land-use and the watershed being primarily within Bourne, it appears that nitrogen management for harbor restoration may likely be more rapidly developed and implemented than otherwise. As management alternatives are being developed and evaluated, it is important to note the ecological differences of the 3 major basins comprising the Estuary. The Back River sub-estuary currently functions primarily as a tidal salt marsh system, which has a high tolerance for nitrogen inputs. In contrast, the drowned kettle pond, Eel Pond, is narrow, relatively deep and has a narrow outlet channel, geomorphological characteristics frequently underlying a sensitivity to nitrogen loading. Finally, the deep, generally well flushed outer basin functions as an extension of the estuary, exchanging tidal waters with Buzzards Bay. These physical and ecological characteristics interact with tidal flushing and watershed nitrogen loading to define the nutrient characteristics

of the Harbor and the associated habitat impacts. There is a gradient in nitrogen level and health moving from Eel Pond through the Phinneys Harbor basin, with highest nitrogen and lowest environmental health in the terminal areas of the system and lowest nitrogen and greatest health near the inlet to Buzzards Bay. The Eel Pond basin is presently showing moderate to poor water quality and "Mesotrophic" conditions. While Phinneys Harbor generally has high to moderate water quality, the Back River Estuary appears to support healthy tidal salt marshes. Eelgrass is currently absent from the whole of the Phinneys Harbor System. A relatively high level of water clarity will be needed to restore eelgrass to the Phinneys Harbor basin, due to its water depth.

I.3 NITROGEN 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 Phinneys Harbor embayment system, phosphorus is highly retained during groundwater transport as a result of sorption to aquifer mineral (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 Phinneys Harbor system follow this general pattern, where the primary nutrient of eutrophication in these systems is nitrogen.

Nutrient related water quality decline represents one of the most serious threats to the ecological health of the nearshore coastal waters. Coastal embayments, because of their enclosed basins, shallow waters and large shoreline area, are generally the first indicators of nutrient pollution from terrestrial sources. By nature, these systems are highly productive environments, but nutrient over-enrichment of these systems worldwide is resulting in the loss of their aesthetic, economic and commercially valuable attributes.

Each embayment system maintains a capacity to assimilate watershed nitrogen inputs without degradation. However, as loading increases a point is reached at which the capacity (termed assimilative capacity) is exceeded and nutrient related water quality degradation occurs. As 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 Phinneys Harbor system monitored by the Coalition for Buzzards Bay BayWatchers 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, within the Phinneys Harbor Estuary, the Eel Pond and Phinneys Harbor basins appear to be beyond their respective abilities to assimilate additional nutrients without impacting ecological health. Nitrogen levels are elevated throughout the system and eelgrass beds only remain on the outer edges of the outer portion of Phinneys Harbor (i.e. outside of the Estuary). 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, it is considered "cultural eutrophication". Although the influence of human-induced changes has increased nitrogen loading to the system and contributed to the degradation in ecological health, it is sometimes possible that eutrophication within a given embayment system 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" for water quality modeling of the Phinneys Harbor System; however, a thorough understanding of estuarine circulation is required to accurately determine nitrogen concentrations within 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 Phinneys Harbor System and each of its basins: Eel Pond, Back River, and Phinneys Harbor. A two-dimensional depth-averaged hydrodynamic model based upon the tidal currents and water elevations was employed for the system. Once the hydrodynamic properties of the estuarine system were computed, two-dimensional water quality model simulations were used to predict the dispersion of the nitrogen at current loading rates.

Using standard dispersion relationships for estuarine systems of this type, the water quality model and the hydrodynamic 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. Virtually all nitrogen entering Bourne's embayment systems is transported by freshwater, predominantly groundwater, either through direct discharge or after discharging to a stream flowing to estuarine waters. Concentrations of total nitrogen and salinity of Buzzards Bay source waters and throughout the Phinneys Harbor system was taken from the Coalition for Buzzards Bay BayWatchers Monitoring Program (associated with the Coastal Systems Program at SMAST) and from previous sampling of Buzzards Bay nearshore waters by MEP staff. Measurements of 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 Phinneys Harbor Estuarine System (Phinneys Harbor, Eel Pond and Back River) for the Town of Bourne. 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 Buzzards Bay (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 each embayment was performed that included a review of existing water quality information, temporal changes in eelgrass distribution, dissolved oxygen records and the results of a benthic infaunal animal analysis (Section VII). The modeling and assessment information is synthesized and nitrogen threshold levels developed for restoration of each embayment 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 in a given estuarine basin. 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 the Phinneys Harbor System. Finally, analyses of the Phinneys Harbor 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 in Eel Pond and Back River. The results of the nitrogen modeling for each scenario have been presented (Section IX).