II. PREVIOUS STUDIES RELATED TO NITROGEN MANAGEMENT

Nutrient additions to aquatic systems cause shifts in a series of biological processes that can result in impaired nutrient related habitat quality. Effects include excessive plankton and macrophyte growth which in turn leads to: 1) reduced water clarity, 2) organic matter enrichment of waters and sediments, 3) concomitant increased rates of oxygen consumption and periodic depletion of dissolved oxygen, especially in bottom waters, and 4) the limitation of the growth of desirable species such as eelgrass. Even without changes to water clarity and bottom water dissolved oxygen, the increased organic matter deposition to the sediments generally results in a decline in habitat quality for benthic infaunal communities (animals living in the sediments). This habitat change causes a shift in infaunal communities from high diversity deep burrowing forms (which include economically important species), to low diversity shallow dwelling organisms. This shift alone causes significant degradation of the marine resource and a loss of productivity to both the local shellfisherman and to the sport-fishery and offshore finfishery. A viable and sustainable coastal fishery is dependant upon these highly productive estuarine systems as a habitat and food resource during migration or during different life cycle phases. The degenerative process sketched above is generally termed “eutrophication” and in embayment systems, unlike in shallow lakes and pond, it is not necessarily a part of the natural evolution of a system.

In most marine and estuarine systems, such as West Falmouth Harbor, the limiting nutrient, and thus the nutrient of primary concern, is nitrogen. In large part, if nitrogen addition is controlled, then eutrophication is controlled. This approach has been formalized through the development of tools for predicting nitrogen loads from watersheds and the concentrations of water column nitrogen that may result. Additional development of the approach generated specific guidelines as to what is to be considered acceptable water column nitrogen concentrations to achieve desired water quality goals (e.g., see Cape Cod Commission 1991, 1998; Howes et al. 2002).

These tools for predicting loads and concentrations tend to be generic in nature, and overlook some of the specifics for any given water body. The present Massachusetts Estuaries Project (MEP) study focuses on linking water quality model predictions, based upon watershed nitrogen loading and embayment recycling and system hydrodynamics, to actual measured values for specific nutrient species. The linked watershed-embayment model is built using embayment specific measurements, thus enabling calibration of the prediction process for specific conditions in each of the coastal embayments of southeastern Massachusetts, including the West Falmouth Harbor System. As the MEP approach requires substantial amounts of site specific data collection, part of the program is to review previous data collection and modeling efforts. These reviews are both for purposes of “data mining” and to gather additional information on an estuary’s habitat quality and unique features.

To this end, there are a number of studies that relate to the nutrient related health of West Falmouth Harbor. The Town of Falmouth was one of the first communities to become concerned over the perceived degradation of its estuaries. The Town of Falmouth (via the Planning Office) has long recognized the potential threat of nutrient over-enrichment of its coastal salt ponds and embayments. In the mid-1980's the Town enacted an innovative Nutrient Overlay By-law that tied watershed development to water quality within the adjacent embayment. Nutrient limits were set for nitrogen in each of the Town’s embayments. The goal was to keep nitrogen concentrations in the receiving systems below thresholds that were projected to cause water quality shifts, much like the approach of MEP and the associated

TMDL process. To acquire baseline water quality data necessary for ecological management of Falmouth's coastal salt ponds and harbors, a citizen-based water quality monitoring program was initiated by the Town of Falmouth. Falmouth PondWatch, was established in 1987 to provide on-going nutrient related embayment health information in support of the By-law. The water quality monitoring program was based on a collaborative effort between scientists, citizens and representatives of the Town of Falmouth. In 1992, PondWatch partnered with the Coalition for Buzzards Bay's BayWatcher Program to collect nutrient related water quality data throughout the West Falmouth Harbor System. The partnership between the two water quality monitoring programs enabled the evaluation of the estuarine effects of the nutrient enriched wastewater plume generated by the Falmouth Wastewater Treatment Facility and continuing watershed build-out.

The Falmouth PondWatch Program, as the water quality monitoring effort came to be known, continues to play an active role in the collection of baseline water quality data to this day. Over time, however, it has evolved beyond its original mandate of providing basic environmental data relative to the Coastal Pond Overlay Bylaw (Nutrient Bylaw). The Pond Watch Program brings together, as requested by Town boards, ecological information relative to specific water quality issues. Additionally, as remediation plans for various systems are implemented, the continued monitoring satisfies demands by State regulatory agencies and provides quantitative information to the Town relative to the efficacy of remediation efforts. This multi-year effort has also provided the baseline information required for determining the link between upland loading, tidal flushing, and estuarine water quality. The PondWatch Program in West Falmouth Harbor has elucidated the long-term trend of declining water quality and its relation to watershed based nutrient loading (see Chapter VII).

Numerous studies relating to nitrogen loading, hydrodynamics and habitat health have been conducted within the West Falmouth Harbor System over the past 10 years. In the late 1980's and early 1990's local concern over the health of the sub-embayments to West Falmouth Harbor (particularly in the upper reaches) focused future impacts of Town of Falmouth activities within the watershed. Future impacts ranged from activities such as the siting of the West Falmouth WWTF and the opening of the Falmouth Technology Park. Field measurements by the Falmouth PondWatch and Coalition for Buzzards Bay's BayWatchers in the mid/late 1990's indicted that the greater issue of habitat degradation from nitrogen enrichment was occurring, particularly in the region of Snug Harbor.

Initial studies to predict changes in embayment health related to increasing watershed nitrogen loads and indicated that harbor resources would be degraded at levels of nitrogen loading that are now entering the estuary. Habitat decline would result primarily from nitrogen inputs from the WWTF, continuing development within the watershed, and entry of the Landfill plume. Nitrogen management particularly for the inner Harbor was recommended as development continued. The authors stated that major water quality declines were not expected to result as long as there were no major additional sources of nitrogen added to the Harbor over the existing development pattern and the 1993 WWTF discharges (Ramsey et al. 1995). The initial and subsequent studies revealed that the Falmouth WWTF nitrogen loading was the single major nitrogen source to the estuary. Furthermore the WWTF loading was not constant but was increasing significantly since the beginning of effluent discharge in October 1986 (Costa 1996, Eichner et al. 1998, Smith 1999). Unfortunately loading increased far beyond 1993 levels, and habitat degradation has subsequently been documented throughout the inner harbor basins.

The concern about nutrient related habitat declines resulted in a nitrogen loading and flushing analysis by the Cape Cod Commission (CCC) under the Cape Cod Coastal Embayment Project (Eichner et al. 1998). In that study the major sub-watersheds to the West Falmouth Harbor System were delineated based upon available water table measurements. A land-use nitrogen loading model was implemented to determine nitrogen inputs to bay waters and a numerical hydrodynamic model was used to evaluate flushing rates of the estuary's sub-basins. The CCC study synthesized the available habitat health, water quality and hydrodynamic information in the context of projecting future resource quality. The analysis revealed that some of the inner basins were currently impaired and as the WWTF approached its capacity of 880,000 gpd (it was at 447,000 in the study), nitrogen loads would cause degradation of the inner harbor basins. Watershed buildout would further exacerbate the habitat decline. While the analysis did not use a water quality model to project a nitrogen loading threshold, the overall conclusions appear to have been qualitatively correct (see Chapter VII).

The CCC study supported earlier analyses indicating that the WWTF was the single largest source of nitrogen to West Falmouth Harbor waters with on-site septic disposal of wastewater being second. In addition, the Harbor's watershed includes a variety of other nutrient sources, among them the Town's landfill, old septage lagoons, composting installations, runoff from roads and lawns, as well as the Town's industrial park. While the overall results of the CCC study have held true, the analysis is insufficient to simulate changes in nitrogen within the estuary under different management alternatives. In addition, as the landuse model did not account for nitrogen attenuation by the wetland ecosystems (no data available at the time), it over estimated the role of nitrogen sources in upper (inland most) sub-watersheds compared to the direct groundwater watersheds to the estuary. While base data from this earlier study was incorporated by the MEP, direct use of the modeling results was problematic. Since the landuse model was based upon the 1996 watershed delineations from well data, rather than the MEP's USGS West Cape Model (see Chapter III), the contributing areas are slightly different. Due to the difference in watershed areas and the MEP's update and refinements to the watershed nitrogen loading model (e.g. to incorporate attenuation and new nitrogen source information), the results from the MEP are different and supercede the earlier studies.

Given the significance of the WWTF nitrogen load to the embayment health (accounts for ~70% of total N load), studies have been undertaken to determine the attenuation of WWTF nitrogen by activities at the facility (Jordan et al., 1997) and by the down-gradient salt marsh (Smith, 1999). The original WWTF was designed to reduce its nitrogen load to the Harbor by incorporating spray irrigation of vegetation, whereby nutrients would be denitrified or absorbed by growing plants. However, this system has been only partially effective. In the initial study, nitrogen uptake by the spray irrigation system was important to the nitrogen balance in the first year of discharge, but diminished significantly in the second year. More recent data by MEP indicates that attenuation declined further and has remained low (see Chapter IV). The nitrogen-rich plume created by this source has entered the groundwater in the northeast section of the watershed and is currently discharging to the Snug Harbor/Mashapaquit Creek sub-estuary. However, the Mashapaquit Marsh creek bottom provides a significant attenuation of nitrogen during transport to the embayment waters of Snug Harbor. Attenuation of nitrogen from the WWTF plume and other watershed sources was determined through a variety of techniques, including tidal mass balance, watershed modeling, direct measures of freshwater inflow, and incubations of creek bottom sediments (Smith 1999, Smith and Howes Unpublished, Hamersley and Howes, 2003). All of the approaches support an annualized nitrogen attenuation of ~40% for watershed nitrogen transiting this salt marsh.

Most recently a habitat assessment and nitrogen thresholds analysis was conducted by DEP and SMAST relative to the upgrade of the West Falmouth WWTF (Howes et al. 2000). This analysis concluded that the data indicate a system in which nitrogen levels are rising, the frequency and magnitude of bottom water oxygen depletion is increasing, and biotic communities (eelgrass and benthic animals) are declining and being replaced by stress-tolerant species. This is the classical example of the response of shallow embayments to nutrient over-enrichment. In addition, the ecological shifts appear to have taken place relatively rapidly, apparently coinciding with the entry of a new significant nitrogen load from the WWTF plume.

The DEP/SMAST study further indicated that "the mass of nitrogen discharged by the WWTF has been increasing since its start-up in October 1986. From 1991-92 to 1996-98 alone, nitrogen loading to the watershed from WWTF effluent discharge nearly doubled. The increasing mass of nitrogen discharged from the WWTF results from increased use of the Facility for septage, additional hook-ups within sewered areas, and increased occupancy. This rising rate of loading from the WWTF is much higher than from continued development within the West Falmouth Harbor watershed for the same interval. While all sources of nitrogen contribute to fertilization of the Harbor, the WWTF clearly presents the largest source and is increasing at the highest rate. The study further underscored the difficulty in assessing West Falmouth Harbor watershed-embayment relationships, since the nitrogen load from the WWTF has a significant time-delay from discharge to entry into the Harbor System. The time lag results from vertical and groundwater flow times of ca. 6 years, based on the travel times predicted by the West Cape Model. The 6-year lag time between discharge at the WWTF and entry to the Harbor waters is a critical part of the nitrogen issue for West Falmouth Harbor. This time lag means that even if the discharges were to have ceased in 2000, total nitrogen loading to the entire Harbor would continue to increase by ca. 50% over 1998 levels by the year 2004.

Two of the key recommendations of the DEP/SMAST study were:

- A nitrogen threshold of 0.35 (to possibly 0.37) mg N L^{-1} within the waters of the inner Harbor basins (South Basin and Snug Harbor) should support the recovery of eelgrass and associated animal and plant communities throughout West Falmouth Harbor's sub-tidal basins.

- Land-disposal of WWTF Effluent should maximize discharge to the Mashapaquit Creek Marsh. Large areas of forested land are located just north of the existing WWTF infiltration beds. Ratios of DIN to Na in groundwater under the existing vegetated spray irrigation areas seem to indicate that the vegetation acts as a sink for effluent nitrogen. In addition, these unused areas are within the subwatershed to Mashapaquit Creek Marsh, which has been shown to remove 40 to 50% of watershed nitrogen.

All of the above efforts were part of the decision to upgrade the West Falmouth WWTF to include nitrogen removal and sewering of portions of the watershed. These decisions are further evaluated in the MEP synthesis and modeling in the following chapters using the Linked Watershed-Embayment Modeling Approach (Chapters VI, VII). In addition, the nitrogen loading threshold for the estuary is refined based upon the additional data from the MEP effort.

The PondWatch effort provided the quantitative watercolumn nitrogen data (1992-2004) required for the implementation of the MEP's Linked Watershed-Embayment Approach. The MEP effort also builds upon the previous hydrodynamic and water quality analyses, and includes high order biogeochemical analyses and water quality modeling necessary to develop critical nitrogen targets for the West Falmouth Harbor embayment system. The MEP has incorporated all appropriate data from all previous studies to enhance the determination of nitrogen thresholds for the West Falmouth Harbor System and to reduce costs to the Town of Falmouth.