II. PREVIOUS STUDIES RELATED TO NITROGEN MANAGEMENT

In most marine and estuarine systems, such as the Great, Green, and Bournes Pond embayment systems in Falmouth, 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 eutrophication management approach via the reduction of nitrogen loads 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).

Until recently, these tools for predicting loads and concentrations tended 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 Great, Green, and Bournes Pond Systems.

The Town of Falmouth, Massachusetts, 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. The goal was to keep nitrogen concentrations in the receiving systems below thresholds that were projected to cause water quality shifts. A water quality monitoring program, Falmouth Pondwatch, was established to provide on-going nutrient related embayment health information in support of the By-law. These approaches were primarily initiated for planning as development within coastal watersheds progressed. Falmouth's Planning Department has continued to enhance its tools for gauging future nutrient effects from changing land-uses. The GIS database used in the present study is part of that continuing effort. Unfortunately, monitoring has documented that most regions within the Town's coastal ponds are currently showing water quality declines and are beyond the limits set by the By-law.

The Falmouth Pondwatch data was utilized to assess the overall nutrient related health of Falmouth's "finger ponds" (Little, Great, Green, and Bournes Ponds), where Howes and Goehringer,1996 concluded that increasing nutrient loading was resulting in "periodic dense algal blooms, malodorous conditions, and occasional fish kills from nutrient-related oxygen depletion in bottom waters." Based on this analysis, in 1994 the Massachusetts Highways Department hired Aubrey Consulting to evaluate potential water circulation improvements to the Menauhant Road causeway across Green Pond. A one-dimensional hydrodynamic analysis and an evaluation of culverts was performed (Aubrey Consulting, 1995). This study concluded that improved circulation would result along the regions immediately adjacent to the causeway if culverts were installed. The Massachusetts Highways Department included the culverts in their design effort for the bridge and the culverts were installed in 1996.

More recently, an additional source of nitrogen to three of the salt ponds on the south shore has been cause for concern. A plume of nitrogen rich groundwater was discovered approaching Green Pond and possibly Great Pond and Bournes Pond. The plume emanated from the Massachusetts Military Reservation's wastewater treatment facility which discharged

secondarily treated effluent to rapid infiltration beds near the southeastern corner of MMR from 1936 through 1995. Although a new facility has come on-line which now discharges to Cape Cod Canal waters, decades of nitrogen discharge is still moving through groundwater towards Falmouth's coastal ponds. Since the plume (Ashumet Valley Wastewater Plume) would ultimately be discharging to already nitrogen-overloaded ecosystems, nitrogen remediation of plume waters was considered. Since the Ashumet Valley wastewater plume contains a large volume of contaminated water but at relatively low nitrogen levels, nitrogen removal is technically difficult and inefficient.

After evaluation of the plume remediation possibilities, an agreement was reached between MMR/AFCEE and the Town of Falmouth for management of nitrogen loading to the three salt ponds (Great, Green and Bournes Ponds) which could potentially receive plume nitrogen upon discharge. An innovative approach was developed whereby the Department of Defense would grant funding to the Town for nitrogen reduction, not of the Ashumet Valley Plume, but of other more readily addressed sources within the pond watersheds. Since all nitrogen inputs to the embayments impact ecological health regardless of the source, focusing on the more readily treatable sources (septic systems, fertilizers etc) should allow for a higher level and more rapid reduction in total nitrogen loading than merely treating the Ashumet Valley Plume. The Nitrogen Offset Program was established with $8.5 million for nitrogen source reductions within the watersheds of the three salt ponds potentially receiving MMR wastewater nitrogen through the Ashumet Valley Plume.

A major component of the MEP nutrient analysis is the evaluation of watershed based nutrient loading and hydrodynamics within the estuarine system. A watershed based nutrient loading model and a two-dimensional hydrodynamic and water quality model was previously developed in 2000 as part of a nutrient and hydrodynamic study of Great, Green, and Bournes Ponds. The study was undertaken as a collaboration between Applied Coastal Research and Engineering, Inc. and the then Center for Marine Science and Technology, University of Massachusetts at Dartmouth. The study was developed to include a detailed summary of the nutrient related water quality studies performed for the Town of Falmouth Nitrogen Offset Program and Horsley & Witten Inc. The nutrient and hydrodynamic study undertaken in 2000 was comprised of several tasks: Task 1 focused on evaluating the distribution and loading intensity of the various nitrogen sources within the watersheds of Great, Green and Bournes Ponds. Task 2 described the results of pond flushing studies and detailed the hydrodynamic modeling which formed the basis for the water quality modeling presented in Task 3 of the report. The results of the water quality modeling (Task 3) indicated which land areas and sources played the greatest role in the nitrogen degradation of these salt ponds.

Previous nitrogen loading analysis to Great, Green, and Bournes Ponds was undertaken under task 1 of the 2000 study. While the results of the watershed N loading analysis are primarily for parameterizing the embayment water quality model (Task 3), the analysis revealed several important factors relating to N sources and potential remediation. The analysis had 5 major findings relating to the N-Offset Program goals of nitrogen management for restoration of Great, Green and Bournes Ponds:

- Septic systems are the major single source of nitrogen to each of the salt ponds.
- The Ashumet Valley Wastewater Plume will only discharge to Great and Green Ponds. This plume will increase the N loading from the upper watershed over current conditions by 5% and 10%, for Great and Green Ponds, respectively. However, it will only increase the total N loading (upper and lower watersheds) to these salt ponds by 2% and 3%, for Great and Green Ponds, respectively.

- At maximum build-out and full discharge of the Ashumet Valley Wastewater Plume, total nitrogen loads from their watersheds are projected to increase over current conditions by 16% for Great Pond, 13% for Green Pond and 21% for Bournes Pond.
- Nitrogen loading from the lower watersheds accounts for most of the total N load to Great Pond-59%, Green Pond-70% and Bournes Pond-79%.

Since most of the nitrogen loading was found to be concentrated in the lower portions of the watersheds, which have little natural attenuation of nitrogen during transport to the salt ponds, engineered nitrogen remediation efforts should focus on these areas.

The previous study of Great, Green, and Bournes Ponds utilized a state-of-the-art computer model to evaluate tidal circulation and flushing. The particular model employed was the RMA-2V model developed by Resource Management Associates for the U.S. Army Corps of Engineers. It is a two-dimensional depth averaged model that solves momentum and flow continuity equations over several tidal cycles. The model is widely accepted and tested for analyses of estuaries or rivers. Prior to the use of the model in Great, Green, and Bournes Pond, Applied Coastal staff members had utilized RMA-2V for numerous flushing studies on Cape Cod, including West Falmouth Harbor, Popponesset Bay, and the Pleasant Bay estuary.

The hydrodynamic modeling undertaken as task 2 produced information on the flushing characteristics throughout Great, Green and Bournes Ponds. The major hydrodynamic findings from task 2 of the historical hydrodynamic and water quality study for Great, Green, and Bournes Pond indicate:

- All of the ponds studied may be considered rapidly flushing systems, based upon their measured residence times.
- The relatively low residence time of upper Bournes Pond in comparison to upper Great Pond and upper Green Pond is due to natural water depth.
- Tides propagate from Vineyard Sound into each estuary, with little attenuation or amplitude damping and tides in all three ponds have flood-dominant characteristics.
- The greatest tide attenuation occurs in Bournes Pond. The restricted inlet causes a tide lag of approximately one-hour.
- Tide attenuation through Great Pond inlet and Green Pond inlet were negligible suggesting that improvements to these inlets will have a negligible impact on estuarine water quality.

The water quality modeling undertaken as task 3 produced information on the nutrient/habitat characteristics throughout Great, Green and Bournes Ponds. The upper reaches of each of the Great, Green and Bournes Ponds are currently showing poor nutrient related water quality as a result of nitrogen loading from the upper and lower watersheds. While the lower portions of each pond support at least moderate quality waters, only lower Bournes Pond exhibits a good level of environmental quality. The severely degraded environmental health of the upper portions of each of the Ponds is manifested in high chlorophyll a levels (>10 μg/L and typically >20 μg/L), periodic oxygen depletions to less than 4 mg/L, low water column transparency, and high nitrogen concentrations (>0.7 mg N/L). The nutrient overloaded nature of these systems is consistent with (a) the loss of eelgrass, (b) periodic fish kills due to oxygen depletion, and (c) periodic appearance of macro-algae. Each of the three ponds have total nitrogen concentrations above the levels set by the Falmouth Nutrient Overlay By-law. Since each of these coastal ponds show signs of degraded water quality, steps should be taken to limit additional nitrogen loading

For the MEP modeling analysis, the data from the previous studies were evaluated relative to the needs of the Linked Watershed-Embayment Model. Since the previous Applied Coastal and SMAST work on Great, Green, and Bournes Ponds utilized a similar modeling approach to the Linked Watershed-Embayment Model, much of the data incorporated into this previous analysis is useful for the updated MEP effort. Specifically, the tide and bathymetry data, as well as the hydrodynamic RMA-2V model, remain valid for the updated analysis. In addition, much of the Falmouth Pondwatch nutrient and salinity data has been incorporated into the water quality calibration and verification effort. Although benthic regeneration was evaluated as part of the original SMAST/Applied Coastal study of Great, Green, and Bournes Ponds, a more thorough analysis of this nitrogen loading component was required for the evaluation contained in this report. In addition, the previous watershed loading analysis has been superceded, due to recent improvements to the watershed delineations and the GIS-based land use evaluation.