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 that lead to reduced water clarity, organic matter enrichment of waters and sediments and concomitant increases in rates of oxygen consumption. Periodic depletion of dissolved oxygen, especially in bottom waters, and the limitation of the growth of desirable species such as eelgrass ultimately result from these assaults on the aquatic system. 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 resource and a loss of productivity to both the local shell fisherman and to the sport-fishery and offshore fin-fishery, both of which are dependant upon these highly productive estuarine systems as habitat and a food resource during migration or different phases of organism life cycles. This process 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 Waquoit Bay and its associated tributary sub-embayments (Quashnet River, Hamblin Pond, and Jehu Pond) that are the focus of this nutrient threshold analysis, 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).

Many of the previously developed tools for predicting loads and concentrations tend to be generic in nature, and overlook some of the specific characteristics of a 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, thereby enabling calibration of the prediction process for specific conditions in each of the coastal embayments of southeastern Massachusetts, including the eastern sub-embayments to the Waquoit Bay (Quashnet River, Hamblin Pond, and Jehu Pond Estuaries).

The eastern tributary sub-embayments to Waquoit Bay are part of the Waquoit Bay National Estuarine Research Reserve (WBNERR). The National Estuarine Research Reserve System (NERR) was established to select "representative" estuarine systems associated with the coastal waters of the United States to support research and long-term monitoring of estuarine change. WBNERR joined the National System in 1988. Over the intervening 15 years, research has been conducted on organisms, land-use, and effects of nitrogen on embayment habitats. In addition, a land-use nitrogen model was developed to assess nitrogen loading. The various scientific publications and technical reports that have been produced were reviewed as part of the MEP assessment to garner quantitative data and qualitative information of use to the present data collection, synthesis, and modeling effort. A brief review of previous studies as relates to their utilization by the MEP approach is given below.

Data collected by Curley et al. (1971) indicated that as far back as the late 1960's, there was early evidence of nutrient related habitat decline within the eastern region of the Waquoit Bay System. This was confirmed and expanded upon two decades later in the first major scientific publication on the Waquoit Bay System (Valiela et al., 1990). This latter study documented eelgrass decline occurring within the Bay and its tributary systems, shifts in benthic species, and the linkage to increasing nitrogen loading from the associated watersheds. Further investigations have supported the detrimental effects on eelgrass (Valiela et al., 1992, Short and Burdick, 1996), enhancement of macroalgal accumulations (Hauxwell et al., 1998, Thompson and Valiela, 1999), system respiration (D'Avanzo et al., 1996), and potential moderate shifts in fish abundance and growth (Tober et al., 2000).

Coupled to these investigations of biological response to nitrogen loading, has been an attempt to determine watershed nitrogen loading rates. This approach has been termed the Waquoit Bay Nitrogen Loading Model (Valiela et al., 1992, Valiela et al., 2000). This approach is aimed at producing a research model which tracks nitrogen from all sources and uptake within the watershed, and attempts to predict the nitrogen discharges to the estuary. The approach is similar to other land-use loading models including the MEP watershed module. From the available information, it has been difficult to determine the various factors employed in the Waquoit Bay Nitrogen Loading Model and particularly difficult to rectify differences in watershed areas, nitrogen loads, and freshwater discharge volumes from the various reports and papers. In addition, validation of the model was based upon groundwater well point measurements which did not sample the full cross-section of the groundwater discharge boundary. Since no fractionation of the groundwater nitrogen pool or any salinity data is presented, it is not possible to evaluate whether the sampling at the "high tide mark at the seepage face" is representative of the groundwater flow. Limitations in this approach to measurement of groundwater nitrogen discharges are underscored by the very large discrepancy in the Sage Lot Pond sub-system which receives little anthropogenic loading (modeled versus measured from Valiela et al., 2000, Table 2, 147 versus 846 kg N yr^{-1}, respectively). In addition, the "measured" loads to Hamblin Pond, Jehu Pond, and Quashnet River using the watershed areas presented in Valiela et al., 2000 yield agreements to modeled loading of 54%, 73% and 118% respectively (see Table 2 in Valiela et al., 2000). Based on a general review of the Waquoit Bay Nitrogen Loading Model results published to date, there appeared to be significant bias in the model at higher nitrogen mass loadings.

In addition to the concerns regarding the groundwater measurement approach, the differences presented above need to be evaluated relative to changes in watershed area found by the MEP/USGS watershed delineation effort that was based on an updated groundwater model and improved parameterization as described in Chapter IV. It should be noted that the modeled Quashnet River Watershed nitrogen load is based upon freshwater discharges. In the earlier work, Quashnet River watershed total freshwater discharge was calculated from watershed area and recharge and compared to measured discharges (Valiela et al., 1992). The two estimates differed by only ~13%. Examination of the USGS discharge data during the likely period of this study (1989-1992) showed annual total river discharges of 1.17 to 1.32 10^7 m^3 yr^{-1}, compared to 1.1 10^7 m^3 yr^{-1} in the study, indicating excellent agreement. This river discharge was estimated to account for >80% of the total freshwater discharge from the Quashnet watershed. However, the 2657 ha watershed area upon which the freshwater flow values were based is ~30% larger than the watershed upon which the nitrogen loading comparison is based, 2055 ha (Valiela, et al., 1992). Interestingly, the USEPA in evaluating the Waquoit Bay nitrogen loading relied upon the "measured" nitrogen inputs from the well point samplers and the estimated groundwater discharges (see Figure 2-1 in USEPA, 2002). It is likely that these estimates will change significantly given the shift in watershed delineations (hence watershed area) and recent improvements in the USGS's groundwater recharge estimates.

A recent approach to evaluate nitrogen levels in Waquoit Bay and subsequent impacts on the Bay in response to watershed nitrogen loading has also been proposed (USEPA, 2002). This approach is not suited for the evaluation of nitrogen management alternatives at this time, as the approach is not robust, is calibrated to inorganic nitrogen concentrations (which generally represent a small fraction of the total nitrogen pool), and does not account for circulation or dispersion of nitrogen within the receiving waters.

Based upon the above concerns and shortcomings related to previous nitrogen loading estimates, and especially the new USGS watershed delineations, the MEP Technical Team was not able to directly assimilate these previous watershed nitrogen loading estimates. Comparison to previous nitrogen loading studies has focused primarily on the watershed delineation aspects.

As part of its mission of long-term monitoring, WBNERR has conducted both a volunteer monitoring program (BayWatcher) and formal monitoring program (System Wide Monitoring Program or SWMP). The WBNERR BayWatcher Program conducts a variety of water quality assays (Secchi Depth, salinity, temperature, dissolved oxygen, and chlorophyll a). Nutrients are also assayed, but only the inorganic forms (ammonium, nitrate, nitrite, ortho-phosphate, silicate). The more formal program (SWMP) is part of the NERR System and employs moored instrumentation to measure dissolved oxygen, salinity, temperature, pH, depth, and turbidity at four sites (upper Waquoit Bay, Childs River, lower Eel Pond, Sage Lot Pond). Organic nitrogen (particulate or dissolved) is not assayed in either monitoring program. Both programs are conducted under the supervision of the WBNERR Staff and the SWMP program is fully vetted through the NERR System. Therefore, the dissolved oxygen and chlorophyll a data collected by both WBNERR Programs has been included in this MEP analysis.

A major component of the MEP nutrient analysis is the evaluation of hydrodynamics within the estuarine system. Although previous hydrodynamic modeling efforts have been performed (e.g. Aubrey et al., 1993 and Valiela et al., 1998), information regarding these analyses are limited. A one-dimensional hydrodynamic model of Waquoit Bay was developed by Aubrey et al. (1993) to study the hydrodynamic effects of both the two and three inlet morphology. Bathymetry data were collected in the main basin of Waquoit Bay, Seapit River, Childs River, and the lower portion of the Quashnet River. Unfortunately, the digital data was not available and the datum described on the depth contour map could not be verified; therefore, the bathymetric information could not be utilized for the present study. If tide gage measurements were made to parameterize the model, results were not included in Aubrey et al., 1993. In Valiela et al. (1998), results of a circulation model are presented; however, there is no indication whether any physical measurements were performed to parameterize, calibrate, or validate the modeling effort. Again, this effort focused on changes to estuarine flushing with regard to formation of the third inlet by Hurricane Bob in 1991. Similar to Aubrey, et al. (1993), Valiela et al. (1998) conclude that the influence of the third inlet on tidal flushing is relatively minor. The MEP analysis presented in this report provides a comprehensive analysis of circulation for the entire Waquoit Bay System and an analysis of water quality within the tributary sub-embayments to the Waquoit Bay estuary (Quashnet River, Hamblin Pond and Jehu Pond); therefore, results from the earlier generation 1994 analysis have been superseded.

For the MEP modeling analysis, the data from the previous studies were evaluated relative to the needs of this project. Bathymetric data associated with Aubrey, et al. (1993) was cursory and was not collected relative to a known tidal datum (e.g. NGVD29). The Town of Mashpee through their designee contacted the Boston University Marine Program (BUMP) and the Waquoit Bay National Estuarine Research Reserve (WBNERR). Unfortunately, no data associated with physical processes (e.g. tide, current, or bathymetry information) was available for MEP use. For these reasons, it was necessary to collect both bathymetry and tide data to support the MEP analysis.

The MEP Technical Team conducted an extensive review of the nitrogen related studies of the Waquoit Bay System, including published articles, technical reports and discussions with WBNERR Staff (September 25, 2003 meeting). As a partner in the MEP, the Town of Mashpee through its wastewater engineering consultant also gathered information including discussions with Boston University Marine Program researchers (Dr. I. Valiela et al.). These data mining efforts determined that total nitrogen measurements were not available for the waters of Waquoit Bay System. Previous measurements of nitrogen in estuarine and surface freshwaters included only assays of inorganic nitrogen species (ammonium, nitrate, nitrite) with ground water assays sometimes including dissolved organic nitrogen. Total nitrogen is required for validation of the MEP Linked Watershed-Embayment Model and other high order estuarine nitrogen models, as nitrogen is rapidly transformed from one species to another. In estuarine systems, like the eastern sub-embayments to Waquoit Bay, inorganic nitrogen entering from the watershed is rapidly transformed to organic forms. The result is that it is not possible to balance the nitrogen budget for these systems without a full accounting of the nitrogen pool, especially since the inorganic forms account for only a minor fraction of the nitrogen pool in these estuarine waters (generally <5%).

As a result of the absence of water column total nitrogen data, the Town of Mashpee with the Coastal Systems Programs at SMAST-UMD conducted surveys of nitrogen levels in the eastern sub-embayments to Waquoit Bay and associated waters. The specific goal of the water quality surveys was to capture the nitrogen gradients within these estuaries to support the MEP Linked Watershed-Embayment Modeling effort. Sampling by the Mashpee Water Quality Monitoring Program was conducted as a joint effort between private citizens, the Mashpee Shellfish Department, Mashpee Harbor Master, Mashpee Waterways Commission, Mashpee Watershed Nutrient Management Committee, and SMAST. Water quality monitoring was conducted during the summer when eutrophication impacts are generally the greatest in Cape Cod embayments. The major findings were that nitrogen levels within both the sub-embayments and the main basin of Waquoit Bay were significantly elevated over adjacent Nantucket Sound waters. In addition, the sub-systems showed gradients in both nitrogen and salinity typical of estuaries.

After extensive review and evaluation of previous studies conducted in Waquoit Bay, the MEP Technical Team has attempted to incorporate all appropriate data from all historical studies. The objective of the in depth review of previous studies was to enhance the determination of nitrogen thresholds for the eastern sub-embayments to the Waquoit Bay System and to reduce costs to the Towns of Mashpee and Falmouth.