II. PREVIOUS NITROGEN MANAGEMENT STUDIES

Nutrient additions to aquatic systems cause shifts in a series of biological processes that can result in impaired nutrient related habitat quality. Effects include: 1) excessive plankton and macrophyte growth, which in turn lead to reduced water clarity, 2) organic matter enrichment of waters and sediments with the concomitant increased rates of oxygen consumption and periodic depletion of dissolved oxygen (especially in bottom waters), and 3) limitation of the growth of desirable species such as eel grass. 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 shellfishermen and to the sport-fishery and offshore finfishery, all of which are dependent upon these highly productive estuarine systems as a habitat and food resource during migration or different life cycle phases. This process of degradation is generally termed “eutrophication” and in embayment systems, unlike in shallow lakes and ponds, it is not necessarily a part of the natural evolution of a system.

In most marine and estuarine systems, such as the Pleasant Bay System, 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 resulting concentrations of water column nitrogen species. 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 Pleasant Bay 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 or unique features.

Numerous studies relating to nitrogen loading, hydrodynamics and habitat health have been conducted within the Pleasant Bay System over the past 10 years. In the late 1990’s local concern over the health of the sub-embayments to Pleasant Bay, particularly in the main tributary embayments of Bassing Harbor and in the upper reaches of The River sub-system, as well as the smaller coves and ponds (Round Cove, Quanset Pond, Paw Wah Pond and Muddy Creek), focused on assessing the water quality related to bacterial contamination and nitrogen inputs. This concern about nutrient related habitat declines resulted in a nitrogen loading and flushing analysis. A detailed watershed loading analysis for the sub-embayment of Round Cove was conducted by the Cape Cod Commission under the Cape Cod Coastal Embayment Project (Eichner et al. 1998). The first hydrodynamic model of Pleasant Bay was conducted at about

the same time (Ramsey 1997). Over the past 5-6 years, water quality monitoring programs were established for "local" waters by the Towns of Chatham (Chatham Water Quality Laboratory 2005) and Orleans (Howes and Ramsey 2002, Wineman 1997) as well as on a regional basis through the Pleasant Bay Alliance (PBA 2001). The initial results of the coordinated monitoring efforts indicated that the upper reaches of the Pleasant Bay System and the drowned kettle ponds and small enclosed coves were experiencing habitat degradation as a result of increasing watershed nitrogen inputs. Specifically, the monitoring results indicated that Muddy Creek, Kescayo Gansett Pond (i.e. Lonnies Pond), Meeting House Pond, Paw Wah Pond and Quanset Pond were already showing signs of nutrient related water quality declines, suggesting that they are beyond their critical loading limit (note only Muddy Creek and Arey's Pond were indicated by the land-use studies). While these assessments were based primarily on water quality data, many of the conclusions as to degradation were clearly supported by unequivocal datasets and have been corroborated by the more detailed MEP assessments (Chapter VII). All of these studies provided useful information and quantitative data which have been integrated into the present MEP analysis.

The Cape Cod Commission (CCC) conducted a nitrogen loading study for the Pleasant Bay System to determine the maximum allowable loads that 16 sub-embayments could tolerate based on a series of regulatory limits (CCC, 1998). The CCC began the study by delineating the watersheds that drain into the various sub-embayments and those delineations enabled the development of nitrogen loads. Land use was determined using data within the CCC's GIS system and then modified as needed in consultation with the local communities. The CCC staff then used their loading protocol as defined in Technical Bulletin 91-001 (CCC, 1991). Total nitrogen concentrations from wastewater were assumed to be 35 mg/L; 1.5 mg/L for road runoff; 0.75 mg/L for roof runoff and direct precipitation; and 0.05 mg/L for natural area runoff. Average residential lawn size was assumed to be 5000 ft^2 with a fertilizer application rate of 3 lb/1000 ft^2. Recharge rates used were 40 in/yr for impervious surfaces and 16 in/yr (Brewster, Harwich) or 17 in/yr (Chatham, Orleans, Eastham, Wellfleet, Truro, Provincetown) for natural areas. Both existing and buildout conditions were analyzed. A major part of the analysis was to examine the effects of the pre- and post- breach inlet conditions on the flushing times and nitrogen related habitat quality within the Pleasant Bay System.

The resulting nitrogen conditions were compared to critical levels as defined by the Buzzards Bay Project Outstanding Resource Waters (BBP ORW) and Outstanding Resource Waters – Nitrogen (ORW-N) limits. The results indicated that Muddy Creek exceeded both the nitrogen limits for both configurations while Ryder Cove exceeded the ORW-N limit with the pre-break configuration. This pattern was repeated for the same water bodies under the buildout scenario but with greater exceedences. In addition, difficulties in predicting the change in offshore nitrogen concentrations as New Inlet migrated south to its pre-breach condition (directed toward Nantucket Sound rather than the Atlantic Ocean) made future evaluation of critical nitrogen loads questionable.

A more recent watershed loading analysis was undertaken using nitrogen coefficients that differed from the original Cape Cod Commission (CCC) study (Carmichael et al. 2004). The study followed the basic Buzzards Bay Project approach, based upon residence times rather than actual circulation and volumetric exchange rates. The watershed analysis used the previous CCC watershed based upon water table elevations, which differs from the groundwater watershed mapped by the USGS for MEP (Chapter 3). The model was not calibrated and the "validation" used only dissolved inorganic nitrogen from 7 sites collected in 2000 and 2001. The model accounted for less than 50% of the observed nitrogen variation. However, the study did

confirm the importance of atmospheric deposition versus watershed derived nitrogen to the nitrogen balance of Pleasant Bay.

As a key process controlling the habitat quality within the whole of the Pleasant Bay System, tidal exchange with high quality Atlantic Ocean waters must be considered and accurately quantified. The MEP has re-evaluated the various studies of the migration and breaching of the Nauset Spit as it affects tidal flushing of Pleasant Bay. The results of these previous studies are fully discussed in Chapter V as part of the MEP hydrodynamic evaluation and modeling of the Pleasant Bay System. The potential inlet size and/or migration of the tidal inlet to Pleasant Bay is critical to the flushing, and as such the nitrogen related habitat quality of the Pleasant Bay sub-embayments. Flushing provides the primary mechanism for lowering nitrogen levels within the estuary once nitrogen has entered bay waters. In Chapter IX, the MEP Technical Team has used the calibrated and validated Linked Watershed-Embayment Model to evaluate potential shifts in habitat health as a result of inlet dynamics.

The Pleasant Bay Resource Management Plan was prepared by the Pleasant Bay Technical Advisory Committee and Ridley & Associates, Inc. (PBTSC and Ridley & Associates, 1998). The purpose of the plan was not only to reconcile both sustainability and restoration of the Pleasant Bay ecosystem but also to enhance public access and enjoyment of the bay, encouraging recreational, residential and commercial use consistent with resource sustainability. The management plan referred to the CCC study for analyses of nutrient loading and water quality and advocated continued monitoring of the water body.

Also over the past decade there were significant efforts at habitat protection/restoration related to Comprehensive Wastewater Management and Planning efforts, particularly within the Town of Chatham. As part of the initial wastewater management planning study a nitrogen loading analysis to Bassing Harbor and Muddy Creek sub-embayments was performed by Stearns & Wheler. This initial wastewater management planning study was part of a needs assessment for the Town of Chatham (Stearns & Wheler, 1999). The study divided Chatham into three groups that were analyzed separately: Pleasant Bay Region, Stage Harbor System, and the South Coast Embayments. The study followed a similar protocol as the earlier studies: 1) use of existing subwatersheds information, 2) calculation of existing and future nitrogen loading to each water body based on land use in respective subwatersheds, 3) calculation of steady-state nitrogen concentration to be expected based on flushing rate estimates, and 4) comparison of calculated loading to critical nitrogen loading limits to determine if exceedences should be expected or at what point exceedences may occur as a result of buildout. The analysis of existing loading to the Pleasant Bay systems embayments was integrated into the previous Pleasant Bay study conducted by the CCC. Similar to previous studies, the 1999 Stearns & Wheler analysis utilized the Buzzards Bay Project methodology (EPA, 1991) that incorporated a simplistic approach aimed at general planning analyses that was based on “local” residence times.

Signs of ecological deterioration and overall habitat stress within all of the Chatham embayment systems prompted the actual measurement of nitrogen concentrations in these embayment systems as initiated in 1998 (Duncanson, 2000; Howes and Schlezinger, 2000) and resulting a multi-year water quality monitoring effort that continues to this day under the direction of the Chatham Water Quality Laboratory. Based upon the initial land-use analysis and the results of the water quality monitoring efforts, additional levels of analysis were undertaken to increase the accuracy of the assessments and predictions. These included embayment specific hydrodynamic modeling, water quality modeling, and habitat assessment (Kelley *et al*., 2001 and Applied Coastal *et al*., 2001). Based on site-specific nutrient analysis

for the coastal systems of Chatham and developed to support embayment nutrient threshold development, it appeared that Muddy Creek and the Bassing Harbor systems already exceeded some or all of the total nitrogen-based water quality criteria used to evaluate critical nitrogen loads.

The water quality analysis and modeling effort in 2001 (Kelley *et al*., 2001) represented an initial effort at the linked water quality modeling approach; however, limitations in the embayment water quality data set and data gaps precluded accurate calibration of the water quality model. Specifically, major shortcomings that limited the utility of the analysis included inconsistent water column nitrogen concentrations in the Bassing Harbor system with regards to the ecological health of the system. To address some of the shortcomings inherent in the 2001 study, the Town of Chatham continued its water column nitrogen monitoring program and updated measurements of benthic nitrogen recycling flux within the Bassing Harbor system.

These efforts by the Chatham Wastewater Planning Committee, provided information and data that was seamlessly incorporated into a recent full application of the assessment and modeling effort by the MEP for the Bassing Harbor and Muddy Creek sub-embayments to Pleasant Bay (Howes et al. 2003). These full applications of the MEP approach developed nitrogen thresholds for these component systems, but indicated their dependence on the state of the greater Pleasant Bay system and the need to incorporate the Chatham embayments tributary to Pleasant Bay into a full Pleasant Bay analysis. This linkage has been fully carried out in the present report. The earlier results remain substantively intact, but have been refined by new datasets. The results of the early MEP analysis are discussed in the context of the new and broader analysis of Pleasant Bay in the chapters that follow. The present refinements include integration and updating of all the watershed analysis (and wateruse) system-wide into a consistent database and incorporation of all of the water quality data produced in intervening years from all water quality monitoring efforts (Chatham, Orleans, Pleasant Bay Alliance). This new data creates a sound baseline and significantly increases the certainty of the analysis for the whole of Pleasant Bay.

In addition to the large scale studies investigating the whole of Pleasant Bay or its major sub-embayments as discussed above, there have been other efforts aimed at specific aspects of the nutrient issue as it pertains to Pleasant Bay. As part of the MEP effort the Town of Orleans, through its Wastewater Management Steering Committee, compiled more than 25 studies relating to the marine systems of Orleans. Of these, 5 studies were selected as likely to contribute information or quantitative data to the Linked Watershed-Embayment Management Approach for the Pleasant Bay System. These studies were reviewed by MEP technical experts for (a) information or quantitative data to support the Linked Management Approach, (b) acceptability of results based upon quality assurance or comparability, and (c) data gaps seen in the integrated data set of the existing studies and present Program. The results of the evaluations of these studies are presented in detail in an SMAST Technical Report (Howes and Ramsey 2002) and briefly discussed above. Moreover, as regards fertilizer application rates, the MEP Technical Team working with the Orleans Wastewater Planning Committee, conducted a survey of 340 homes throughout the Town of Orleans. The results of this survey indicated that the number of fertilizations per lawn in Orleans was similar to that in an upper Cape survey involving the Towns of Falmouth, Mashpee and Barnstable, 1.76 versus 1.44. However, within the survey there was a very high number of homes serviced by commercial lawn companies (over 1/3). These lawns were fertilized at a high rate relative to home-owner serviced properties. The overall results indicated a potentially higher nitrogen loading per lawn in Orleans of 1.51 lb/lawn/yr (weighted average). However, this is due to the high fraction of homes with professionally maintained lawns in the survey. Given the large areas of the

watershed within Harwich, Brewster and Chatham, the uncertainty in the regional percentage of lawns maintained professionally; and the fact that if the Orleans rates are applied to the entire Pleasant Bay watershed the change in loading is <2%, however, it cautions of the potential for behavioral changes to greatly increase the nitrogen loading from this source.

The marine systems of the Pleasant Bay estuary have been the subject of a variety of studies ranging from investigations of physical processes to watershed nitrogen loading surveys and site specific investigations of nitrogen transformations. In addition, nutrient related water quality monitoring was undertaken by the Towns of Chatham and Orleans as well as the Pleasant Bay Alliance (partnership between the Towns of Chatham, Harwich and Orleans). Given the need for diverse data sets to implement the MEP Linked Watershed-Embayment Nitrogen Management Approach, all relevant sources of information were evaluated for inclusion. The MEP as incorporated all appropriate data from all previous studies to enhance the determination of the nitrogen thresholds for the Pleasant Bay system and to reduce costs to the Towns of Chatham, Harwich, Orleans and Brewster of watershed based nitrogen management.