VIII. CRITICAL NUTRIENT THRESHOLD DETERMINATION AND DEVELOPMENT OF WATER QUALITY TARGETS

VIII-1. ASSESSMENT OF NITROGEN RELATED HABITAT QUALITY

Determination of site-specific nitrogen thresholds for an embayment requires the integration of key habitat parameters (infauna and eelgrass), sediment characteristic data and nutrient related water quality information (particularly dissolved oxygen and chlorophyll a). Additional information on temporal changes within each sub-embayment and associated watershed further strengthens the analysis. These data were all collected by the MEP Technical Team to support threshold development within the component sub-embayments comprising the Pleasant Bay System and are discussed in Section VII. Nitrogen threshold development builds on these data and links habitat quality to summer water column nitrogen levels obtained from long-term baseline water quality monitoring (Towns of Chatham and Orleans and Pleasant Bay Alliance Water Quality Monitoring Programs, and MEP Technical Team).

The Pleasant Bay System is comprised of a variety of basins showing a range of habitat health from “Healthy” (supportive of eelgrass, infaunal communities and with little oxygen stress) to “Degraded” (absence of eelgrass and benthic animals and periodic hypoxia/anoxia). There appears to be a clear relationship between habitat quality and the level of nitrogen enrichment. The less well flushed enclosed basins tend to be focal points for watershed nitrogen inputs and have relatively lower tidal flushing rates. In contrast, the larger basins and areas near the tidal inlet have a range in habitat quality, Moderately Impaired to Healthy, related to their flushing rate and depth.

The spatial distribution of habitat quality among the Pleasant Bay sub-embayments shows significant spatial variation, typical of other embayments within the MEP region. Although there are a large number of sub-embayments to the Pleasant Bay System, the habitat health or impairment associated with each of the key indicators (oxygen/chlorophyll a, eelgrass, infauna communities) tends to follow the 4 classifications listed below based upon the basin type:

(A) small enclosed basin (Meetinghouse Pond, Lonnies Pond, Areys Pond, Round Cove, Quanset Pond, Paw Wah Pond, Upper Muddy Creek),
(B) moderate sized tributary sub-embayment (The River, Muddy Creek),
(C) salt marsh dominated tidal sub-estuary (Pochet),
(D) large lagoonal estuarine basin (Little Pleasant Bay, Pleasant Bay, Chatham Harbor).

Dissolved Oxygen. The general pattern is for a high level of oxygen stress (frequent hypoxia or anoxia) in the bottom waters of the small enclosed basins (group A). These small enclosed basins tend to have higher nitrogen levels and high rates of sediment metabolism associated with their circulation and focus of watershed nitrogen loads. The Meetinghouse Pond basin and outlet channel, Lonnies Pond and its outlet channel, the Areys Pond outlet channel (Namequoit River), and Quanset Pond all showed significant levels of oxygen depletion, were routinely hypoxic and, except for Quanset Pond, D.O. levels were frequently <2 mg/L. In the same group of enclosed basins, Areys Pond, Paw Wah Pond and upper Muddy Creek showed frequent anoxia (absence of oxygen). Among the enclosed basins only Round Cove showed mild hypoxia with levels above 4 mg/L and generally above 5 mg/L during the full deployment.

In contrast, the salt marsh dominated tidal creek of Pochet showed frequent oxygen depletions to 3-4 mg/L, but was generally above 4 mg/L. The oxygen conditions in Pochet creek are consistent with the biogeochemistry of salt marshes. Salt marsh creeks (that do not empty at low tide) frequently become hypoxic in summer as a result of the high organic matter loading associated with marshes. Even pristine salt marshes can exhibit this behavior.

The large main basins of the lagoonal estuarine component showed oxygen conditions consistent with rates of sediment metabolism associated with deep waters and a depositional environment (Little Pleasant Bay, Pleasant Bay) or high tidal velocities (Chatham Harbor and eastern channel form Chatham Harbor to Little Pleasant Bay, channel between Strong Island and Bassing Harbor). Upper Pleasant Bay at Namequoit Point showed oxygen levels frequently declining to 4-5 mg/L and the western most basin of Pleasant Bay (between Round Cove and Muddy Creek) had a single event to 2-4 mg/L, although it was generally >5 mg/L. Approaching Chatham Harbor, oxygen conditions improve (see Strong Island results), with oxygen conditions generally >6 mg/L with short declines to 5 mg/L and associated with the outflow of lower oxygen waters from Pleasant Bay.

Overall, the oxygen and chlorophyll records show a consistent pattern of higher organic matter production (chlorophyll) in embayments with greater oxygen depletions. The pattern is one of sub-embayments that are enclosed (group A) having habitat impairment by frequent low oxygen events, with the larger lagoonal basins (group B) showing less frequent and extreme levels of oxygen depletion and moderate impairment, grading to good oxygen conditions near (and presumably in) Chatham Harbor. This pattern follows the nitrogen gradients in the System (Chapter VI), the eelgrass distribution (below) and the infaunal habitat quality.

Eelgrass. At present, eelgrass is present within large portions of the Pleasant Bay System, indicative of a system with areas of high habitat quality. These eelgrass beds are generally restricted to the larger lagoonal basins, such as Little Pleasant Bay, Pleasant Bay and Chatham Harbor. There are also smaller eelgrass areas in Pochet and fringing shallow areas in The River and Meetinghouse Pond. The only tributary embayment to Pleasant Bay with significant eelgrass habitat is Bassing Harbor (see below). The basins presently supporting eelgrass habitat also supported habitat in the 1951 historical analysis. However, it is clear from the 1951, 1995 and 2001 temporal sequence that the eelgrass areas in each basin, except Chatham Harbor, are declining in coverage. In The River and Pochet the eelgrass areas were always patchy and present in the shallows. In the 2001 survey this pattern persists, but the beds appear to be on the decline. The overall pattern of eelgrass distribution and temporal decline in coverage is fully consistent with the spatial pattern of nitrogen enrichment (Chapter VI) and oxygen and chlorophyll levels in the various basins (see above). The present rate of eelgrass habitat throughout the Pleasant Bay System is ~11 acres per year.

Virtually all of the small enclosed basins (group A, above) did not appear to support eelgrass historically and do not support it today, with the exception of the small patch in the shallows of Meetinghouse Pond and in lower Muddy Creek (see below). This general pattern is consistent with the deeper waters of these basins and their location and structure which tends to result in nitrogen enrichment.

Based upon the 1951 coverage it appears that nitrogen management to restore eelgrass habitat has the potential to recover a significant resource to this System and to the lower Cape (Table VII-5), on the order of 500-600 acres system-wide. However, for the reasons discussed above creation of eelgrass habitat within the enclosed basins is unlikely and not supported by the historical analysis.

Infaunal Animal Communities. As for the oxygen and chlorophyll indicators and the distribution of sediment metabolism, the enclosed basins (group A, above) are generally significantly to severely impaired relative to benthic infaunal habitat quality. Among the enclosed basins, all were at least significantly impaired. Paw Wah Pond is virtually devoid of benthic animals (only 1-4 individuals per sample) as would be expected from its high level of oxygen stress. Similarly, Areys Pond, Quanset Pond, Upper Muddy Creek supported significantly depleted benthic animal populations, consistent with their nitrogen related oxygen stress. The other enclosed basins were able to support benthic infauna, but the community was dominated by opportunistic species (*Capitella*, *Streblospio*) indicative of very high organic matter loading (Lonnies Pond, Meetinghouse Pond outlet channel) or by intermediate stress indicators (*Gemma*, Amphipods). The dominance of these intermediate indicators in The River, Round Cove, Meetinghouse Pond suggests that these systems, which also showed only moderate oxygen stress, are only moderately beyond their nitrogen loading limits (Table VII-8).

The larger lagoonal basins of Little Pleasant Bay generally supported infaunal communities indicative of a moderate level of stress from organic matter loading and oxygen depletion. However, the pattern was for a decrease in habitat quality moving from the marginal to depths. This pattern is typical of a system near, but beyond its nitrogen loading limit, where organic matter deposition in the deep basin areas is the proximate cause of the impairment of benthic habitat quality. Chatham Harbor habitat supported only moderate numbers of individuals and species, but this appeared to result from the dynamic nature of the bottom sediments (unstable bottom), due to the high tidal velocities, rather than nutrient related impairment.

The results of the evaluations of the 3 key habitat indicators (infaunal animals, eelgrass. dissolved oxygen/chlorophyll a) coupled with macroalgal survey data were used to assess the overall habitat quality of each component sub-embayment to the Pleasant Bay System (Table VIII-1). The results of the habitat assessment show consistent assessments between indicators and follow the pattern of nitrogen enrichment (see Section VIII.3, below). All of these data were integrated in the development of the nitrogen thresholds for the restoration of eelgrass and infaunal habitats throughout the Pleasant Bay System (Section VIII.2).

Table VIII-1. Summary of Nutrient Related Habitat Health within the Pleasant Bay Estuarine System Cape Cod, MA., based upon assessment data presented in Chapter VII. D.O. and Chl a are dissolved oxygen and chlorophyll a from the mooring data (VII.2).

	Nutrient related Health Indicator					
Sub-Embayment	**D.O.**	**Chl a**	**Macro-algae**	**Eelgrass**	**Infaunal Animals**	**Overall**
Meetinghouse Pond & Outlet	SI/SD[1,2]	SI/MI	MI[3]	--	SI	**SI**
Lonnies Pond	SI[2]	MI	MI	--	SI	**SI/MI**
Areys Pond & Outlet	SD[1]	SI	SI/SD[13]	--	SD[9]	**SD/SI**
The River	MI/SI[3]	MI	MI/SI	MI	SI	**MI**
Paw Wah Pond	SD[1]	SI	SI	--	SD[10]	**SD**
Quanset Pond	SI	SI	--[c]	--	SD[9]	**SI**
Round Cove	MI[4]	SI	--[c]	--	SI	**SI/MI**
Muddy Creek Upper	SD[1]	SI/SD	--[c]	--	SD[9]	**SD**
Muddy Creek Lower	SI/SD[1]	SI/MI	--[c]	SI	SI	**SI**
Bassing Hbr: Ryders Cove		SI	MI	MI[7]	MI	**MI**
Bassing Hbr: Crows Pond		MI	MI	MI[7]	H/MI	**MI**
Bassing Hbr: Lower Basin		MI/H	--[c]	H/MI	MI	**H/MI**
Bassing Hbr: Frost Fish Crk		SI	SI	--	SI	**SI**
Pochet	H/MI[3a]	H	--[c]	--	H/MI	**H**
Little Pleasant Bay	MI[3]	H	--[c]	MI[7]	MI	**MI**
Pleasant Bay	MI/SI	MI	--[c]	MI/SI	MI-SI	**MI**
Chatham Harbor	H[b]	H[b]	--[c]	H	H	**H**

1 – frequent oxygen depletions to 0-2 mg/L (i.e periodic anoxia)
2 – periodic oxygen depletions to <2 mg/L and frequently <4 mg/L
3 – infrequent oxygen depletions to 3-4 mg/L, periodic 4-5 mg/L., generally >5 mg/L.
4– generally >5 mg/L..
5 – high macroalgal accumulations during summer
6 – moderate macroalgal accumulations or patches on bottom.
7 – eelgrass present but beds appear to be thining or declining in areal coverage
8 – modest numbers of individuals dominated by stress indicator species.
9 – depleted infaunal community (<100 individuals/grab).
10– absence of infaunal community (<15 individuals/grab).
11 – no evidence this basin is supportive of eelgrass.
12 – infaunal community dominated by opportunistic species.
13 – dense macroalgal accumulation in the Namequoit River
a – periodic oxygen depletion is typical of salt marsh creeks.
b – based upon Strong Island Channel data
c – no accumulations observed during MEP field surveys
H = healthy habitat conditions; MI = Moderate Impairment; SI = Significant Impairment;
SD = Severe Degradation; -- = not applicable to this estuarine reach

VIII-2. THRESHOLD NITROGEN CONCENTRATIONS

The approach for determining nitrogen loading rates, which will maintain acceptable habitat quality throughout an embayment system, is to first identify a sentinel location within the embayment and second to determine the nitrogen concentration within the water column which will restore that location to the desired habitat quality (threshold nitrogen level). The sentinel location is selected such that the restoration of that one site will necessarily bring the other regions of the system to acceptable habitat quality levels. Once the sentinel site and its target nitrogen level are determined, the Linked Watershed-Embayment Model is used to adjust nitrogen loads sequentially until the targeted nitrogen concentration is achieved. For the Pleasant Bay System, the restoration target should reflect both recent pre-degradation habitat quality and be reasonably achievable.

The threshold nitrogen level for an embayment represents the tidally averaged watercolumn concentration of nitrogen that will support the habitat quality being sought. The watercolumn nitrogen level is ultimately controlled by the watershed nitrogen load and the nitrogen concentration in the inflowing tidal waters (boundary condition). The watercolumn nitrogen concentration is modified by the extent of sediment regeneration.

The threshold nitrogen level for the Pleasant Bay System was developed to restore or maintain SA waters or high habitat quality. High habitat quality was defined as supportive of eelgrass and infaunal communities. Dissolved oxygen and chlorophyll-*a* were considered in the assessment. While there is a single sentinel station, given the number of semi-enclosed sub-embayments, several secondary “check” stations were also selected.

The approach developed by the MEP has been to select a sentinel sub-embayment within an embayment system. First, a sentinel sub-embayment is selected based upon its location within the system. The sentinel sub-embayment should be close to the inland-most reach as this is typically where water quality is lowest in an embayment system. Therefore, restoration or protection of the sentinel sub-embayment will necessarily create high quality habitat throughout the estuary. Second, a sentinel sub-embayment should be sufficiently large to prevent steep horizontal water quality gradients, such as would be found in the region of entry of a stream or river or in the upper most region of a narrow, shallow estuary. This second criteria relates to the ability to accurately determine the baseline nitrogen level and to conduct the predictive modeling runs. Finally, the sentinel system should be able to obtain the minimum level of habitat quality acceptable for the greater system (unless a multiple classification is to be used).

After the sentinel sub-system (or systems) is selected, the nitrogen level associated with high and stable habitat quality typically derived from a lower reach of the same system or an adjacent embayment is used as the nitrogen concentration target. Finally, the watershed nitrogen loading rate is manipulated in the calibrated water quality model to determine the watershed nitrogen load which will produce the tidally averaged target nitrogen level at the sentinel location. Differences between the required modeled nitrogen load to achieve the target nitrogen level and the present watershed nitrogen load represent nitrogen management goals for restoration or protection of the embayment system as a whole.

Based upon the significant historical and present eelgrass habitat within the Pleasant Bay System, 2400 acres and 1800 acres respectively (Chapter VII), eelgrass was selected as the target for the development of the site-specific nitrogen threshold. In addition, a secondary threshold supportive of benthic animal communities (infauna) was developed in areas that do not have documented eelgrass habitat. The eelgrass threshold applies to the sentinel station (and secondary eelgrass station in Ryders Cove) and the secondary "check" thresholds for infauna habitat is for the smaller sub-basins not naturally supportive of eelgrass based on historical records.

The MEP's previous analysis of Bassing Harbor found very high levels of dissolved organic nitrogen within the embayment's waters (based upon data from the Chatham and Pleasant Bay Alliance Water Quality Monitoring Programs). While some portion of the dissolved organic nitrogen is actively cycling, the vast majority is refractory (non-biologically active) within the timeframe of the flushing of the Pleasant Bay System. The result is that the dissolved organic nitrogen presents a large non-active pool generally separate from the nitrogen fractions active in eutrophication (i.e. ammonium and nitrate+nitrite, particulate organic nitrogen). The biologically active nitrogen pools are represented by the species directly available to phytoplankton and algae (plant available nitrogen), ammonium and nitrate+nitrite, and the particulate organic nitrogen comprised primarily of phytoplankton (live and dead). Together this nitrogen group is termed bioactive nitrogen. Given the large dissolved organic nitrogen pool within Pleasant Bay the MEP Technical Team adopted the same approach used previously for the TMDL analysis of Bassing Harbor. In this previous analysis, the threshold was developed based upon the bioactive nitrogen pool, which appears to be relatively consistent between embayments both within and outside of Pleasant Bay, and then the bioactive threshold was transformed to the total nitrogen level by adding back in the dissolved organic nitrogen concentration derived for the site from direct measurements. In meeting the threshold value and achieving restoration, the bioactive nitrogen threshold has slightly less uncertainty than the total nitrogen threshold given the biogeochemistry of this system. Therefore, while both values form the basis for guiding nitrogen reductions to achieve ecological restoration, the total nitrogen value should only be evaluated in light of the bioactive nitrogen threshold. Critical nitrogen threshold levels were developed to support both healthy eelgrass and healthy infaunal habitat as described below.

While there is significant variation in the dissolved organic nitrogen levels, hence total nitrogen levels supportive of healthy eelgrass habitat, the level of bioactive nitrogen supportive of this habitat appears to be relatively constant. Therefore, the MEP Technical Team set a single eelgrass threshold based upon stable eelgrass beds, tidally averaged bioactive N levels and the stability of eelgrass as depicted in coverages from 1951-2001. The eelgrass threshold was set at 0.16 mg bioactive N/L based upon the Chatham (Dec 2003 MEP report) analysis for Bassing Harbor. That report for Bassing Harbor indicated a bioactive level for high quality eelgrass habitat of 0.160 mg bioactive N/L based upon Healthy eelgrass community in both Bassing Harbor at 0.135 bioactive N/L and in Stage Harbor at 0.160 bioactive N/L (Oyster River Mouth). The higher value was used as the eelgrass habitat in Bassing Harbor was below its nitrogen loading limit at that time.

Although the Bassing Harbor System (comprised of Ryder Cove, Crows Pond, Frost Fish Creek and Bassing Harbor) has two inland-most sub-embayments, Ryder Cove and Crows Pond, only Ryder Cove was selected as the sentinel system for this sub-embayment. This resulted from the fact that Crows Pond has a relatively low nitrogen load from its watershed and appears to currently support higher quality habitat than Ryder Cove. Ryder Cove currently shows a gradient in habitat quality with lower quality habitat in the upper reach and higher quality in the lower reach. Ryder Cove represents a system capable of fully supporting eelgrass beds and stable high quality habitat based upon the 1951-2001 surveys. At present, this basin is transitioning from high to low habitat quality in response to increased nitrogen loading. Restoration of nitrogen levels in upper Ryder Cove to levels supportive of high quality habitat should also result in the restoration and protection of the whole of the Bassing Harbor System.

Following the approach used for the Stage Harbor System in the Town of Chatham, a region of stable high quality habitat was selected within the Bassing Harbor System. The region selected was Bassing Harbor which has both high quality eelgrass and benthic animal communities, which appear to be stable. Unfortunately, total nitrogen within this system appears to be very high. In fact, the whole of lower Pleasant Bay appears to contain very high levels of total nitrogen. Analysis of the composition of the watercolumn nitrogen pool within these embayments revealed that the concentrations of dissolved inorganic nitrogen (DIN) and particulate organic nitrogen (PON) were the same as for the Stage Harbor System. In fact, the level of these combined pools (DIN+PON) was lower in Bassing Harbor (0.133 mg N L^{-1}) than in the Stage Harbor (0.158 mg N L^{-1}) and the mouth of Oyster River (0.160 mg N L^{-1}). Note that the mouth of the Oyster River exhibits a documented stable healthy eelgrass habitat (MEP 2003). It appears that the reason for the higher total nitrogen levels in the Pleasant Bay waters results from the accumulation of dissolved organic nitrogen. The bulk of dissolved organic nitrogen (DON) is relatively non-supportive of phytoplankton production in shallow estuaries, although some fraction is actively cycling. It is likely that the high background DON results from the relatively long residence time of Pleasant Bay waters relative to the smaller systems. This allows the accumulation of the less biologically active nitrogen forms, hence the higher background. Decomposition of phytoplankton, macroalgae and eelgrass release DON to estuarine waters as do salt marshes and surface freshwater inflows.

Based upon these site-specific observations, an adjusted nitrogen threshold was developed for the Bassing Harbor System. The approach was to determine the baseline dissolved organic nitrogen level for the region (average of inner and outer Ryder Cove, Bassing Harbor), is 0.363 mg N L^{-1} based upon the long-term monitoring data, 2000-05. A site specific threshold level was then developed using the conservative DIN+PON level from the Stage Harbor System plus the new analysis of the Pleasant Bay System (see below) of 0.160 mg N L^{-1}. This yields an equivalent Total Nitrogen Threshold for the Bassing Harbor Sub-embayment (average upper and lower Ryders Cove stations) of 0.523 mg N L^{-1}. This value is very close to the previous Bassing Harbor specific threshold range of 0.527-0.552 mg N L^{-1}. The slight shift in threshold level results from the greatly expanded water quality database for the present versus previous analysis. The nitrogen boundary condition (the concentration of nitrogen in inflowing tidal waters from Pleasant Bay) for the Bassing Harbor System is 0.45 mg N L^{-1}.

The above analysis was expanded into a full Pleasant Bay analysis, which was based upon examining eelgrass beds which appear in all three surveys between 1951-2001 and using MEP field observations made in 2003. This detailed analysis strongly supported the use of a 0.16 mg Bioactive N/L threshold for all of Pleasant Bay. These additional lines of evidence (PBA#, WMO# refer to water quality sampling stations Chapter VI) are as follows:

a) The upper most reach of the contiguous eelgrass beds in Little Pleasant Bay (PBA-12) have been extant from 1951-2001. The mapping indicates a large contiguous areal coverage within Little Pleasant Bay with PBA-12 approximately at the uppermost point. Above these beds moving into the mouth of The River (PBA-13) and the lowermost basin of Pochet (WMO-03) eelgrass coverage appears to have declined since 1951, although eelgrass is still present. This loss of beds indicates that the habitat quality has become impaired, but since eelgrass remains, the impairment is judged to be “moderate”. Under existing conditions the tidally averaged bioactive nitrogen levels at each of these sites are 0.178 for upper Little Pleasant Bay (PBA-12), 0.195 for the mouth of The River (PBA-13), and 0.183 for the lowermost basin in Pochet (WOM-03). It appears from the bathymetry that the eelgrass in Pochet and the patches in The River are restricted to the shallows, generally <1 meters depth. This is consistent with the persistence of these beds at a higher nitrogen level since the effect of eutrophication on eelgrass (through shading effects) is directly dependent on depth (i.e. deeper beds are lost first). Based upon these data the conditions of the eelgrass beds in upper Little Pleasant Bay were examined. Visual surveys by MEP staff indicated that the eelgrass beds in deeper waters of upper Little Pleasant Bay indicated the presence of filamentous green algae in moderate amounts. In addition some of the upper beds had coverages of 30%-50%, suggesting a decline in habitat quality, although healthy beds were also observed. Equally important was an absence of some beds in the deeper waters along the western shore of Little Pleasant Bay (Paw Wah Pond shoreline) which showed eelgrass in the 1951-2001 surveys. This suggests that this basin has recently exceeded its nitrogen loading threshold (i.e. the 0.178 mg bioactive N/L is too high). However, the data from the lower reach of Upper Pleasant indicates a healthy eelgrass habitat at tidally averaged bioactive N levels of 0.161 mgN/L. In addition, the decline in eelgrass coverage at the mouth of The River and in Pochet is consistent with a recent initial (gradual) decline in the deeper areas of Upper Little Pleasant Bay. As a result the eelgrass threshold for the Pleasant Bay system appears to be between 0.160 and 0.178 mg Bioactive N/L.

b) Eelgrass beds are no longer present in the Pleasant Bay basin bounded by Round Cove and Muddy Creek on the West and Strong Island on the east. The major proximate cause appears to be the much greater depth of this basin than the depth of Little Pleasant Bay and the basin between Strong Island and the western barrier beach boundary. However, even when comparing similar depths from these 3 basins, it is clear that the western Pleasant Bay basin does not support eelgrass habitat, while the others do. The western Pleasant Bay basin's tidally averaged bioactive N levels are between 0.168 (PBA-07) and 0.192 (PBA-06. Furthermore the uppermost station in this basin, off Simpson Island has a small remaining eelgrass bed near water quality station, PBA-08, which had a tidally averaged bioactive N level of 0.149 mg N/L. and a measured ebb tide average of 0.162 mg N/L. Supportive of an eelgrass threshold of 0.160 mg N/L tidally averaged bioactive N level.

c) Crows Pond in the Bassing Harbor sub-system currently supports a high level of habitat quality, with eelgrass beds surrounding the central deep basin and sparse coverage throughout. Note that the deep basin in Crows Pond is similar to the deep basin in Pleasant Bay and the terminal kettle ponds in the upper reaches of the Pleasant Bay System. Crows Pond supports healthy habitat in its shallower waters (similar depths to Little Pleasant Bay) at a tidally averaged bioactive N level of 0.162 mg N/L and measured ebb tidal average of 0.208 mg N/L. Infaunal diversity and evenness is consistent with a high quality habitat. Oxygen levels are consistently above 5 mg L^{-1} and chlorophyll a levels also are moderate (generally 10-15 ug L^{-1}). The apparent slight decline in habitat quality stems from the observed very sparse coverage in deep central basin (Chatham mapping 2000), although the MASSDEP mapping programs 1951 and 2001 analysis show similar overall coverages. At present it appears that Crows Pond approaching and possibly at its threshold nitrogen level. However, the Crows Pond data supports an eelgrass threshold of 0.160 mg N L^{-1} tidally averaged bioactive N level.

The sentinel station for the Pleasant Bay System based on a nitrogen threshold targeting restoration of eelgrass was placed within the uppermost reach of Little Pleasant Bay (PBA-12) near the inlets to The River and Pochet. The threshold bioactive nitrogen level at this site (as for Ryders Cove) is 0.160 mg bioactive N L^{-1}. Based upon the background dissolved organic nitrogen average of upper Little Pleasant Bay and Lower Pochet 0.563 mg N L^{-1} and the bioactive threshold value, the total nitrogen level at the sentinel station (PBA-12) is 0.723 mg N L^{-1}. The restoration goal is to improve the eelgrass habitat throughout Little Pleasant Bay and the historic distribution in Pleasant Bay, which will see lower nitrogen levels when the threshold is reached. In addition, the fringing eelgrass beds within The River and within Pochet should also be restored, as they are in shallower water than the nearby sentinel site and therefore are able to tolerate slightly higher watercolumn nitrogen levels. Moreover, the same threshold bioactive nitrogen level should be met for the previous sentinel station (upper Ryders Cove) in Bassing Harbor System when levels are achieved at the sentinel station in upper Little Pleasant Bay. However, given the partial independence of the Bassing Harbor sub-embayment system relative to the greater Pleasant Bay System (i.e. its own local watershed nitrogen load plays a critical role in its health), the upper Ryders Cove sentinel station should be maintained as the guide for this sub-embayment to Pleasant Bay. It should also be noted that while the bioactive threshold is the same at both sites, the Total Nitrogen level in Ryders Cove is 0.523 mg N L^{-1}, due to the lower dissolved organic nitrogen levels in the lower Bay.

While eelgrass restoration is primary nitrogen management goal within the Pleasant Bay System, there are small basins which do not appear to have historically (1951) supported eelgrass habitat. For these sub-embayments, restoration and maintenance of healthy animal communities is the management goal. It should be noted that restoration of eelgrass is not the only criteria for restoration of habitat health throughout the Pleasant Bay System. Based upon the 1951 eelgrass analysis there are eight (8) sub-embayments to Pleasant Bay that are not likely to support eelgrass habitat for structural reasons. These are all drowned kettle ponds or coves that have been enclosed by a barrier beach. The typical structure of each of these sub-embayments is that they have a relatively narrow tidal channel from the Bay into a relative deep basin. While these systems may not be supportive of eelgrass habitat, they are generally capable of supporting healthy benthic animal habitat. Infaunal animals are sensitive to the organic matter loading and resulting periodic oxygen depletions associated with nitrogen overloading. Since these conditions typically occur at higher nitrogen loads than does the shading of the bottom by increased phytoplankton production (principal cause of eelgrass loss), the nitrogen threshold level for healthy benthic animal habitat is higher than for healthy eelgrass habitat. This has been found to be the case throughout the MEP study area.

The infaunal habitat threshold was derived in a similar manner to the site-specific eelgrass threshold for Pleasant Bay as described above. The threshold depends heavily upon the present distribution of infaunal communities relative to watercolumn nitrogen levels and measured oxygen depletions. The presence of some eelgrass is also noted. At present, moderately impaired infaunal communities are present in Ryders Cove (PBA-03) at tidally averaged bioactive nitrogen levels of 0.244 mg N L^{-1}. Similarly, there are moderately impaired infaunal communities, designated primarily by the dominance of amphipods (amphipod mats) in most of the 8 sub-embayments of focus. These communities are present adjacent the inlet to Lonnies Pond (in The River Upper) at bioactive nitrogen levels of 0.217 mg N L^{-1}, in the Namequoit River at 0.216-0.239 mg N L^{-1} and in Round Cove at mg N L^{-1} at 0.239 mg N L^{-1}. These communities can be found at even higher levels in the fringing shallow areas of deep basins like Areys Pond (0.299 mg N L^{-1}) and Meetinghouse Pond (0.411 mg N L^{-1}). Very shallow waters tend to minimize oxygen depletion that severely stress infaunal communities in deeper basins. Paw Wah Pond is periodically hypoxic and as a result does not presently support infaunal habitat. These data are at higher bioactive nitrogen levels than the healthy infaunal habitat in the lower Pochet Basin (WMO-03) at 0.178 mg N L^{-1}. It appears that the infaunal threshold lies between 0.18 and 0.22 mg N L^{-1} tidally averaged bioactive nitrogen. Note that within the shallow margins of the river eelgrass is present at 0.191 mg N l^{-1}, suggesting that healthy infaunal habitat is likely at this level.

Based upon the animal community and nitrogen analysis mentioned above the restoration goal for these 8 systems is to restore a healthy habitat to the full basin in the shallower or more open waters and to the margins in the deep drowned kettles that periodically stratify. This would argue for a bioactive nitrogen threshold of 0.21 mg N L-1, lower than the lowest station with significant amphipod presence. Note that achieving the infaunal threshold in all of the sub-embayments and the eelgrass threshold in Upper Pleasant Bay (and Ryders Cove) will generate high quality habitats throughout the Pleasant Bay system. To achieve these goals, infaunal check stations were placed (where appropriate) in the inlet to kettle ponds (for deeper ponds) or in the center of the ponds for shallower ponds.

At present all eight sub-embayments are above the level required for healthy infaunal habitat. The tidally averaged bioactive nitrogen levels and associated total nitrogen levels and threshold levels are shown in Table VIII-2, along with current water quality station identification numbers.

Table VIII-2. Bioactive nitrogen thresholds and associated Total Nitrogen (TN) levels in sub-embayments to Pleasant Bay targeting restoration of benthic animal habitat under one possible restoration scenario. Note that the range in TN levels stems from the varying levels of dissolved organic nitrogen within the Pleasant Bay System. The site-specific DON level was used to adjust the bioactive nitrogen threshold to total nitrogen.

Location	WQ Station ID	Bioactive N Threshold mg/L	DON mg/L	TN Threshold mgN/L
Meetinghouse @Rattles Dock	WMO-10	0.210	0.700	**0.910**
Lonnies Pond	PBA-15	0.210	0.496	**0.706**
Namequoit River Upper (Areys Pond)	WMO-6	0.210	0.529	**0.739**
Pochet - Upper off Town Landing	WMO-05	0.210	0.555	**0.765**
Paw Wah Pond	PBA-11	0.210	0.439	**0.649**
Little Quanset Pond	WMO-12	0.210	0.394	**0.604**
Round Cove	PBA-09	0.210	0.461	**0.671**
Muddy Creek – Lower	PBA-05	0.210	0.331	**0.541**

The secondary “infaunal” thresholds for each of these sub-embayments must be reached in order to restore their habitat quality. Depending upon the specific strategy for lowering watershed nitrogen loading to the entire Pleasant Bay System to achieve the threshold at the sentinel station in upper Pleasant Bay, it may be possible that a specific sub-embayment may or may not achieve its secondary threshold, even though the eelgrass threshold at the sentinel station for the System is reached. This results from the size of the Pleasant Bay System and the relatively isolated nature of some of the small sub-embayments. Even though these sub-embayments receive water from the main System, their localized watershed load predominates in some cases. Therefore, restoration success will be gauged by reaching the target at the sentinel station and at the secondary stations for eelgrass (Ryders Cove) and infauna. Overall, there are 3 primary (PBA-12, PBA-03 and CM-13) and 8 secondary target stations within this System, the largest embayment on Cape Cod.

VIII.3 DEVELOPMENT OF TARGET NITROGEN LOADS

It is important to note that load reductions can be produced by reduction of any or all sources or by increasing the natural attenuation of nitrogen within the freshwater systems to the embayment. The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the communities that impact Pleasant Bay waters. The purpose of the load reduction scenario presented is to establish the general degree and spatial pattern of reduction that will be required for restoration of this nitrogen impaired embayment.

The develop the scenario presented, nitrogen thresholds determined in the previous section were used to determine the amount of total nitrogen mass loading reduction required for restoration of eelgrass and infaunal habitats in the Pleasant Bay system. Tidally averaged total nitrogen thresholds derived in Section VIII.1 were used to adjust the calibrated constituent transport model developed in Section VI. Watershed nitrogen loads were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold levels at the sentinel stations selected for eelgrass and infaunal habitat restoration within the Pleasant Bay system.

Development of nitrogen load reductions needed to meet the threshold concentration of 0.16 mg/l bioactive nitrogen (DIN+PON) in Ryders Cove (the average of PBA-03 and CM-13) and Upper Little Pleasant Bay (PBA-13) focused primarily on septic load removal within the River and Bassing Harbor systems. Due to the relatively large size of the Pleasant Bay system, achieving the primary threshold concentration for the restoration of eelgrass at the sentinel stations alone did not achieve the secondary threshold at the series of small embayments surrounding Pleasant and Little Pleasant Bays. The secondary threshold concentration of 0.21 mg/l bioactive nitrogen (DIN+PON) in Meetinghouse Pond (Outer), Lonnies Pond, Upper Namequoit River, Upper Pochet, Paw Wah Pond, Little Quanset Pound, Round Cove and Lower Muddy Creek required site-specific removal of septic nitrogen from the watersheds directly impacting these sub-embayments. Table VIII-3 shows the percent of septic load removed from the various watersheds to achieve both the primary and secondary threshold concentrations of bioactive nitrogen at the sentinel stations.

Tables VIII-4 and VIII-5 provide additional loading information associated with the threshold scenario developed for this Report. Table VIII-4 shows the change to the total watershed loads, based upon the removal of septic loads depicted in Table VIII-3. For Example, removal of 100% of the septic load from the Meetinghouse Pond sub-watershed results in an 83% reduction in total nitrogen load to that sub-embayment. Table VIII-4 shows the breakdown of threshold sub-embayment and surface water loads used for total nitrogen modeling. In Table VIII-5, loading rates are shown in kilograms per day, since benthic loading varies throughout the year and the values shown represent ‘worst-case’ summertime conditions. Table VIII-5 illustrates the significant role of atmospheric deposition relative to the total nitrogen load to the Pleasant Bay system. Unlike most estuarine systems in southeastern Massachusetts, the water surface area of the estuarine system is large relative to the overall watershed area. For the case of Pleasant Bay, the atmospheric load actually is larger than the watershed nitrogen load under the selected conditions necessary to meet the various thresholds. In addition, benthic flux within the main body of Pleasant Bay is larger than either the threshold watershed load or the atmospheric deposition. Again, the significant magnitude of the load associated with benthic regeneration within Pleasant Bay is caused by the substantial surface area of the water body.

Model results for the septic load removal scenario described in Table VIII-3 achieve the target bioactive nitrogen concentrations at the primary and secondary sentinel stations, as shown in Table VIII-6 and Figure VIII-1. To achieve the threshold nitrogen concentrations at the sentinel stations, a reduction in bioactive nitrogen concentration of between 15% and 40% is required in the upper regions of the Pleasant Bay system, with bioactive nitrogen reduction levels decreasing toward Chatham Harbor and New Inlet. The maximum reduction in bioactive nitrogen levels occurs in Upper Muddy Creek, followed by Meetinghouse Pond, Lower Frost Fish Creek, Ryders Cove, and Upper Pochet, respectively.

The results from the 2 tributary sub-embayments, Muddy Creek and Bassing Harbor requires a higher proportional amount of nitrogen removal to achieve the threshold nitrogen level than was previously determined by the MEP analysis in 2003. Note that for watershed planning it is the proportion of septic systems being removed that is the critical consideration. The reason for the increased wastewater nitrogen management within the sub-watersheds associated with these sub-embayments stems from the significantly larger data base on water quality and habitat health and the ability (for the first time) to accurately determine the water quality of the Pleasant Bay waters which flow into these sub-embayments.

In the earlier analysis (2003), it was noted that a refinement would be needed, since restoration of these 2 sub-embayments is effected by the nitrogen levels in Pleasant Bay waters as the boundary condition. The integration of the 2 previous models (Muddy Creek and Bassing Harbor) into the Pleasant Bay System-wide model decreased uncertainty of model parameters and allowed for the necessary evaluation of these sub-embayments in the context of the Pleasant Bay System as a whole. However, this integration required that the previous models for Muddy Creek and Bassing Harbor be recalibrated and revalidated as part of being joined to the large system-wide model.

The specific reasons for the greater level of wastewater management (i.e. proportional reduction in septic system loadings) for these 2 sub-systems to Pleasant Bay are: (1) the near doubling of the water quality database yielding a better assessment of the nitrogen levels relative to the habitat indicators and (2) the sub-system habitats relative to nitrogen levels could also be compared to other similar areas within Pleasant Bay. Both of these factors resulted in the selection of a nitrogen threshold for these sub-systems which was at the low end of the stated acceptable range presented in the 2003 analysis (0.523 mgTN-N/L versus 0.527-0.553 mgTN-N/L). It is the shift in threshold that required that more title 5 septic system be taken off-line in the threshold loading analysis (Table VIII-3). In addition, in the earlier analysis it was not possible to develop an accurate boundary condition for Muddy Creek, as the system-wide model for Pleasant Bay was not available. It was clear in the earlier effort that nitrogen management in the Muddy Creek sub-embayment was linked to the adjacent Pleasant Bay waters. It should be noted that due to the proportional nature of the shift in sub-watershed nitrogen loads as determined in the 2003 report the shift does not effect the level of wastewater management required to meet the threshold. If the threshold and boundary condition parameters had not been refined for the present effort, the number of homes requiring wastewater nitrogen management (for example, number of residences to be hooked to a WWTF), would not have changed. Taking that into consideration, it is useful to indicate the reasons for the watershed loading shift for these 2 sub-embayments. First, the Town of Chatham requested that the MEP move forward with 3 quarters of water-use data, as that was all that was available. The MassDEP decided that the MEP should move forward, partially because these 2 sub-embayments would be refined in the Pleasant Bay analysis. This led to an overestimate of the extent of the wastewater load. While the water use data was inflated (as subsequent analysis of years of data collected by the CCC, the Chatham TAC and CAC has demonstrated), it also had secondary effects on estimates of population that were based on water use. A second issue resulted from use of the wastewater effluent and consumptive use terms that inflated the per capita load contribution. These issues were discovered very early on and resolved. Most importantly, wastewater planning is not effected by these input data issues. In sensitivity analyses conducted by the Technical Team in 2004, changes in wastewater coefficients of 33% resulted in only a 1%-2% change in the proportion of dwellings that needed to be hooked to a WWTF to accomplish habitat restoration. This results from the robustness of the models. However, it should be noted that it is not possible to set a threshold under one set of conditions and then compare the load reductions required using another set of conditions. It only works when a consistent set of input data are used throughout the analysis.

Table VIII-3. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading under one possible restoration scenario of the Pleasant Bay system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Meetinghouse Pond	5.140	0.000	-100.0%
The River – upper	2.071	1.036	-50.0%
The River – lower	2.871	1.436	-50.0%
Lonnies Pond	1.630	0.815	-50.0%
Areys Pond	0.778	0.389	-50.0%
Namequoit River	2.011	1.005	-50.0%
Paw Wah Pond	1.510	0.377	-75.0%
Pochet Neck	6.614	2.315	-65.0%
Little Pleasant Bay	4.512	2.256	-50.0%
Quanset Pond	1.403	0.701	-50.0%
Tar Kiln Stream	1.797	0.899	-50.0%
Round Cove	3.162	1.897	-40.0%
The Horseshoe	0.474	0.474	0.0%
Muddy Creek - upper	7.156	1.789	-75.0%
Muddy Creek - lower	6.340	0.000	-100.0%
Pleasant Bay	13.077	6.538	-50.0%
Pleasant Bay/Chatham Harbor Channel	-	-	-
Bassing Harbor - Ryder Cove	7.137	1.784	-75.0%
Bassing Harbor - Frost Fish Creek	2.200	0.000	-100.0%
Bassing Harbor - Crows Pond	3.326	3.326	0.0%
Bassing Harbor	1.400	1.400	0.0%
Chatham Harbor	14.195	14.195	0.0%
TOTAL - Pleasant Bay System	88.803	42.632	-52.0%

Table VIII-4. Comparison of sub-embayment ***total watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present and threshold loading under one possible restoration scenario of the Pleasant Bay system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Meetinghouse Pond	6.197	1.058	-82.9%
The River – upper	2.773	1.737	-37.4%
The River – lower	3.879	2.444	-37.0%
Lonnies Pond	2.441	1.626	-33.4%
Areys Pond	1.304	0.915	-29.8%
Namequoit River	2.737	1.732	-36.7%
Paw Wah Pond	1.860	0.728	-60.9%
Pochet Neck	8.422	4.123	-51.0%
Little Pleasant Bay	7.496	5.240	-30.1%
Quanset Pond	1.781	1.079	-39.4%
Tar Kiln Stream	6.123	5.225	-14.7%
Round Cove	4.225	2.960	-29.9%
The Horseshoe	0.638	0.638	0.0%
Muddy Creek - upper	9.981	4.614	-53.8%
Muddy Creek - lower	8.477	2.137	-74.8%
Pleasant Bay	23.159	16.621	-28.2%
Pleasant Bay/Chatham Harbor Channel	-	-	-
Bassing Harbor - Ryder Cove	9.819	4.466	-54.5%
Bassing Harbor - Frost Fish Creek	2.904	0.704	-75.8%
Bassing Harbor - Crows Pond	4.219	4.219	0.0%
Bassing Harbor	1.668	1.668	0.0%
Chatham Harbor	17.099	17.099	0.0%
TOTAL - Pleasant Bay System	127.203	81.032	-36.3%

Table VIII-5. Threshold sub-embayment loads used for bioactive nitrogen (DIN+PON) modeling of the Pleasant Bay system under one possible restoration scenario, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	watershed load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Meetinghouse Pond	1.058	0.584	7.857
The River – upper	1.737	0.288	4.102
The River – lower	2.444	2.241	8.517
Lonnies Pond	1.626	0.225	1.304
Areys Pond	0.915	0.181	4.929
Namequoit River	1.732	0.523	12.232
Paw Wah Pond	0.728	0.082	2.665
Pochet Neck	4.123	1.767	-0.622
Little Pleasant Bay	5.240	24.023	35.222
Quanset Pond	1.079	0.170	4.787
Tar Kiln Stream	5.225	0.066	-
Round Cove	2.960	0.170	6.739
The Horseshoe	0.638	0.063	-
Muddy Creek - upper	4.614	0.162	2.700
Muddy Creek - lower	2.137	0.205	-0.710
Pleasant Bay	16.621	19.153	134.187
Pleasant Bay/Chatham Harbor Channel	-	17.786	-38.017
Bassing Harbor - Ryder Cove	4.466	1.296	6.705
Bassing Harbor - Frost Fish Creek	0.704	0.096	-0.087
Bassing Harbor - Crows Pond	4.219	1.389	0.612
Bassing Harbor	1.668	1.071	-4.460
Chatham Harbor	17.099	14.153	-38.398
TOTAL - Pleasant Bay System	**81.032**	**85.693**	**150.264**

Table VIII-6. Comparison of model average bioactive N (DIN+PON) concentrations from present loading and the threshold scenario, with percent change, under one possible restoration scenario for the Pleasant Bay system. Loads are based on atmospheric deposition and a scaled N benthic flux (scaled from present conditions). The threshold stations for eelgrass restoration are shown in bold print (0.16 mg/L at PBA-12 and the average of PBA-03 and CM-13) and for benthic infauna restoration are shown in italics (0.21 mg/L at WMO-10, PBA-15, WMO-6, WMO-5, PBA-11, WMO-12, PBA-09 and PBA-05).

Sub-Embayment	monitoring station	present (mg/L)	Threshold (mg/L)	% change
Meetinghouse Pond	PBA-16	0.380	0.262	-31.1%
Meetinghouse Pond (Outer)	*WMO-10*	*0.261*	*0.207*	*-20.7%*
The River - upper	WMO-09	0.239	0.196	-18.0%
The River – mid	WMO-08	0.211	0.182	-14.0%
Lonnies Pond (Kescayo Ganset Pond)	*PBA-15*	*0.250*	*0.208*	*-16.7%*
Areys Pond	PBA-14	0.297	0.253	-14.9%
Namequoit River - upper	*WMO-6*	*0.239*	*0.206*	*-13.6%*
Namequoit River - lower	WMO-7	0.216	0.188	-13.0%
The River - lower	PBA-13	0.195	0.172	-11.9%
Pochet – upper	*WMO-05*	*0.269*	*0.211*	*-21.3%*
Pochet - lower	WMO-04	0.209	0.179	-14.1%
Pochet – mouth	WMO-03	0.183	0.164	-10.4%
Little Pleasant Bay - head	**PBA-12**	**0.178**	**0.160**	**-10.1%**
Little Pleasant Bay - main basin	PBA-21	0.162	0.148	-8.5%
Paw Wah Pond	*PBA-11*	*0.257*	*0.209*	*-18.8%*
Little Quanset Pond	*WMO-12*	*0.229*	*0.194*	*-15.3%*
Quanset Pond	WMO-01	0.191	0.171	-10.8%
Round Cove	*PBA-09*	*0.241*	*0.207*	*-13.9%*
Muddy Creek - upper	PBA-05a	0.674	0.405	-40.0%
Muddy Creek - lower	*PBA-05*	*0.286*	*0.208*	*-27.3%*
Pleasant Bay - head	PBA-08	0.149	0.139	-7.1%
Pleasant Bay - off Quanset Pond	WMO-02	0.160	0.147	-8.0%
Pleasant Bay- upper Strong Island	PBA-19	0.117	0.113	-3.8%
Pleasant Bay - mid west basin	PBA-07	0.168	0.153	-8.9%
Pleasant Bay - off Muddy Creek	PBA-06	0.192	0.169	-12.0%
Pleasant Bay - Strong Island channel	PBA-20	0.124	0.118	-4.8%
Ryders Cove - upper	**PBA-03**	**0.250**	**0.190**	**-24.0%**
Ryders Cove - lower	**CM-13**	**0.158**	**0.138**	**-12.7%**
Frost Fish - lower	CM-14	0.243	0.173	-29.1%
Crows Pond	PBA-04	0.162	0.149	-8.0%
Bassing Harbor	PBA-02	0.127	0.120	-6.0%
Pleasant Bay - lower	PBA-18	0.116	0.112	-3.9%
Chatham Harbor - upper	PBA-01	0.104	0.102	-1.9%
Chatham Harbor - lower	PBA-17a	0.099	0.098	-1.0%

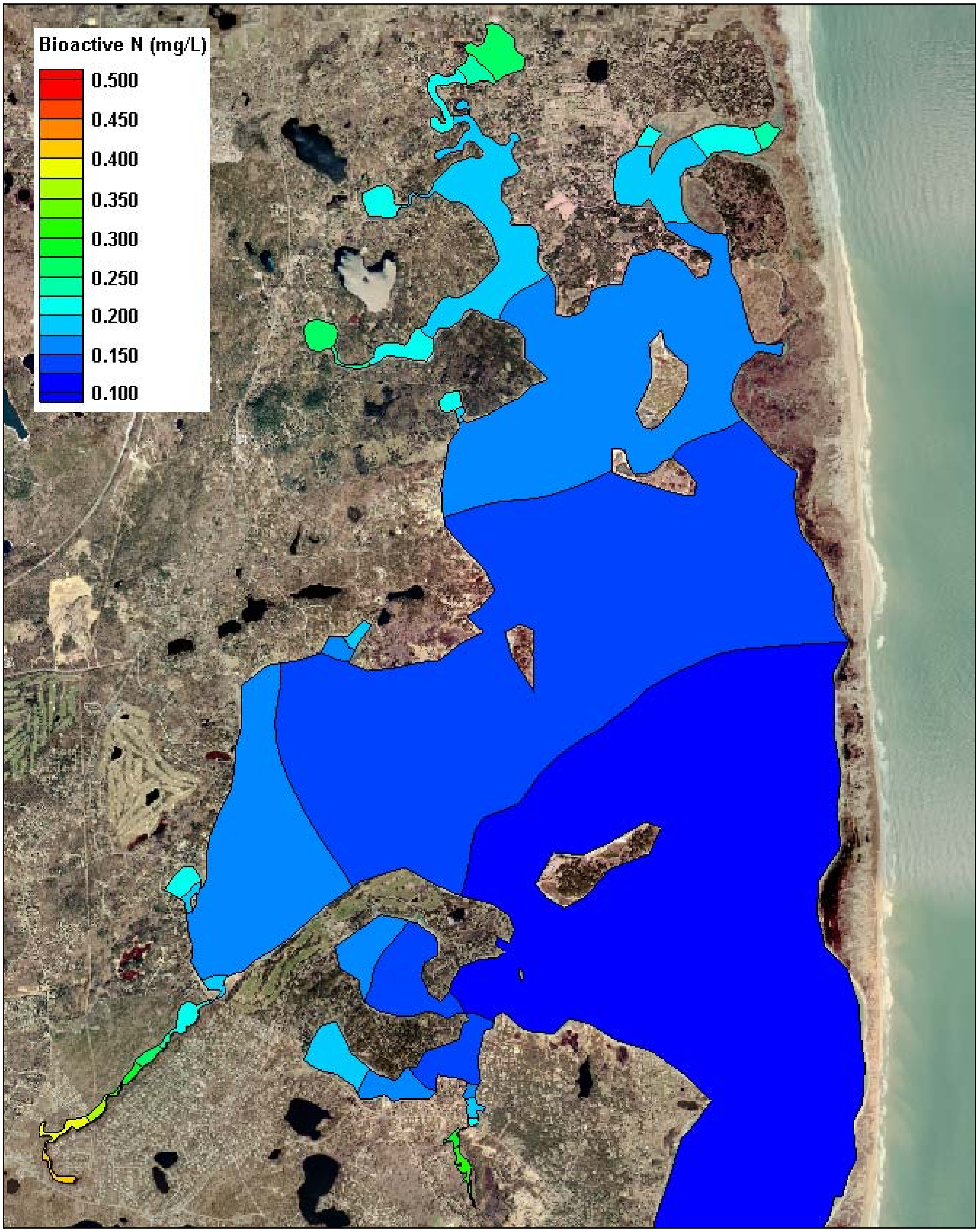

Figure VIII-1. Contour plot of modeled bioactive nitrogen (DIN+PON) concentrations (mg/L) in the Pleasant Bay system, for threshold conditions (0.16 mg/L at Upper Little Pleasant Bay and Ryder Cove).