# 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 integration of key habitat parameters (infauna and eelgrass), sediment characteristics, and nutrient related water quality information (particularly dissolved oxygen and chlorophyll) a). Additional information on temporal changes within each sub-embayment and its associated watershed nitrogen load further strengthens the analysis. These data were collected by the MEP to support threshold development for the Lewis Bay Embayment System and were discussed in Chapter VII. Nitrogen threshold development builds on this data and links habitat quality to summer water column nitrogen levels from the baseline Water Quality Monitoring Program coordinated between the Towns of Barnstable and Yarmouth (with technical and analytical support from the Coastal Systems Program at SMAST-UMass Dartmouth).

The Lewis Bay Embayment System is a complex estuary composed of 2 functional types of component basin types: embayments (Lewis Bay, Uncle Roberts Cove, Hyannis Inner Harbor) and a salt marsh pond/embayment (Mill Creek). In addition, associated with the Lewis Bay System is the adjacent Halls Creek Estuary, which like Mill Creek is primarily a salt marsh surrounding an open water basin. Halls Creek was included in the Lewis Bay MEP analysis as it receives nitrogen enriched groundwater resulting from discharge of treated effluent from the Hyannis WWTF. This discharge and almost all of the treated wastewater originates within the Lewis Bay watershed. Each of these 2 functional components (embayment and salt marsh) has different natural sensitivities to nitrogen enrichment and organic matter loading. Evaluation of eelgrass and infaunal habitat quality must consider the natural structure of each system and their ability to support eelgrass beds and specific types of infaunal communities.

At present, the Lewis Bay Embayment System is showing variations in nitrogen enrichment and habitat quality among its various component basins. In general the system is showing healthy to moderately impaired benthic habitat. However, the smaller tributary embayments and limited inner areas of Lewis Bay (e.g. Uncle Roberts Cove, Hyannis Inner Harbor) are presently moderately impaired based upon infaunal habitat criteria. Overall, the dominant habitat issue for this system is the significant impairment of the Lewis Bay basin and Uncle Roberts Cove, based on eelgrass criteria. Historical eelgrass beds have been lost in these areas and eelgrass is virtually non-existent within this system. These significantly impaired habitats comprise ca. 90% of the estuarine area of the Lewis Bay Embayment System. In contrast, the Halls Creek System is presently supporting high quality habitat, representative of a New England salt marsh system. As there is no record of eelgrass within this system, typical of salt marshes, the primary resource within the basin relates to infaunal animal communities.

***Eelgrass:*** The present virtual absence of eelgrass throughout the Lewis Bay Embayment System is consistent with the observed nitrogen and the chlorophyll levels and functional basin types comprising this estuary. Lewis Bay and Uncle Roberts Cove supported extensive eelgrass beds in 1951 under lower nitrogen loading conditions.

Currently, eelgrass exists only within a small portion at the tidal inlet of Lewis Bay. The absence of eelgrass throughout the Lewis Bay Embayment System is consistent with the observed moderate level of nutrient enrichment throughout each of the sub-embayments to this complex estuary. Total nitrogen levels (TN) within the lower basins that supported eelgrass in

1951 (Lewis Bay and Uncle Roberts Cove) have mean summertime levels of ~0.4 mg N $L^{-1}$ compared to the levels at the outer beds in adjacent Hyannis Harbor of 0.30-0.35 mg N $L^{-1}$ (monitoring data, Chapter VI). Other key water quality indicators, dissolved oxygen and chlorophyll a, show similar levels of moderate enrichment with periodic oxygen depletions below 5-4 mg/L and chlorophyll levels of 3-6 ug/l to 2-10 ug/l in the Lewis Bay basin and 5-15 ug/L in Uncle Roberts Cove. Given the sensitivity of eelgrass to declining light penetration resulting from nutrient enrichment and secondary effects of organic enrichment and oxygen depletion, the loss of eelgrass in these basins is expected.

The observed pattern of loss is consistent with nutrient enrichment and it appears that the major environmental differences between the Hyannis Harbor sites and Lewis Bay sites are related to nitrogen enrichment. In estuaries on Cape Cod, the general pattern is for highest nitrogen levels to be found within the innermost basins, with concentrations declining moving toward the tidal inlet. This pattern is also observed in nutrient related habitat quality parameters, like phytoplankton, turbidity, oxygen depletion, etc. The consequence is that eelgrass bed decline typically follows a pattern of initial loss in the innermost basins (and sometimes also from the deeper waters of other basins). The temporal pattern is a “retreat” of beds toward the region of the tidal inlet. It appears from the eelgrass and water quality information that eelgrass beds within Lewis Bay and Uncle Roberts Cove have declined as a result of nitrogen enrichment and should be the target for restoration and that this habitat would be recovered with appropriate nitrogen management. Recovery generally follows the reverse pattern of eelgrass loss, with colonization first in the outer and shallow basin areas and later within the inner basin and tributaries.

The other sub-embayments to the Lewis Bay System do not have evidence of ever having supported eelgrass habitat. The basins of Mill Creek are strongly influenced by surrounding tidal salt marshes and as such, do not typically support eelgrass habitat. Salt marsh basins are generally shallow, nutrient and organic matter enriched based on their structure and function and generally show summertime oxygen depletion, conditions not supportive of eelgrass. Basins like Hyannis Inner Harbor may support eelgrass habitat under low to moderate nitrogen loading conditions. However, this sub-basin to the Lewis Bay system is a busy working harbor, which is dredged for navigation, lacked eelgrass even in the 1951 analysis, and has no other evidence of eelgrass coverage within the past 75 years. The necessary conclusion is therefore that this small basin should not be considered for eelgrass restoration within Lewis Bay System.

It appears from the eelgrass and water quality information that eelgrass beds within the Lewis Bay main basin and Uncle Roberts Cove should be the target for restoration and that this habitat should be recovered with appropriate nitrogen management. From the historical analysis, it appears that more than 212 acres of eelgrass habitat could be recovered, if nitrogen management alternatives were implemented. More acreage recovered is likely, as the analysis of the 1951 aerial photography is likely to have underestimated the acreage of eelgrass habitat within Lewis Bay. Note that restoration of this habitat will necessarily result in restoration of other resources throughout the Lewis Bay Embayment System. Since Uncle Roberts Cove, Hyannis Inner Harbor and Mill Creek all receive flood tidal waters from Lewis Bay, nitrogen management focused on lowering nitrogen levels within this large lagoon will de facto result in a lowering of nitrogen levels throughout the estuarine system. Therefore, an improvement of infaunal habitats in each of the 3 tributary sub-embayments will result. It appears that only limited nitrogen reduction is required as Hyannis Inner Harbor and Mill Creek have traditionally only supported infaunal habitat and are only moderately impaired. Similarly, though Uncle Roberts Cove is considered significantly impaired as a result of losing its eelgrass coverage, its nitrogen levels are presently only 0.4 mg N $L^{-1}$ (tidally averaged) and are controlled primarily by nitrogen levels in flood waters from Lewis Bay and rates of flushing.

Based upon the above analysis, eelgrass habitat was selected as the primary nitrogen management goal for Lewis Bay and Uncle Roberts Cove while infaunal habitat quality was selected as the management target for Hyannis Inner Harbor and possibly Mill Creek. These goals are the focus of the MEP management alternatives analysis presented in Chapter IX.

**Water Quality:** Overall, the oxygen levels within the major sub-basins to the Lewis Bay Embayment System are indicative of relatively healthy or only moderately impaired conditions. This is based on the definition of the Hyannis Inner Harbor and Mill Pond basins as infaunal habitats (e.g. historically have not supported eelgrass) and consideration of each sub-basins physical structure and natural biogeochemical cycling. Similar to other embayments in southeastern Massachusetts, the inner basins evaluated in this assessment showed high frequency variation, apparently related to diurnal and tidal influences. Nitrogen enrichment of embayment waters generally manifests itself in the dissolved oxygen record, both through oxygen depletion and through the magnitude of the daily excursion. The high degree of temporal variation in bottom water dissolved oxygen concentration at each mooring site underscores the need for continuous monitoring within these systems.

The level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll a levels indicate moderately nutrient enriched waters within each sub-embayment basin to Lewis Bay. The oxygen data is consistent with organic matter enrichment, primarily from phytoplankton production, as seen from the parallel measurements of chlorophyll a. The measured levels of oxygen depletion and enhanced chlorophyll a levels match the spatial pattern of total nitrogen concentrations in this system. The parallel variation in these water quality parameters is consistent with watershed based nitrogen enrichment of this estuarine system.

The oxygen records show that the inner sub-embayments of Mill Creek and Hyannis Harbor, which receive significant watershed nitrogen loads, have the largest daily oxygen excursions (a nutrient related response). The effect of nitrogen enrichment is to cause oxygen depletion; however, with increased phytoplankton (or epibenthic algae) production, oxygen levels will rise in daylight to above atmospheric equilibration levels in shallow systems (generally ~7-8 mg $L^{-1}$ at the mooring sites). The clear evidence of oxygen levels above atmospheric equilibration indicates that the upper tidal reaches of the Lewis Bay system are nitrogen enriched. In contrast, oxygen levels within Lewis Bay were generally high and chlorophyll a and total nitrogen showed a low level of enrichment, consistent with the generally high level of infaunal habitat quality and the recent loss of the eelgrass that is more sensitive to nutrient enrichment.

Measured dissolved oxygen depletion indicates that the Lewis Bay sub-embayments, Uncle Robert's Cove and to a lesser extent, Hyannis Inner Harbor, exhibit moderate levels of oxygen stress. The largest oxygen depletions were observed in Mill Creek, but this is primarily functioning as a salt marsh pond. As such this system is naturally nutrient and organic matter enriched, with oxygen depletions common. The observed spatial pattern indicated increasing levels of oxygen depletion (Table VII-1) and chlorophyll a (Table VII-2), and increased total nitrogen levels with increasing distance from the tidal inlet and into the smaller sub-embayments. The pattern of oxygen depletion, elevated chlorophyll a and nitrogen levels is consistent with the observed pattern of eelgrass loss (Section VII.3) and quality of infaunal habitats (Section VII.4). All the information put together reflects an estuarine system that is beyond its ability to assimilate nitrogen loads without impairment.

***Infaunal Communities:*** The infaunal study indicated an overall system supporting generally healthy to only moderately impaired infaunal habitat relative to the ecosystem types represented (i.e. embayment versus salt marsh creek/pond). The range of habitat quality within Lewis Bay, results from a gradient in nutrient related habitat degradation from the inland reaches to the high quality habitat near the tidal inlet. This gradient continues into Hyannis Harbor and Uncle Roberts Cove. While the basin of Mill Creek is naturally nutrient and organic matter enriched, the present conditions of macroalgae and high chlorophyll a levels suggest a moderate level of impairment for this system as well.

The outer stations within Lewis Bay currently support high numbers of individuals distributed among a large number of species (32). The community is composed of a variety of polychaete, crustacean and mollusk species, with high diversity and eveness. The data are clearly indicative of a high quality embayment habitat. Throughout the rest of the large basin of Lewis Bay, infaunal communities are indicative of a high to slightly impaired benthic habitat (in limited areas). In contrast, Uncle Roberts Cove had depleted benthic communities, a pattern observed in systems with periodic oxygen stress. The benthic habitat in this tributary system is clearly significantly impaired. Hyannis Inner Harbor showed infauna typical of a moderately nitrogen enriched basin. The communities showed high spatial variability, with some species found in very high numbers (*Gemma*). However, the number of species remained moderate-high and stress indicator species were not prevalent, so only a moderate level of impairment was evident. The benthic habitat data was consistent with the levels of total nitrogen (0.518-0.574 mg N $L^{-1}$, tidally averaged) and chlorophyll a and oxygen depletion in this basin.

Mill Creek showed infaunal communities consistent with a salt marsh basin, with moderate numbers of species and individuals, and species indicative of a nutrient and organic rich environment, but not nutrient contamination (i.e. not Capitella). Deposit and filter feeders were observed at these sites with mollusks and crustaceans. The benthic habitat data suggests a high quality infaunal habitat, but did appear to be "patchy", potentially the result of drift algae. This variability is cause for concern as it suggests that this system may be moderately impaired. However, in general the habitat appeared typical of larger salt marsh basins in less developed watersheds

Overall, the infaunal habitat quality was consistent with the gradients in dissolved oxygen, chlorophyll, nutrients and organic matter enrichment in this system. Classification of habitat quality necessarily included the structure of the specific estuarine basin, specifically as to it being dominated by wetlands versus being more characteristic of a tidal embayment. Based upon this analysis it is clear that the tributary sub-embayment basins are presently supporting moderately to significantly impaired benthic habitat, while the main basin of Lewis Bay is generally of high quality. The Mill Creek basin is supporting moderately impaired habitat for a salt marsh basin. Impairment in these basins is through nitrogen and organic matter enrichment.

Table VIII-1. Summary of Nutrient Related Habitat Health within the Lewis Bay Embayment System on Nantucket Sound within the Towns of Barnstable and Yarmouth, MA., based upon assessment data presented in Chapter VII. The main basin of Lewis Bay and its tributary sub-embayments of Hyannis Inner Harbor and Uncle Roberts Cove are typical coastal embayment basins. In contrast, Mill Creek is primarily a salt marsh basin.

| Health Indicator | Lewis Bay Embayment System | | | | | |
|---|---|---|---|---|---|---|
| | Lewis Bay | | Uncle Roberts Cove | Hyannis Inner Harbor | Mill Creek | Halls Creek |
| | Outer | Inner | | | | |
| Dissolved Oxygen | H-MI[2] | MI-SI[3] | MI-SI[4] | H-MI[2] | H-MI[1, 15] | H[24] |
| Chlorophyll | H-MI[5] | MI[6] | MI-SI[7] | MI[6] | MI[8] | H[5] |
| Macroalgae | MI[9] | MI[9] | MI[10] | --[11] | MI[12] | --[11] |
| Eelgrass | SI[13] | SI[13] | SI[13] | --[14] | --[14] | --[14] |
| Infaunal Animals | H[16] | H-MI[17] | SI[18] | MI[19] | H[20] | H[20] |
| **Overall:** | **SI[21]** | **SI[21]** | **SI[21]** | **MI[22]** | **MI[23]** | **H** |

1 – primarily a salt marsh pond, periodic oxygen depletions to <4 mg/L, very rarely to 3-2 mg/L.
2 – oxygen levels generally >6 mg/L, with periodic depletions 6-5 mg/L.
3 – oxygen depletions periodically 4-3 mg/L, generally >5 mg DO/L.
4 -- oxygen depletions periodically to 4-4.5 mg/L, with infrequent declines to 3.7 mg/L.
5 – low to moderate chlorophyll a levels generally 3-6 ug/L, generally <5 ug/L 73% of time.
6 – moderate chlorophyll a levels generally ~3-10 ug/L, generally >5 ug/L frequently >10 ug/L
7 – elevated chlorophyll a levels generally 5-15 ug/L, frequently >13 ug/L
8 – high chlorophyll a levels generally >10 ug/L, frequently >20 ug/L
9 – extensive attached dense bed of *Codium* throughout basin, serving as SAV.
10 -- moderate amounts of filamentous drift algae
11 -- drift algae sparse or absent, little surface microphyte mat.
12 -- moderate to high levels of drift algae, Ulva and Codium some in situ, some transported in
13 -- eelgrass lost from this system between 1951-1995.
14 – no evidence this basin is supportive of eelgrass.
15 -- basin supports fringing salt marsh areas.
16 -- Inlet: high numbers, diversity, eveness, large #'s polychaete, crustacean, mollusk species
17 -- moderate numbers of species and high-moderate number individuals;
high-moderate diversity and eveness; with polychaetes, mollusks and crustaceans
18 -- low numbers of species and individuals, organic enrichment indicators
19 -- moderate-high (*Gemma*) numbers of individuals, moderate species, moderate H' & Eveness
20 -- Infauna: moderate numbers of individuals, moderate species, high diversity and
Eveness; organic enrichment indicators typical of salt marsh ponds, some deep burrowers.
21 -- Significant Impairment based upon loss of eelgrass from system, 1951-1995.
22 -- Moderate Impairment based upon moderate oxygen depletion, elevated chlorophyll;
variable infaunal communities, with wide range of numbers, moderate numbers of species
with organic enrichment indicators (*Spionids, Gemma, Mullinia*).
23 -- Moderate Impairment based primarily on the high sustained chlorophyll levels.
24 – No moorings were deployed, monitoring data showed moderate depletion of oxygen.

H = healthy habitat conditions; MI = Moderate Impairment; SI = Significant Impairment;
SD = Severe Degradation; -- = not applicable to this estuarine reach

The results of the infauna survey indicate that the nitrogen management threshold analysis (Section VIII.2) needs to include a lowering of the level of nitrogen enrichment in Hyannis Inner Harbor and Uncle Roberts Cove and potentially in Mill Creek thereby leading to restoration of nitrogen impaired benthic habitats. However, it is important to note that in general the Lewis Bay Embayment System is supportive of high quality infauna habitat throughout much basin area. Although there are some moderately impaired infaunal habitats within the Lewis Bay Embayment System, restoration needs to also target eelgrass habitat. While most of Lewis Bay shows high quality infauna habitat, it is clearly significantly impaired based on eelgrass criteria, since historical eelgrass beds have been recently lost. As a result, both eelgrass and infaunal animal habitats are impaired in this estuary, and nitrogen management is required for their restoration.

All of the key habitat indicators are consistent within the Halls Creek Estuary, and particularly its tidal creeks, supporting high quality habitat in line with the system's salt marsh structure and function (Chapter VII). Similar to other salt marshes throughout the region, Halls Creek does not appear structured to support eelgrass beds. In contrast, the systems is presently supporting high quality infaunal animal habitat typical of organic rich New England salt marshes, hence high quality relative to this estuarine ecosystem type. This is consistent with the absence of significant accumulations of drift macroalgae within the creek bottoms which can result if there is "excessive" external nitrogen loading. The absence of macroalgal accumulations is consistent with the low levels of total nitrogen within this system, 0.385-0.469 mg N $L^{-1}$ (tidally averaged). Based upon all lines of evidence it appears that the Halls Creek Estuary is presently supporting high quality infaunal habitat and has not exceeded its threshold nitrogen level for assimilating additional nitrogen without impairment.

## 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. 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 sequentially adjust nitrogen loads until the targeted nitrogen concentration is achieved.

Determination of the critical nitrogen thresholds for maintaining high quality habitat within Lewis Bay Embayment System and Halls Creek are based primarily upon the nutrient and oxygen levels, temporal trends in eelgrass distribution and current benthic community indicators. Given such a database, it is possible to develop a site-specific threshold, which is a refinement upon more general threshold analyses frequently employed.

*Lewis Bay Estuary:* The Lewis Bay Embayment System presently supports a range of infaunal habitat quality. Within Lewis Bay, a gradient in nutrient related habitat degradation was observed from the inland reach to the high quality habitat near the tidal inlet. This gradient continues into Hyannis Harbor and Uncle Roberts Cove. While the basin of Mill Creek is naturally nutrient and organic matter enriched, the present conditions of macroalgae and high chlorophyll a levels suggest a moderate level of impairment for this system as well. However, the primary habitat issue within the Lewis Bay Embayment System relates to the loss of the extensive eelgrass beds from Lewis Bay and the shallow marginal beds from Uncle Roberts Cove. This loss of eelgrass classifies these areas as "significantly impaired", although Lewis

Bay presently supports generally high quality infaunal communities. The impairments to both the infaunal habitat and the eelgrass habitat within the component basins of the Lewis Bay Embayment System are supported by the variety of other indicators, oxygen depletion, chlorophyll, and TN levels, all of which support the conclusion that these impairments are the result of nitrogen enrichment, primarily from watershed nitrogen loading.

The habitat assessment data are also internally consistent. For example, the observed loss of eelgrass, and continuing presence of SAV (*Codium*) within the Lewis Bay basin, suggests a system not far above its nitrogen threshold level supportive of eelgrass. The tidally averaged nitrogen levels throughout Lewis Bay were found to range from 0.385-0.415 mg N $L^{-1}$, compared to the inlet station (adjacent existing beds) that supported a TN concentration of 0.369 mg N $L^{-1}$ (tidally averaged). Similarly, the moderate impairment of infaunal habitat in the inner basins of Hyannis Inner Harbor is consistent with the moderate levels of oxygen depletion, chlorophyll a enhancement and tidally averaged total nitrogen levels of 0.518-0.574 mg N $L^{-1}$.

Only Uncle Roberts Cove can be classified as having both significantly impaired eelgrass and infaunal habitats. The observed loss of eelgrass is consistent with the observed oxygen depletions and elevated chlorophyll and total nitrogen levels (0.432 mg N $L^{-1}$). The impairment to infauna appears to be related to structural features of the inner basin that provide for a depositional environment and supports periodic stratification and oxygen depletion. The effect of the sedimentation of the inlet to the Cove in enhancing the impacts of nitrogen enrichment in this basin needs to be evaluated. However, as the infaunal community is presently diverse, small reductions in organic matter deposition to reduce the level of oxygen depletion will likely be sufficient to restore this habitat.

The results of the water quality and infaunal data, coupled with the temporal trends in eelgrass coverage, clearly support the need to lower nitrogen levels within Lewis Bay and Uncle Roberts Cove in order to restore eelgrass habitat. Lesser loading reductions would be necessary within Hyannis Inner Harbor and potentially in Mill Creek for restoration of nitrogen impaired benthic habitats. Restoration of the limited areas of moderately impaired and areas of significantly impaired infaunal habitats within Lewis Bay and Uncle Roberts Cove, respectively, will be achieved with the restoration of eelgrass habitat within these basins.

Considering the eelgrass and water quality information it is clear that eelgrass beds within the Lewis Bay basin should be the primary target for restoration of the Lewis Bay Embayment System and that restoration would require appropriate nitrogen management. From the historical analysis, it appears that at least 200 acres of eelgrass habitat could be recovered, if nitrogen management alternatives are implemented. Therefore, the sentinel station (BHY-3) for the Lewis Bay Embayment System was selected based upon its location within the inner region of documented eelgrass coverage in this estuary. The sentinel station is within the mid basin of the easternmost basin of Lewis Bay (sometimes called Little Lewis Bay), between Pine Island and Englewood Beach and is a long-term sampling station of the Yarmouth/Barnstable Water Quality Monitoring Program.

The target nitrogen concentration (tidally averaged TN) for restoration of eelgrass at the sentinel location within Lewis Bay was determined to be 0.38 mg TN $L^{-1}$. As there is not high quality eelgrass habitat within the Lewis Bay Embayment System, this threshold was based upon comparison to other local embayments of similar depths and structure under MEP analysis as well as conditions near the eelgrass areas adjacent the tidal inlet to Hyannis Harbor. A well studied eelgrass bed within the lower Oyster River (Chatham) has been stable at a tidally averaged water column TN concentration of 0.37 mg N $L^{-1}$, while eelgrass was lost within the

Lower Centerville River at a tidally averaged TN concentration of 0.395 mg N $L^{-1}$, and also lost within Waquoit Bay at 0.39 mg N $L^{-1}$. The nitrogen threshold for the lower main basin of Popponesset Bay and for the complex Stage Harbor System was 0.38 mg N $L^{-1}$. These latter 2 systems have a similarly complex multiple component structure to the Lewis Bay System. These values from other Cape Cod embayments are consistent with the data from Lewis Bay. Eelgrass beds still exist to the west of the inlet to Lewis Bay within Hyannis Harbor. These beds are exposed to tidally averaged nitrogen levels of 0.37 mg N $L^{-1}$, similar to that in the Oyster River (Chatham). In addition, extensive SAV (*Codium*) persists within the main basin of Lewis Bay which has a basin-wide tidally averaged TN concentration of 0.393 mg N $L^{-1}$ (range 0.385-0.408 mg N $L^{-1}$). These site specific data indicate that the threshold for eelgrass in this system is between 0.370 and 0.393 (or 0.385) mg N $L^{-1}$, tidally averaged TN. This is strong support for the 0.380 mg N $L^{-1}$ value determined for the sentinel station (BHY-3). Restoration of the shallow marginal eelgrass habitat within Uncle Roberts Cove allows a higher TN threshold than within the deeper habitat of Lewis Bay.

The selection of the TN level for the shallow marginal bed within Uncle Roberts Cove followed the process noted above for the sentinel station. Since water depth is important in determining the criteria for eelgrass restoration, as the same phytoplankton concentration that results in shading of eelgrass in deep water will allow sufficient light to support eelgrass in shallow water, the shallower water at the upper basin site allows for a higher TN level compared to the sentinel station. Analysis of comparable beds within the Green Pond Estuary (Falmouth) recommends the secondary criteria for this site to be 0.40 mg TN $L^{-1}$ for stability. The target nitrogen concentration for restoration of eelgrass within the lower basin of Green Pond, was determined to be 0.40 mg TN $L^{-1}$ based in part upon the findings that: (1) eelgrass beds have been lost in that basin at 0.41 mg TN $L^{-1}$, although sparse eelgrass were observed adjacent the inlet, (2) eelgrass beds in Bournes Pond in very shallow water persisted at 0.42 mg TN $L^{-1}$. It should be noted that 0.40 mg N $L^{-1}$ within Uncle Roberts Cove is a secondary criteria to ensure restoration of eelgrass habitat within this sub-embayment and should be met when the threshold is met at the sentinel station in Lewis Bay. Nitrogen management specific to the watershed of Uncle Roberts Cove will likely not be required, although it will be important to maintain unrestricted tidal exchange to this basin. The sentinel station under present loading conditions supports a tidally averaged concentration of 0.408 mg TN $L^{-1}$, so watershed nitrogen management will be required for restoration of the estuarine habitats within this system.

Although the nitrogen management target is restoration of eelgrass habitat (and associated water clarity, shellfish and fisheries resources), benthic infaunal habitat quality must also be supported as a secondary condition. At present, the regions with moderately impaired infaunal habitat within the Hyannis Inner Harbor and the potentially impaired habitat within Mill Creek have total nitrogen (TN) levels in the range of 0.518 - 0.574 mg N $L^{-1}$. The observed moderate impairment at these sites is consistent with observations by the MEP Technical Team in other enclosed basins along Nantucket Sound (e.g. Perch Pond, Bournes Pond, Popponesset Bay) where levels <0.5 mg N $L^{-1}$ were found to be supportive of healthy infaunal habitat and in deeper enclosed basins in Buzzards Bay (e.g. Eel Pond in Bourne) where healthy infaunal habitat had a slightly lower threshold level, 0.45 mg N $L^{-1}$, due to it being a "deep" depositional basin. Similarly, the Centerville River system showed moderate impairment at tidally averaged TN levels of 0.526 mg N $L^{-1}$ in Scudder Bay (analogous to Mill Creek) and at 0.543 mg TN $L^{-1}$ in the middle reach of the Centerville River. Additionally, moderate impairment was also observed at the same TN levels (0.535-0.600 mg N $L^{-1}$) within the Wareham River, with high quality infaunal animal habitat at TN levels of 0.444-0.463 mg TN $L^{-1}$. Based upon these observations, the MEP Technical Team concluded that an upper limit of 0.50 mg N $L^{-1}$ tidally averaged TN would support healthy infaunal habitat in the Lewis Bay System.

For restoration of the Lewis Bay Embayment System, both the primary nitrogen threshold at the sentinel station and the secondary criteria within the sub-embayments need to be achieved. However, the secondary criteria established by the MEP are to merely provide a check on the acceptability of conditions within the tributary basins at the point that the threshold level is attained at the sentinel station. Three secondary criteria were established for the Lewis Bay Embayment System: (1) a TN level of 0.40 mg N $L^{-1}$ was set to restore the shallow marginal eelgrass bed within Uncle Roberts Cove (tidal average at BHY-4), this will also ensure restoration of infaunal habitat throughout that basin; (2) a tidally averaged TN level of <0.5 mg N $L^{-1}$ with the Hyannis Inner Harbor basin (average of BH-1 and BH-2) and (3) a tidally averaged TN level of <0.5 mg N $L^{-1}$ within the salt marsh basin of Mill Creek to reduce the magnitude of the phytoplankton blooms and improve infaunal habitat in the lower basin.

It should be emphasized that these secondary criteria values were not used for setting nitrogen thresholds in this embayment system. These values merely provide a check on the acceptability of conditions within the tributary basins at the point that the threshold level is attained at the sentinel station. The results of the Linked Watershed-Embayment modeling are used to ascertain that when the nitrogen threshold is attained, TN levels in these regions are within the acceptable range. The goal is to achieve the nitrogen target at the sentinel location and restore eelgrass habitat throughout Lewis Bay and Uncle Roberts Cove as well as infaunal habitat throughout the System. The nitrogen loads associated with the threshold concentration at the sentinel location and secondary infaunal check stations are discussed in Section VIII.3, below and depicted in Figure VIII-1.

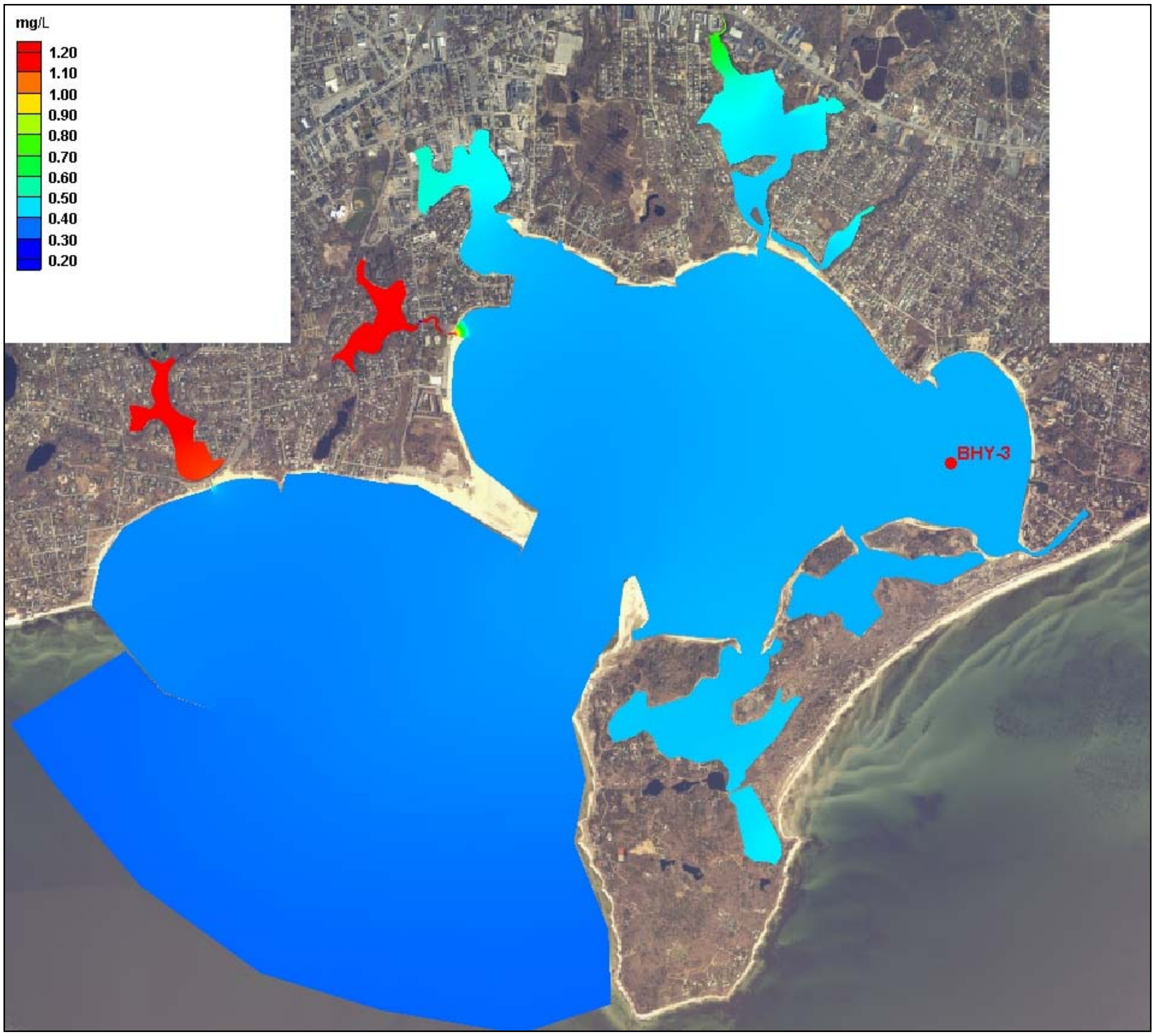


Figure VIII-1. Contour plot of modeled average total nitrogen concentrations (mg/L) in the Lewis Bay system, for threshold conditions (0.38 mg/L at water quality monitoring station BHY-3, and less than 0.5 at water quality monitoring station MC-1 and the average of stations BH-1 and BH-2). The approximate location of the sentinel threshold station for Lewis Bay (BHY-3) is shown.

*Halls Creek Estuary:* All of the key habitat indicators are consistent within the Halls Creek Estuary, and particularly its tidal creeks, supporting high quality habitat in line with the salt marsh structure and function of this system (Chapter VII). Given that Halls Creek does not appear to be a system structured to support eelgrass habitat, its nitrogen threshold needs to focus on infaunal animal communities. Overall, the infauna survey described in Chapter VII indicated that most areas within the creeks and basin of the Halls Creek Estuary are supporting infauna habitat typical of organic rich New England salt marshes, hence high quality relative to this estuarine ecosystem type. This is supported by the absence of macroalgal accumulations and algal mats within the creek bottoms which can result if there is "excessive" external nitrogen loading. The absence of macroalgal accumulations is consistent with the low total nitrogen levels within this system, 0.385-0.469 mg N $L^{-1}$ (tidally averaged). This is in comparison to a similar marsh, Cockle Cove Creek (Chatham), which supports high quality habitats, both emergent marsh and creek bottom, at levels of 2 mg N $L^{-1}$. Based upon all lines of evidence it appears that the Halls Creek Estuary is presently supporting high quality infaunal habitat and has not exceeded its threshold nitrogen level for assimilating additional nitrogen without impairment.

A principal component of the high tolerance of salt marsh systems to nitrogen inputs from groundwater and surface water inflows is that unlike embayments, creek waters cannot accumulate nutrients over multiple tidal cycles as embayments do. In addition, increasing the nitrogen concentration in the tidal waters that flood the marsh plain will have a negligible or possibly a stimulatory effect on marsh primary and likely secondary production (i.e. an enhancement of habitat). In addition, since the inflowing fresh waters flow down gradient through the marsh creek and out to the Centerville Harbor and Nantucket Sound, the nitrogen level in estuarine waters will never exceed the inflowing freshwater nitrogen level. As was the case for the Cockle Cove Creek system (similar in structure to the Halls Creek system), it was determined that a highly conservative nitrogen threshold would yield a total nitrogen level of <2 mg N $L^{-1}$ throughout the salt marsh (e.g. from headwaters to tidal inlet). As this system closely resembles the structure and hydrodynamics of Halls Creek, this threshold level appears to be appropriate for Halls Creek marsh as well. It should be noted that the upper most marsh reach of Cockle Cove is currently exposed to 2-3 mg N $L^{-1}$ without discernable habitat impairment. Also, it is important to note that since the creek bottom sediments remove nitrate during transport, the TN concentration declines along the tidal reach. As such, the lower tidal reach has a significantly lower tidally averaged concentration compared to the headwaters. This can be seen in the existing TN gradient, where the tidally averaged TN concentration in Halls Creek is 0.469 mg N $L^{-1}$ and 0.385 mg N $L^{-1}$ at the inlet.

Putting all the assessment elements together, it appears that for Halls Creek, the critical values are a total nitrogen level of 2 mg N $L^{-1}$ in the headwaters (Station BC-13) and a level of 1 mg N $L^{-1}$ at the border of the upper and lower reach (Station BC-14). As this upper/lower boundary station is the uppermost long-term marine water quality sampling site and integrates all of the watershed and upper marsh nitrogen inputs and removals, it was selected as the sentinel station for this system (BC-14). The threshold (tidally averaged) total nitrogen level of 1 mg N $L^{-1}$ was determined to be appropriate for the sentinel station (BC-14). It should be noted that the tidally averaged total nitrogen level at the middle marsh station in Cockle Cove Creek is currently 1.378 mg N $L^{-1}$ and the tidal inlet station shows concentrations of 0.472 mg N $L^{-1}$, consistent with the 1 mg N $L^{-1}$ at the sentinel station in Halls Creek. This threshold applies as long as the tidal creek maintains its present hydrodynamic characteristics (flushing and velocity). The nitrogen threshold for Halls Creek salt marsh is intentionally conservative based upon all available data from comparable systems. However, it indicates that additional nitrogen may enter this system without impairment of its habitat quality throughout the estuary. The nitrogen loads associated with the threshold concentration at the sentinel location are discussed in Section VIII.3, below. The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-2.

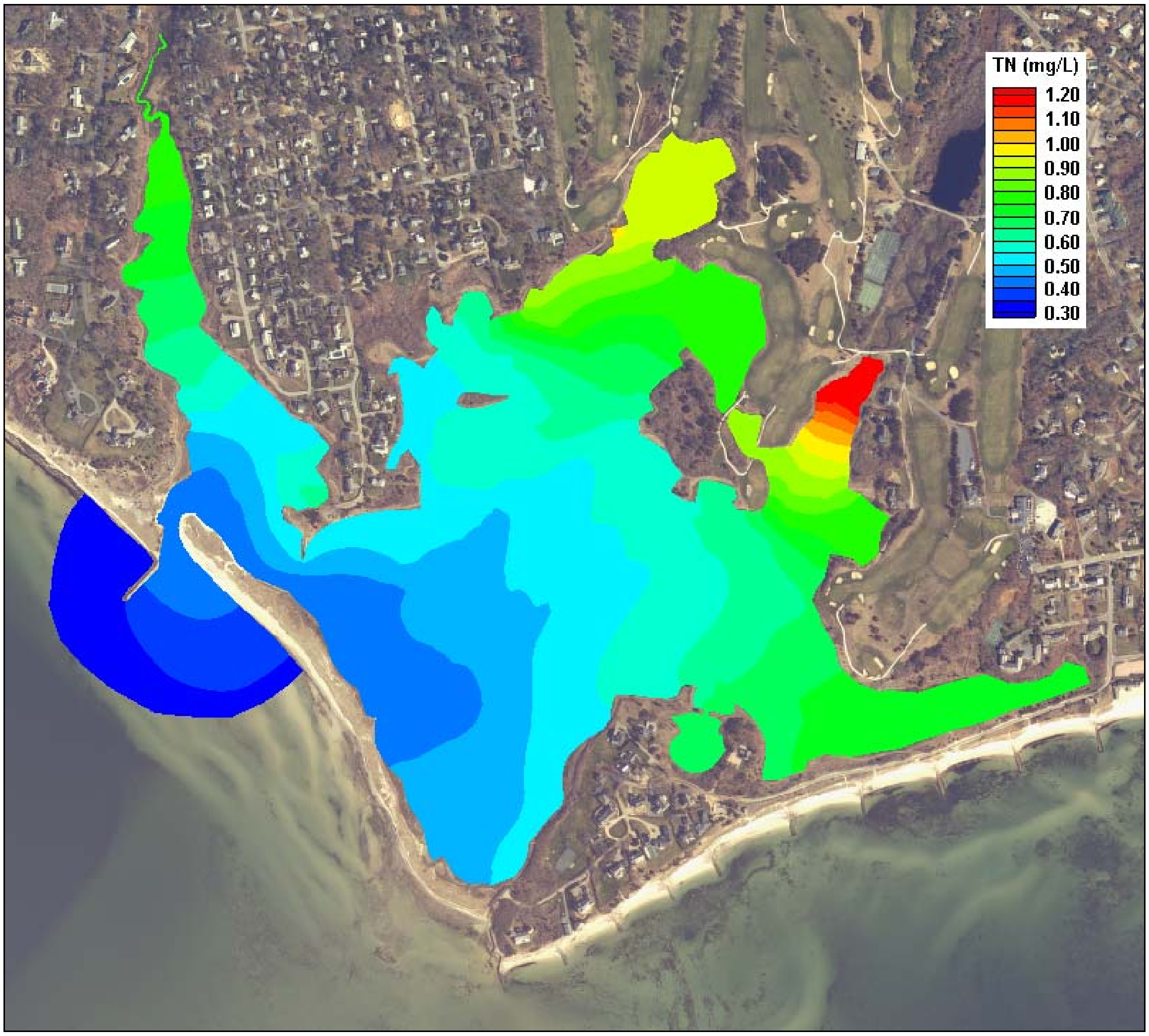


Figure VIII-2. Contour plot of tidally averaged modeled total nitrogen concentrations (mg/L) in the Halls Creek system, for threshold conditions (maximum concentration of 2.0 mg/L at monitoring station BC-13 and 1.0 mg/L at BC-14).

## VIII.3. DEVELOPMENT OF TARGET NITROGEN LOADS

The nitrogen thresholds developed 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 Lewis Bay Embayment System and the level of additional nitrogen loading to Halls Creek which will still sustain high quality habitat in that system. Tidally averaged total nitrogen thresholds derived in Section VIII.1 and VIII.2 were used to adjust the calibrated constituent transport model developed in Section VI.

It should be noted, one approach to achieving the nitrogen load reductions within the Lewis Bay Embayment System necessary to achieve the threshold nitrogen concentrations built upon the "Existing Removal Scenario B", presented to the MEP Technical Team by the Towns of Yarmouth and Barnstable and described in Chapter IX. Since this version of Scenario B did not achieve the threshold targets (Chapter IX), additional removal of septic N loading was necessary. The threshold nitrogen level at the sentinel station and at the secondary stations was achieved when removal of septic N loading was increased to produce an 80% total reduction in loading from this source to the main basin of Lewis Bay (Watershed 16) and an 80% reduction from this source to Hyannis Inner Harbor (Watershed 13). The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-1.

*Lewis Bay Estuary:* Watershed nitrogen loads to Lewis Bay were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold level at the sentinel station chosen for the Lewis Bay Embayment System (BHY-3 located in the eastern basin of Lewis Bay), and at the secondary stations in Uncle Roberts Cove, Hyannis Inner Harbor and Mill Creek. 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 community. The presentation is to establish the general degree and spatial pattern of reduction that will be required for restoration of this nitrogen impaired embayment.

As shown in Table VIII-2, the nitrogen load reductions within the system necessary to achieve the threshold nitrogen concentrations required using: 1) Existing Removal Scenario B (as requested by the Towns of Yarmouth and Barnstable) with 2) additional removal of septic N loading to produce an 80% total reduction in loading from this source to the main basin of Lewis Bay (Watershed 16) and 3) an 80% reduction from septic N Loading to Hyannis Inner Harbor (Watershed 13). The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-1.

Table VIII-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Lewis 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 |
|---|---|---|---|
| Lewis Bay | 26.490 | 5.299 | -80.0% |
| Uncle Roberts Cove | 0.214 | 0.214 | 0.0% |
| Mill Creek | 13.570 | 1.926 | -85.8% |
| Hyannis Inner Harbor | 6.847 | 1.808 | -73.6%[1] |
| Snows Creek | 7.970 | 9.088 | +14.0% |
| Stewarts Creek | 21.564 | 24.178 | +12.1% |
| Surface Water Sources | | | |
| Chase Brook | 2.488 | 2.479 | -0.3% |
| Mill Pond | 10.425 | 10.068 | -3.4% |
| Hospital Creek/Hyannis Inner | 1.907 | 0.326 | -82.9% |

[1] Hyannis Inner Harbor is a combination of Hyannis Inner Harbor watershed (13), and Wells Mary Dunn watershed (6) thus the 80% reduction in septic loading for the threshold does not result in a direct 80% reduction in septic loading.

Tables VIII-3 and VIII-4 provide additional loading information associated with the thresholds analysis. Table VIII-3 shows the change to the total watershed loads, based upon the removal of septic loads depicted in Table VIII-2. Removal of septic loads from Existing

Removal Scenario B along with the additional septic removals from Lewis Bay and Hyannis Inner Harbor results in the total nitrogen loads presented in Table VIII-4. Table VIII-4 shows the breakdown of threshold sub-embayment and surface water loads used for total nitrogen modeling. In Table VIII-4, loading rates are shown in kilograms per day, since benthic loading varies throughout the year and the values shown represent 'worst-case' summertime conditions. The benthic flux for this modeling effort is reduced from existing conditions based on the load reduction and the observed particulate organic nitrogen (PON) concentrations within each sub-embayment relative to background concentrations in Nantucket Sound.

Table VIII-3. Comparison of sub-embayment ***total attenuated watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Lewis 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 |
|---|---|---|---|
| Lewis Bay | 30.855 | 9.663 | -68.7% |
| Uncle Roberts Cove | 0.540 | 0.540 | 0.0% |
| Mill Creek | 15.964 | 4.321 | -72.9% |
| Hyannis Inner Harbor | 12.153 | 7.115 | -41.5% |
| Snows Creek | 15.115 | 16.233 | +7.4% |
| Stewarts Creek | 38.992 | 41.605 | +6.7% |
| Surface Water Sources | | | |
| Chase Brook | 3.345 | 3.337 | -0.2% |
| Mill Pond | 15.038 | 14.682 | -2.4% |
| Hospital Creek/Hyannis Inner | 1.907 | 0.326 | -82.9% |

Table VIII-4. Threshold sub-embayment loads and attenuated surface water loads used for total nitrogen modeling of the Lewis Bay system, with total watershed N loads, atmospheric N loads, and benthic flux

| sub-embayment | threshold load (kg/day) | direct atmospheric deposition (kg/day) | benthic flux net (kg/day) |
|---|---|---|---|
| Lewis Bay | 9.663 | 13.507 | 23.916 |
| Uncle Roberts Cove | 0.540 | 0.759 | 10.991 |
| Mill Creek | 4.321 | 0.627 | -1.208 |
| Hyannis Inner Harbor | 7.115 | 0.633 | 9.780 |
| Snows Creek | 16.233 | - | -4.533 |
| Stewarts Creek | 41.605 | 0.236 | -10.402 |
| Surface Water Sources | | | |
| Chase Brook | 3.337 | - | - |
| Mill Pond | 14.682 | - | - |
| Hospital Creek/Hyannis Inner | 0.326 | - | - |

Comparison of model results between existing loading conditions and the selected loading scenario to achieve the target TN concentrations at the sentinel station is shown in Table VIII-5. To achieve the threshold nitrogen concentrations at the sentinel station, a reduction in TN concentration of approximately 7% is required at station BHY-3. To meet the secondary threshold requirement for stations BHY-4 (Uncle Roberts Cove), MC-1 (Mill Creek) and the average of BH-1 and BH-2 (Hyannis Inner Harbor), a reduction in TN concentration of approximately 7.0%, 13% and 12% were required, respectively.

The basis for the watershed nitrogen removal strategy utilized to achieve the embayment thresholds may have merit, since this example nitrogen remediation effort is focused on watersheds where groundwater is flowing directly into the estuary. For nutrient loads entering the systems through surface flow, natural attenuation in freshwater bodies (i.e., streams and ponds) can significantly reduce the load that finally reaches the estuary. Presently, this attenuation is occurring due to natural ecosystem processes and the extent of attenuation being determined by the mass of nitrogen which discharges to these systems. The nitrogen reaching these systems is currently "unplanned", resulting primarily from the widely distributed non-point nitrogen sources (e.g. septic systems, lawns, etc.). Future nitrogen management should take advantage of natural nitrogen attenuation, where possible, to ensure the most cost-effective nitrogen reduction strategies. However, "planned" use of natural systems has to be done carefully and with the full analysis to ensure that degradation of these systems will not occur. One clear finding of the MEP has been the need for analysis of the potential associated with restored wetlands or ecologically engineered ponds/wetlands to enhance nitrogen attenuation. Attenuation by ponds in agricultural systems has also been found to work in some cranberry bog systems, as well. Cranberry bogs, other freshwater wetland resources, and freshwater ponds provide opportunities for enhancing natural attenuation of their nitrogen loads. Restoration or enhancement of wetlands and ponds associated with the lower ends of rivers and/or streams discharging to estuaries are seen as providing a dual service of lowering infrastructure costs associated with wastewater management and increasing aquatic resources associated within the watershed and upper estuarine reaches.

Table VIII-5. Comparison of model average total N concentrations from present loading and the modeled threshold scenario, with percent change, for the Lewis Bay system. Sentinel threshold stations are in bold print.

| Sub-Embayment | monitoring station | present (mg/L) | threshold (mg/L) | % change |
|---|---|---|---|---|
| **Hyannis Inner Harbor** | **BH-1** | **0.549** | **0.477** | **-13.1%** |
| **Hyannis Inner Harbor** | **BH-2** | **0.496** | **0.440** | **-11.4%** |
| Hyannis Inner Harbor | BH-3 | 0.440 | 0.400 | -9.0% |
| Snows Creek | BH-4 | 1.638 | 1.745 | +6.6% |
| Lewis Bay | BH-5 | 0.387 | 0.365 | -5.5% |
| Lewis Bay | BH-6 | 0.368 | 0.353 | -4.2% |
| Stuarts Creek | BH-7 | 1.374 | 1.435 | +4.4% |
| Lewis Bay | BHY-1 | 0.384 | 0.364 | -5.3% |
| Lewis Bay | BHY-2 | 0.414 | 0.383 | -7.5% |
| **Lewis Bay** | **BHY-3** | **0.407** | **0.378** | **-7.2%** |
| **Uncle Roberts Cove** | **BHY-4** | **0.431** | **0.400** | **-7.0%** |
| **Mill Creek** | **MC-1** | **0.531** | **0.462** | **-13.0%** |
| Mill Creek | MC-2 | 0.473 | 0.421 | -11.0% |

Although the above modeling results provide one manner of achieving the selected threshold level for the sentinel site within the estuarine system, the specific example does not represent the only method for achieving this goal. However, the thresholds analysis provides general guidelines needed for the nitrogen management of this embayment.

*Halls Creek Estuary:* The nitrogen thresholds developed in Section VIII.2 were used to determine the amount of total nitrogen mass loading reduction required for restoration of eelgrass and infaunal habitats in the Halls Creek system. Total nitrogen thresholds derived in Section VIII.1 and VIII.2 were used to adjust the calibrated constituent transport model developed in Section VI. Contrary to most other estuarine systems evaluated as part MEP, the threshold concentration was set higher than present conditions, meaning that the system would be allowed to have a higher load than present to meat the threshold. Therefore, watershed nitrogen loads were sequentially raised in the model until the nitrogen levels either reached the 1.0 mg/L threshold level at the sentinel station (BC-14) chosen for Halls Creek, or reached a tidally averaged maximum of 2.00 mg/L at the headwaters of the system. It is important to note that load increases could be produced by increasing any or all sources of nitrogen to the system. The load increases presented below represent only one of a suite of potential approaches that need to be evaluated by the community. The presentation is to establish the general degree and spatial pattern of loading that will be allowable for this system. A comparison between present watershed loading and the loadings for the modeled threshold scenario is provided in Tables VIII-6, 7 and 8.

As shown in Table VIII-6, the threshold scenario run for this system would allow up to 1.57 times (57% increase) the present watershed loading. The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-2.

Table VIII-7 shows the breakdown of threshold sub-embayment and surface water loads used for total nitrogen modeling. In Table VIII-7, loading rates are shown in kilograms per day, since benthic loading varies throughout the year and the values shown represent 'worst-case' summertime conditions. The benthic flux for this modeling effort is modified from existing conditions based on the load reduction and the observed particulate organic nitrogen (PON) concentrations within each sub-embayment relative to background concentrations in Nantucket Sound, as discussed in Section VI.2.6.1.

Comparison of model results between existing loading conditions and the selected loading scenario to achieve the target TN concentrations at the sentinel station is shown in Table VIII-8. To achieve the threshold nitrogen concentrations at the sentinel station, increases in average TN concentrations of typically greater than 19% occur in the system, between the main harbor basin and the marsh.

Although the above modeling results provide one manner of achieving the selected threshold level for the sentinel site within the estuarine system, the specific example does not represent the only method for achieving this goal. However, the thresholds analysis provides general guidelines needed for the nitrogen management of this embayment.

Table VIII-6. Comparison of sub-embayment ***total watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Halls Creek 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 |
|---|---|---|---|
| Halls Creek | 21.534 | 32.918 | +52.9% |
| Halls Creek Stream (freshwater) | 1.597 | 3.345 | +109.4% |
| System Total | 23.132 | 36.263 | +56.8% |

Table VIII-7. Threshold sub-embayment loads used for total nitrogen modeling of the Halls Creek system, 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) |
|---|---|---|---|
| Halls marsh | 32.918 | 0.630 | 6.649 |
| Halls Creek (freshwater) | 3.345 | - | - |
| System Total | 36.263 | 0.630 | 6.649 |

Table VIII-8. Comparison of model average total N concentrations from present loading and the threshold scenario, with percent change, for the Halls Creek system. Loads are based on atmospheric deposition and a scaled N benthic flux (scaled from present conditions). The threshold station is shown in bold print.

| Sub-Embayment | monitoring station | present (mg/L) | threshold (mg/L) | % change |
|---|---|---|---|---|
| Halls Creek - stream | BC-13 | 1.189 | 2.037 | +71.4% |
| **Halls Creek - mid** | **BC-14** | **0.469** | **0.557** | **+18.9%** |
| Halls Creek - inlet | BC-15 | 0.385 | 0.432 | +12.1% |