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, chlorophyll-*a* and macroalgae). Additional information on temporal changes within each sub-embayment and its associated watershed nitrogen load further strengthen the analysis. These data were collected by the MEP Technical Team to support threshold development for the Slocums River and Little River Estuaries and were discussed in Chapter VII. Nitrogen threshold development builds on this data and links habitat quality to summer water column nitrogen levels derived from the baseline BayWatcher Water Quality Monitoring Program (2000-2006), conducted by the Coalition for Buzzards Bay with technical support from the Coastal Systems Program at SMAST and, for 2004-05 sampling season, by the Turn the Tide Project for the Restoration of Dartmouth's Estuaries (a partnership between the Town of Dartmouth, Coalition for Buzzards Bay, Lloyd Center and the Coastal Systems Program at SMAST-UMassD),.

The Slocums River System is a riverine estuary composed of an upper tidal river dominated by fringing wetlands, a large depositional basin in the middle of the system and a lower reach comprised of a main tidal channel and tributary coves, one of which is predominantly a salt marsh pond (Giles Creek). Each of these functional components 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 the systems ability to support eelgrass beds and a various types of infaunal communities. At present, the Slocums River System is showing variations in nitrogen enrichment and habitat quality among its various component basins (Table VIII-1). In general the system is showing healthy to moderately impaired benthic habitat within the upper tidal reach. As a wetland dominated basin, impairment in the upper tidal reach is only moderate resulting mainly from the patches of drift macroalgal accumulation and surface microphyte mats. However, the middle basin currently supports significantly impaired habitat for infaunal animals (with periodic fish kills), as a result of spatially distributed and significant accumulations of drift macroalgae, moderate to high chlorophyll levels and periodic oxygen depletions. The lower basin is generally supporting high quality infaunal habitat except in regions of macroalgal accumulation (likely transported from the middle basin). However, the lower basin is significantly impaired relative to eelgrass habitat. The lower basin historically supported eelgrass as indicated by the 1951 analysis by MassDEP and field data from 1985 (Costa 1988), but eelgrass beds are no longer present within the system. Based upon all lines of data, the Slocums River is presently impaired by nitrogen loading from its watershed and restoration of this estuary should focus on the impaired infauna habitat within the middle basin and eelgrass habitat within the lower basin.

Table VIII-1. Summary of Nutrient Related Habitat Health within the Slocums River and Little River Estuaries on Buzzards Bay within the Town of Dartmouth, MA, based upon assessment data presented in Chapter VII. The Slocums River Estuary is a typical riverine estuary, while the Little River Estuary is primarily a salt marsh basin.

Health Indicator	Embayment System			
	Slocums River			Little River[A]
	Upper[A]	Mid	Lower	
Dissolved Oxygen	H[1]	MI-SI[2]	MI-SI[2]	H[1]
Chlorophyll	H-MI[6]	SI[4]	MI-SI[5]	H[3]
Macroalgae	H-MI[7]	SI[8]	H-MI[9]	H[10]
Eelgrass	--[11]	--[11]	SI[12]	--[11]
Infaunal Animals	H[13]	SI[14]	H-MI[15]	H[16]
Overall:	**H-MI[17]**	**SI[18]**	**SI[19]**	**H**

A -- basin or estuarine reach supports fringing salt marsh areas.
1 – primarily a salt marsh pond or wetland dominated tidal river, periodic oxygen depletions to <4 mg/L, very rarely to 3-2 mg/L.
2 -- oxygen depletions periodically to <4 mg/L, with infrequent declines to <3.5 mg/L.
3 – low to moderate chlorophyll a levels generally 2-8 ug/L, generally <6 ug/L
4 – high chlorophyll a levels generally 4-15 ug/L, frequently >15 ug/L (15% of time)
5 – moderate to high chlorophyll a levels generally 5-10 ug/L, >15 ug/L (8% of time)
6 – high chlorophyll a levels generally >10-15 ug/L, frequently >20 ug/L (21% of time)
7 -- drift algae in sparse patches, patches of surface algal mat
8 -- moderate to high accumulations of drift algae, primarily Ulva.
9 -- low accumulations of drift algae in tributary basins, little surface microphyte mat.
10 – diverse attached macroalgal community with some *Codium* & *Ruppia* (SAV), little drift algae
11 – no evidence this basin is supportive of eelgrass.
12 -- MassDEP mapping indicates that eelgrass lost from this system between 1951-1995.
13 -- Infauna: moderate numbers of individuals, moderate species, high diversity and Eveness; organic enrichment indicators typical of wetland dominated tidal rivers, indication of salinity "stress" (*Cyathura polita*), little accumulation of macroalgae (*Ulva*).
14 -- low to moderate numbers of species and individuals, low to moderate diversity and evenness. Organic enrichment indicators and opportunistic and disturbance indicators.
15 -- tributary coves: moderately impaired habitat in depositional areas where drift macroalgae periodically accumulate; main channel: high quality infaunal habitat, with high species diversity & Eveness, high # of species & moderate # of individuals, distributed evenly among polychaetes, crustaceans & mollusks & with deep deposit feeders evident.
16 -- moderate to high # of individuals and species, with moderate to high diversity & Eveness; lowermost reach supports the highest # of species within the Slocums/Little River complex.
17 -- Moderate Impairment based upon patches of drift macroalgae and moderate-high chlorophyll levels, assessment based upon this reach being a wetland dominated tidal river
18 -- Significant impairment of infaunal communities within this broad basin, large accumulations of macroalgae and periodic oxygen depletion.
19 -- Significant Impairment based upon loss of eelgrass from system, 1951-->1985-->1995.

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

The Little River Estuary is predominantly a salt marsh dominated tidal basin. This estuary is presently supporting high quality infaunal animal habitat and water quality conditions associated with a salt marsh basin receiving watershed nitrogen inputs below its tolerance level. This system has infaunal communities consistent with a wetland dominated organic matter enriched estuarine sediment, with moderate to high numbers of individuals, distributed among a diversity of species. The lower-most reach of this system is a tidal channel supporting the highest number of species within the entire Slocums and Little River complex. The assessment of high quality infauna habitat is consistent with the generally low total nitrogen and chlorophyll-a levels, with oxygen depletion evident, but typical of salt marsh basins. Significantly, accumulations of drift macroalgae are not typical of this basin, with macroalgae present primarily as attached forms, e.g. *Codium, Enteromorpha, Fucus* (see below).

Eelgrass:

At present, the Little River and Slocums River Estuaries do not support eelgrass habitat. Little River is predominantly a salt marsh basin and the absence of eelgrass is typical of the basin configuration, water quality and hydrodynamics of this class of coastal system. There is no historical evidence of eelgrass coverage within this basin, from the 1951 analysis or any of the field surveys from 1985-2005. That the Little River basin is not configured to sustain eelgrass is also supported by the absence of eelgrass in this system in 1985 (at very low watershed N loading), when eelgrass patches were still extant within the adjacent lower Slocums River (at much higher N loadings). It should be noted that the absence of eelgrass in similar salt marsh dominated basins is typical throughout southeastern Massachusetts, for example Mill Creek in Lewis Bay, Upper Broad Marsh River in Wareham River Estuary, Namskaket Creek, and Back River in the Phinneys Harbor System. As a result of these findings, management of the Little River Estuary should focus on maintaining the present high level of infaunal habitat quality.

It contrast, the Slocums River Estuary has historically supported eelgrass. The 1951 analysis indicates 2 small beds in the lower basin. Remnants of the southern bed were observed in the 1985 field survey, but these were lost by the 1995 survey and no eelgrass was recorded in the 2001-2005 surveys. As a result of these findings, management of the Slocums River Estuary should focus on restoration of eelgrass habitat in the lower basin and infaunal habitat quality within the upper reaches.

The current absence of eelgrass throughout the Slocums River is consistent with the depth of the basin and the chlorophyll levels measured by the MEP moorings (Section VIII.2) and the BayWatcher Program (~10 ug/L) in addition to the observed total nitrogen levels (0.38-0.40 mg N L^{-1}) in the lower basin (higher than the 0.35 threshold for eelgrass in nearby West Falmouth Harbor) and generally >0.5 mg N L^{-1} in the middle and upper reaches. The historical beds appear to have been restricted to the margins of the lower basin and were not observed in the deeper channel that runs from the tidal inlet along the eastern shore. Eelgrass was also not observed in the region of the tidal inlet due to the unstable substrate (shifting sands) and continuing alteration of the western barrier spit by coastal processes.

Although some regions of the Slocums River presently support healthy infaunal habitat (tolerant of higher levels of enrichment), this system appears to have become sufficiently nutrient enriched to significantly impair its eelgrass habitat. However, it is likely that if nitrogen loading were to decrease, eelgrass could be restored at a minimum in the lower basin to the 1951 pattern. A greater acreage of eelgrass recovery is certain as the outer basin (bounded by Mishaum Point and Barneys Joy Point) would also undergo an expansion of surviving eelgrass beds. Recovery of eelgrass within the down-gradient outer basin should result as the major nitrogen source to this basin is the Slocums River ebb tide discharge.

Based upon the documented loss of eelgrass coverage in the lower basin of the Slocums River Estuary, this basin is classified as significantly impaired (SI) for eelgrass habitat. The outer basin would be classified as moderately impaired as it still supports some eelgrass habitat, though it has declined in recent decades. The difference between the lower basin of the Slocums River and the offshore basin (outer basin) stems from the greater dilution of nitrogen enriched Slocums River waters by low nitrogen Buzzards Bay waters within the outer basin. The spatial and temporal pattern of the declining eelgrass habitat associated with the Slocums River Estuary is consistent with the results of the water quality and benthic infauna analysis and the observed eelgrass loss is typical of nutrient enriched shallow embayments.

Based upon the above analysis, eelgrass habitat should be the primary nitrogen management goal for the lower basin of the Slocums River Estuary while infaunal habitat quality should be the management target for the middle basin. These goals are the focus of the MEP management alternatives analysis presented below.

Macroalgae:

Macroalgae grows within the Slocums and Little River Estuarine basins in both attached and drift forms. The predominant drift algae is *Ulva lactuca,* also referred to as sea lettuce. This macroalgae is generally associated with nitrogen enrichment in both embayment basins and salt marsh creeks. It forms dense accumulations which "smother" the bottom communities, significantly impairing both infaunal animal communities and even eelgrass beds. Accumulations of drift macroalgae are indicative of significant to severe impairment of estuarine habitat. In contrast, macroalgal species which grow as attached forms, are not indicative of nitrogen enrichment and can be associated with high water quality and may even provide additional animal habitat (e.g. as SAV) in some cases.

The middle basin of the Slocums River presently has large regions of high accumulations of drift algae, generally *Ulva lactuca* (sea lettuce). The infaunal habitat throughout this basin was significantly impaired by the large accumulations of *Ulva* (at more than 50% coverage) while most of the area had coverages of at least 20%. Given that these are drift accumulations extant at high levels, the mobility of this drift macroalgae virtually ensures impact to the sediment animal communities throughout the middle basin. In contrast, macroalgae was generally absent from the upper estuarine reach, with only a few patches of drift algae consistently present, although some thin algal mats were observed to colonize the sediment surface in some regions. These thin mats also alter benthic habitat, and can affect infaunal colonization. The lower basin of Slocums River does not accumulate drift macroalgae in the channel regions due to high water velocities. However, in more protected waters as in Giles Creek and smaller coves, minor accumulations can develop (Figure VII-15). It appears that some drift algae within the lower basin is "imported" from the middle basin on ebbing tides.

The finding of higher macroalgal accumulations in the 2003 macroalgae survey discussed in Chapter VII compared to the 1985 – 1986 analysis (Adam 1989; and aerial photos provided by Dr. J. Sears, UMass-Dartmouth) is consistent with continuing nitrogen enrichment of the Slocums River and the loss of eelgrass from the lower basin over this same period.

Water Quality:

Overall, the level of oxygen depletion and the magnitude of daily oxygen excursion and chlorophyll-a concentrations was sufficient to impair infaunal habitat within the middle basin and eelgrass habitat within the lower basin of the Slocums River. In contrast, the Little River is primarily a salt marsh basin that is naturally organic matter enriched and is expected to exhibit periodic low oxygen at moderate to low nitrogen and chlorophyll-a levels. These patterns were documented for the Little River Estuary in the MEP analysis, as was the high quality of habitat for a salt marsh basin (refer to discussion in Chapter VII).

Nitrogen levels within the upper and middle basins of the Slocums River are generally moderate to high, >0.6 and >0.5 mg TN L^{-1}, respectively, and as such are levels that are typically related to periodic oxygen depletion in many southeastern Massachusetts estuaries. However, total nitrogen (TN) levels in the lower Slocums River are generally only moderately enriched <0.4 mg TN L^{-1},and it appears that oxygen depletion in this region of the estuary is influenced by the water quality entering from the middle basin during ebbing tides. Overall, chlorophyll levels also indicated a nitrogen enriched estuarine system with levels within the upper basin generally ~15 ug/L and the middle basin ~8 ug/L. It appears that phytoplankton generated in the upper and middle basins are being transported to the lower basin, causing organic matter enrichment effects.

The observed periodic depletion of dissolved oxygen indicates that much of the tidal reach of the Slocums River is currently under seasonal oxygen stress, consistent with nitrogen enrichment (Table VII-1). That the cause is eutrophication is supported by the documented moderate to high levels of chlorophyll-a (Table VII-2). Oxygen conditions and chlorophyll-a levels improved with decreasing distance to the tidal inlet, although all basins showed oxygen depletions below 5 mg L^{-1} and periodically below 4 mg L^{-1}. The observations of moderate to high nitrogen levels, moderate to high chlorophyll-a levels and periodic oxygen depletions to <4 mg L^{-1} all support the assessment that watershed nitrogen inputs are currently impairing habitat quality within the Slocums River through the process of nitrogen enrichment of estuarine waters.

In contrast, Little River is presently supporting a low level of nitrogen enrichment (TN levels ~0.4 mg N L^{-1}) with associated low to moderate levels of chlorophyll-a. The difference in the nitrogen and chlorophyll-a levels and oxygen depletion status of this system compared to the Slocums River results from it being a salt marsh basin which is naturally organic matter enriched. A similar pattern was found in another Buzzards Bay sub-embayment, the Phinneys Harbor System. This system contains a salt marsh dominated basin, the Back River, similar to the present Little River basin. The Back River also exhibited oxygen depletions (to 3-4 mg/L), and similar low chlorophyll-a levels (general range 4-8 ug/L). This is consistent with its functioning as primarily a tidal salt marsh sub-basin. While oxygen depletion to 3 mg/L would indicate impairment in an embayment like the Slocums River and Apponagansett Bay (and the Phinneys Harbor basin), it is consistent with the organically enriched nature of salt marsh creeks. It is important to note that the uppermost reach of the Slocums River functions as a wetland dominated tidal river, much like the salt marsh creeks and basins just discussed. As a result, this portion of the Slocums River was assessed as a tidal wetland system, and the observed water quality indicators suggest high quality to moderately impaired habitat quality for this tidal reach. This is in contrast to the moderately to significantly impaired habitat observed within the middle and lower basins.

The assessments of significantly impaired habitat quality within the middle basin of the Slocums River due to high and increasing levels of macroalgal accumulation is consistent with the site-specific water quality analysis and with the conclusions of the eelgrass and infaunal animal surveys.

Infaunal Communities:

The infauna study conducted by the MEP indicated that the Slocums River is presently supporting a range of high quality to significantly impaired habitat for infaunal animal communities (Table VII-4) while the Little River Estuary is generally supportive of high quality habitat. These habitat assessments are based upon both the infaunal community characteristics (Section VII.4), the ecosystem type (basin, salt marsh, eelgrass bed) and stresses represented by salinity variation, macroalgal accumulations and organic matter enrichment (e.g. nitrogen loading).

The habitat quality of the uppermost reach of the Slocums River Estuary is generally reflective of its function as a tidal river with bordering wetlands. This upper reach of the estuary is strongly influenced by the large freshwater inflows from the Paskamansett River and Destruction Brook as well as its related function as a wetland dominated tidal river. The upper reach of the river is nitrogen enriched, but at an level generally found in healthy salt marsh systems, and does exhibit little accumulation of macroalgae (generally in patches). The infaunal community is consistent with its wetland dominated tidal river status. However, it appears that the large freshwater inflow represents a "stress" in this environment as seen in the fresh/brackish/marine invertebrates typical of transition between fresh and estuarine habitats. The presence of the stress indicator species *Cyathura polita,* which is tolerant of the salinity stress, helps to define this as a wetland influenced sub-basin (this species was found in similar environment in the Mashpee River in Popponesset Bay and the upper Agawam River in Wareham River).

In contrast, the significant impairment of infaunal animal habitat within the large middle basin of the Slocums River is clearly associated with nitrogen enrichment. This assessment is based upon the low to moderate diversity and evenness of the community. While the number of individuals was generally high, the high numbers were related to "blooms" of opportunistic species, indicative of organic enrichment and disturbance. During the summer, an amphipod mat was observed within the lower region of this basin, also indicative of nitrogen enrichment and disturbance. Organic enrichment indicators typically dominated the community and there was variability in the numbers of individuals suggesting localized disturbance, likely from shifting accumulations of drift algae.

The lower basin is comprised of 3 components, the salt marsh basin of Giles Creek, small tributary coves and the main deep channel. The basin of Giles Creek supports an infaunal community typical of a salt marsh basin but does contain some patches of drift algae (Ulva), with localized negative effects. The tributary coves to the east and west of the main channel (Chapter VI) presently support moderately impaired habitat. However, it appears that the habitat impairment is again associated with depositional areas where drift macroalgae periodically accumulate and possibly low oxygen waters discharging from the middle basin build-up. Generally high quality habitat is associated with the main channel. The channel does not accumulate macroalgae but has the same water quality as the tributary coves, supports high species diversity and evenness, high numbers of species and moderate numbers of individuals. Species appeared to be distributed among polychaetes, crustaceans and mollusks with deep deposit feeders evident as well. Habitat near the tidal inlet is affected by the shifting substrate related to coastal processes as these processes are modifying the tidal inlet and barrier beach. Overall, the lower reach of the Slocums River is supporting high infaunal habitat quality with small patches of moderate impairment associated with macroalgal accumulation, likely from transport from the large areas of accumulation within the middle basin.

The Little River Estuary is predominantly a salt marsh dominated tidal basin. As a consequence, this system has infaunal communities consistent with a wetland dominated organic matter enriched estuarine sediment, with moderate to high numbers of individuals and species and generally moderate to high diversity and evenness. The lower-most reach of this system is a tidal channel supporting the highest number of species within the Slocums and Little River complex. The assessment of high quality infauna habitat is consistent with the generally low total nitrogen and chlorophyll-a levels, with oxygen depletion evident but typical of salt marsh basins. Significantly, accumulations of drift macroalgae were not typical of this basin, with macroalgae present primarily as attached forms, e.g. *Codium, Enteromorpha, Fucus* (see below).

Overall, the infaunal habitat quality throughout the Slocums River and Little River Estuaries was consistent with the distribution of drift and attached macroalgae, the gradients in dissolved oxygen, chlorophyll, nutrients and organic matter enrichment in these systems. Classification of habitat quality necessarily included the structure of the specific estuarine basin, specifically as to wetland dominance or characterization as a purely tidal embayment with open water and shoreline free of wetlands. Based upon this analysis it is clear that infaunal habitat within the middle reach of the Slocums River is significantly impaired as a consequence of organic matter nitrogen enrichment and infaunal restoration should focus on this region. In contrast, the Little River Estuary is generally showing high quality infaunal habitat for a salt marsh dominated tidal basin and management should focus on maintaining existing habitat quality within this system.

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 secondly, 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.

For the Slocums River and Little River Estuaries, determination of the critical nitrogen threshold for maintaining high quality habitat is based primarily upon the nutrient and oxygen levels, temporal trends in eelgrass distribution, macroalgal accumulations and current benthic community indicators. Given the database developed for the MEP analysis, it is possible to develop a site-specific threshold which is a refinement upon general threshold analysis frequently employed. All of the habitat assessment data clearly indicate that the Slocums River System is presently beyond its ability to tolerate nitrogen inputs, with the result being that the middle basin is supporting significantly impaired infaunal habitat throughout its tidal reach and the lower basin is supporting significantly impaired eelgrass habitat. Restoration of these impaired habitats is the primary target of the thresholds analysis. In contrast, the Little River Estuary is generally showing high quality infaunal habitat and the primary target of the thresholds analysis is the maintenance of existing habitat quality within this system.

Slocums River:

The present lack of eelgrass throughout the Slocums River System is consistent with the observed oxygen depletions in each basin and the chlorophyll levels and functional basin types comprising this estuary. This loss of eelgrass classifies the lower tidal reach as "significantly impaired", although it presently supports healthy to moderately healthy infaunal communities. The impairments to both the infaunal habitat (middle basin) and the eelgrass habitat (lower basin) are supported by a variety of other indicators: oxygen depletion, chlorophyll, and TN levels. Considered in combination, all the indicators support the conclusion that these impairments are the result of nitrogen enrichment, primarily from watershed nitrogen loading.

Based on the available data, it is possible to make a conservative estimate of the extent of eelgrass habitat that can be recovered through watershed nitrogen management. Based upon the 1951 coverage data, it appears that a conservative estimate of the amount of eelgrass habitat that would be restored in the inner portion of the Slocums River system if nitrogen management alternatives were implemented would be 8 acres (Table VII-3). A greater acreage of recovery is likely (74 acres) as the outer basin (bounded by Mishaum Point and Barneys Joy Point) should also see an expansion of surviving eelgrass beds. Recovery of eelgrass within this down-gradient outer basin should result as the major nitrogen source to this basin is the Slocums River ebb tide discharge.

The target nitrogen concentration (tidally averaged TN) for restoration of eelgrass at the sentinel location, SRT-12 (Chapter VI) within the lower reach of the Slocums River, was determined to be 0.37 mg TN L^{-1}. As the present TN level at this site is 0.390 mg TN L^{-1}, watershed nitrogen management will be required for restoration of the estuarine habitats within this system.

As there is no eelgrass habitat within the Slocums River Estuary, this threshold was based upon comparison to other local embayments of similar depths and structure under MEP analysis. A well studied eelgrass bed within the lower Oyster River (Chatham) has been stable at a tidally averaged water column TN of 0.37 mg N L^{-1}, while eelgrass was lost within the Lower Centerville River at a tidally averaged TN of 0.395 mg N L^{-1}, and also within Waquoit Bay at 0.39 mg N L^{-1}. The Slocums River threshold is the same as for the Centerville River System (0.37 mg N L^{-1}) and similar to the threshold for the lower main basin of Popponesset Bay and for the complex systems of Wareham River and Stage Harbor (0.38 mg N L^{-1}). These latter 3 systems have complex multi-component structures compared to the Slocums River Estuary. The selected threshold for the Slocums River System is higher than for the nearby deeper water systems of Phinneys Harbor and West Falmouth Harbor (0.35 mg TN L^{-1}), where detailed eelgrass/nitrogen analysis was available. The sentinel station under present loading conditions supports a tidally corrected average concentration of 0.390 mg TN L^{-1},

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. Therefore, in addition to the primary nitrogen threshold at the sentinel station, the MEP establishes secondary criteria to ensure that all impaired regions are restored if the threshold at the sentinel station is achieved. These values merely provide a check on the acceptability of conditions within the up-gradient basins at the point that the threshold level is attained at the sentinel station. The secondary criteria for the Slocums River targeted infaunal habitat restoration within the presently significantly impaired middle basin. The infaunal "check" station is the long-term monitoring station, SRT-6, which has an average TN level of 0.594 mg N L^{-1}. The tidally averaged total nitrogen level required at this station (SRT-6) to restore the infaunal animal habitat throughout the Slocums River System is <0.5 mg N L^{-1}. Watershed nitrogen management to achieve this "check" nitrogen level will ensure restoration of infaunal habitats within the down-gradient reach as well.

The secondary criteria developed for the infaunal "check" stations were developed by the MEP Technical Team based upon comparison to other nearby estuaries. The observed significant impairment within the middle basin of the Slocums River is consistent with observations by the MEP Technical Team in 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 of 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. The higher TN levels observed in the upper Slocums River wetland reach are within the nitrogen threshold to support the observed healthy infaunal habitat in this ecosystem type. Conversely, the Centerville River System supports moderately impaired infaunal habitat at tidally averaged TN levels of 0.526 mg N L^{-1} in its upper basin (Scudder Bay) and at 0.543 mg N L^{-1} within its middle reach. Similarly, within the nearby Wareham River System, the Wareham River and Broad Marsh River sub-basins were found to have moderately impaired infaunal habitat at total nitrogen (TN) levels in the range of 0.535 - 0.600 mg N L^{-1}.

Based upon the above analysis, eelgrass habitat should be the primary nitrogen management goal for the lower Slocums River System and infaunal habitat quality the management target for the upper reaches. These goals are the focus of the MEP management threshold loading analysis (Section VIII.3) and alternatives analysis. It must be stressed that the nitrogen threshold for the Slocums River Estuarine System is at the sentinel location. The secondary criteria (infaunal habitat) should be met when the threshold is met at the sentinel station. The secondary criteria were not used for setting the nitrogen threshold, but serve as a “check”. The nitrogen loads associated with the threshold concentration at the sentinel location and secondary infaunal check stations are discussed in Section VIII.3, below.

Little River:

Little River is presently supporting a low level of nitrogen enrichment (TN levels ~0.4 mg N L^{-1}) with associated low to moderate levels of chlorophyll-a. Infaunal communities within Little River are consistent with a wetland dominated organic matter enriched estuarine sediment, with moderate to high numbers of individuals and species, with generally moderate to high diversity and Eveness. The lower-most reach of this system is a tidal channel supporting the highest number of species within the Slocums and Little River complex. The assessment of high quality infauna habitat is consistent with the generally low total nitrogen and chlorophyll-a levels, with oxygen depletion evident, but typical of salt marsh basins. Accumulations of drift macroalgae were not typical of this basin, with macroalgae present primarily as attached forms, e.g. *Codium, Enteromorpha, Fucus* (see below).

The Little River Estuary does not support eelgrass habitat nor is there historical evidence of eelgrass coverage within this basin based on the analysis of the 1951 aerial photography (MassDEP Eelgrass Mapping Program) or any of the field surveys from 1985-2005. That this basin is not configured to support eelgrass, is also supported by the absence of eelgrass in this system in 1985 (at very low watershed N loading), when eelgrass patches were still extant within the adjacent lower Slocums River (at much higher N loadings). It should be noted that the absence of eelgrass in similar salt marsh dominated basins is typical throughout southeastern Massachusetts, for example Mill Creek in Lewis Bay, Upper Broad Marsh River in Wareham

River Estuary, Namskaket Creek, Back River in the Phinneys Harbor System. As a result of these findings, management of the Little River Estuary should focus on maintaining the present high level of infaunal habitat quality.

Since the Little River Estuary is presently supporting high quality habitat and low total nitrogen levels (ca. 0.4 mg TN L^{-1}) and is predominantly a salt marsh basin, its nitrogen threshold level is higher than the present conditions of watershed nitrogen loading (at present tidal flushing rates). A conservative estimate of the nitrogen threshold level of this system would follow the 0.5 mg TN L^{-1} developed above for the Slocums River System. However, as Little River is a wetland dominated system, it is capable of tolerating even higher levels of TN within its waters. The MEP has taken the approach to evaluate if the watershed build-out scenario (Chapter VI) exceeds the 0.5 mg TN L^{-1} infaunal habitat threshold (it does not) and then to determine the additional watershed loading that would be required to raise water column nitrogen levels at the sentinel station (SRT-15) to the threshold level, 0.5 mg TN L^{-1}. More specific evaluation of a still higher limit of loading to the Little River System that would result in habitat impairment will require some additional site-specific analysis and modeling but can be undertaken in the future as needed.

VIII.3. DEVELOPMENT OF TARGET NITROGEN LOADS

At present the Slocums River Estuary is supporting significantly impaired eelgrass habitat within its lower basin and significantly impaired infaunal habitat within its broad middle basin. These impairments result from watershed nitrogen inputs that exceed the nitrogen tolerance of these basins, resulting in the loss of historical eelgrass beds and stress to infaunal communities by organic enrichment through phytoplankton blooms, macroalgal accumulations and periodic oxygen depletion. In contrast, the Little River Estuary, which functions primarily as a salt marsh basin and therefore does not represent potential eelgrass habitat, is presently supporting high quality infaunal habitat typical of this type of estuary. This estuary is presently receiving watershed nitrogen inputs below its tolerance level with the result that some additional nitrogen loading can occur before habitat impairment occurs.

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 Slocums River Estuary and to maintain the high quality of infaunal habitat, within the Little River Estuary. 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 (Slocums River) or raised (Little River). Watershed nitrogen reduction was through lowering the total septic effluent discharges only (e.g. wastewater treatment), until the nitrogen levels reached the threshold level at the sentinel stations chosen for lower basin of the Slocums River and at the secondary station for the middle basin. 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 for the Slocums River 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. The Little River analysis focused on increases in watershed nitrogen at projected build-out of the watershed, which includes all nitrogen sources associated with changing land use (Section IV.1).

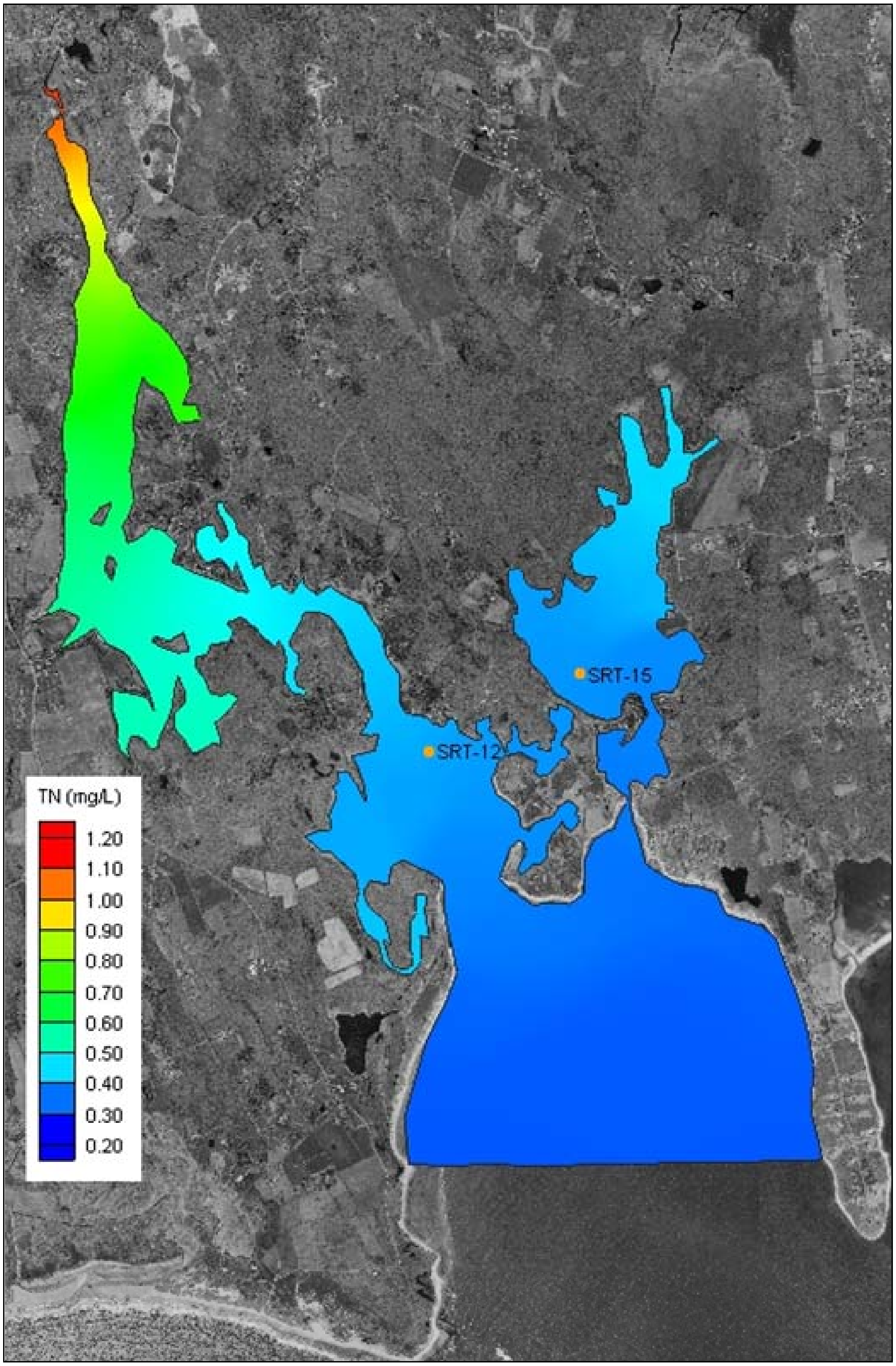

Figure VIII-1. Contour plot of modeled average total nitrogen concentrations (mg/L) in the Slocums River and Little River Estuary, for threshold conditions (<0.37 mg N L^{-1} at the sentinel station SRT-12 and <0.5 mg N L^{-1} at the secondary "check" station SRT-6, and 0.5 mg N L-1 at sentinel station SLR-15). Little River is presently below its threshold rate of nitrogen loading.

The nitrogen load reductions within the Slocums River Estuary necessary to achieve the threshold nitrogen concentrations required a 75% reduction in the total watershed N-load for the Slocums River West sub-watershed, Slocums River East sub-watershed, and Slocums River South sub-watershed, as well as removing 30% of total watershed N-load associated with the Paskamansett River (equivalent to 23.5% of the combined River and Destruction Brook load). The latter equal distribution was for demonstration since the removals could be distributed in a variety of combinations as long as the combined total mass load reduction for the River and Brook is met. The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figure VIII-1.

As a subset of the total nitrogen reduction required to achieve the threshold nitrogen concentrations for Slocums River and Little River, there was reduction of nitrogen septic loading to Slocums River Estuary West, East, and South sub-watersheds and Paskamanset River. The reduction in septic loading is shown in Table VIII-2. The nitrogen septic load reductions within the Slocums River Estuary West, East, and South sub-watersheds were reduced by approximately 75% for the threshold model run along with an approximate 75% reduction is nitrogen septic load for Paskamanset River. The reduction in nitrogen septic loads does not represent the entire reduction in nitrogen load required to meet the threshold. Removal of 100% of the septic load would not represent a large enough reduction in nitrogen to meet the threshold nitrogen concentrations for Slocums River and Little River Systems.

Table VIII-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Slocums River and Little River Systems. The “threshold septic load” is insufficient to meet the threshold concentration at the sentinel station, without additional source reductions (see Table VIII-3, below). 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[2]
Slocums River[1]	2.855	0.690	-75.8%
Little River[1]	1.784	1.784	+0.0%
Surface Water Sources			
Paskamanset R & Destruction Brk	24.299	6.252	-74.3%
Barneys Joy River North	0.241	0.241	0.0%
Barneys Joy River South	0.808	0.808	0.0%

[1] Total estuarine reach which receives septic N inputs through direct groundwater discharge and from surface water (stream) inflows.
[2] A reduction of 100% of the nitrogen septic load from Slocums River groundwater sub-watersheds and Paskamanset River and Destruction Brook sub-watersheds would not achieve the required threshold nitrogen concentration within Slocums River System.

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 load reductions to meet the threshold and the removal of septic loads depicted in Table VIII-2. The total nitrogen loads for Slocums River and Little River are 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 Buzzards Bay.

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 Slocums River and Little River Systems. 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
Slocums River[1]	8.488	2.121	-75.0%
Little River[1]	4.690	4.690	0.0%
Surface Water Sources			
Paskamanset R & Destruction Brk[2]	118.863	91.151	-23.3%
Barneys Joy River North	3.260	3.260	0.0%
Barneys Joy River South	5.485	5.485	0.0%

[1] Total estuarine reach which receives N inputs from the watershed through direct groundwater discharge and from surface water (stream) inflows.
[2] In this example, 30% of the total load from the combined Paskamanset River (equivalent to 23.5% of the combined River & Destruction Brook watersheds). Note that removing an equivalent total N mass amount distributed in any manner between the River and Brook would have the same result.

Table VIII-4. Threshold sub-embayment loads and attenuated surface water loads used for total nitrogen modeling of the Slocums River and Little River Systems, 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)
Slocums River[1]	2.121	5.395	-3.867
Little River[1]	4.690	1.186	8.898
Surface Water Sources			
Paskamansett R & Destruction Brk	91.151	-	-
Barneys Joy River North	3.260	-	-
Barneys Joy River South	5.485	-	-

[1] Total estuarine reach which receives N inputs through direct atmospheric deposition and through direct groundwater discharge and from surface water (stream) inflows.

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 6% is required at station SRT-12. However, to meet secondary threshold requirement for station SRT-6 a greater reduction was required. With a reduction in TN concentration of approximately 7.3% at station SRT-12, the TN concentration of 0.5 mg/L was achieved at the secondary "check" station SRT-6. These reductions will restore eelgrass habitat in the lower estuary and infaunal animal habitat throughout almost all the estuary. It should be noted that while station SRT-6 still does not meet the secondary threshold, this option provides a reasonable and achievable goal for the Slocums River system, restoration of infaunal habitat quality for a majority of the upper reaches. The threshold analysis for the Slocums River System is similar to the major tidal river to Popponesset Bay (Mashpee River) where the narrow upper estuarine reach is strongly influenced by bordering wetlands and a higher TN threshold (0.500 – 0.600 mg/L) was found to be appropriate for infaunal animals. Salt marshes have a much greater tolerance for nitrogen loading than do open water basins, supporting a slightly higher acceptable threshold TN level for the upper estuarine reach of the Slocums River Estuary.

The basis for the watershed nitrogen removal strategy utilized to achieve the embayment thresholds was selected as the example for nitrogen remediation because it focuses on watersheds where groundwater is flowing directly into the estuary without attenuation of nitrogen in transport to the estuary. Removal of nitrogen sources from these sub-watersheds maximizes the load reduction to the estuary per unit of nitrogen managed at the source, which generally has positive implications relative to the cost of management. For nutrient loads entering the systems through surface water inflows, 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 is transported through to these freshwater systems. The nitrogen entering these surface water systems primarily results, under present conditions, 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, if use of natural systems is to be part of a planning effort (i.e. planned source location) care has to be taken 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 Slocums River and Little River Systems. Sentinel threshold station are in bold print. The secondary "check" station in the Slocums River Estuary is SRT-6.

Sub-Embayment	monitoring station	present (mg/L)	threshold (mg/L)	% change
Head Slocums	SRT-3	1.499	1.152	-23.12%
Upper Slocums	SRT-4	0.994	0.789	-20.59%
Upper Slocums	SRT-5	0.826	0.671	-18.78%
Mid Slocums	SRT-6	0.690	0.576	-16.62%
Mid Slocums	SRT-7	0.586	0.503	-14.28%
Mid Slocums	SRT-10	0.450	0.405	-10.00%
Lower Slocums: Giles	SRT-11	0.398	0.368	-7.57%
Lower Slocums	**SRT-12**	**0.392**	**0.364**	**-7.34%**
Lower Slocums	SRT-13	0.337	0.323	-3.92%
Inner Little River	SRT-14	0.365	0.360	-1.34%
Basin Little River	**SRT-15**	**0.349**	**0.345**	**-1.32%**
Inlet - Little River	SRT-16	0.325	0.321	-1.14%
Outer Basin	SRT-17	0.290	0.289	-0.35%

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.