

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 watershed further strengthen the analysis. These data were collected to support threshold development for the Little Pond System by MEP Team 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 long-term baseline Falmouth water quality monitoring program collected by PondWatch. At present, Little Pond, both upper and lower reaches, is showing significantly impaired habitat quality. The lower reach is only moderately better habitat than the upper reach, in spite of its proximity to the tidal inlet and high quality waters of Vineyard Sound. All of the habitat indicators are consistent in the evaluation of the whole of Little Pond being classified as a significantly impaired estuarine habitat (Chapter VII, Table VIII-1).

Eelgrass: Currently, there is only sparsely distributed eelgrass in the central region of the lower basin in Little Pond. The larger distribution in 1995 diminished to 2001 and the extensive eelgrass beds of 1951 are no longer present. However, the presence of sparse eelgrass in Little Pond in 2001 indicates that eelgrass recovery within the lower basin of estuary is a good target for nitrogen management. The system's pattern of eelgrass bed loss and its current lack of eelgrass beds, indicates that the lower basin is moderately to significantly impaired and the upper tributary has not generally been supportive of eelgrass habitat. The pattern of eelgrass loss from the lower basin supports nitrogen loading as the primary mechanism. The loss occurred first in the deeper regions, consistent with decreased light penetration as increasing nitrogen inputs stimulated phytoplankton production. Eelgrass recovery following nitrogen management would likely follow the reverse of this pattern, with beds first being re-established in the marginal areas and moving finally to the deeper regions.

Water Quality: The upper and lower reaches of Little Pond are currently under seasonal oxygen stress, consistent with nitrogen enrichment (Table VII-1). That the cause is eutrophication is supported by the high levels of chlorophyll a, 15 ug/L to >20 ug/L (Table VII-2). Oxygen conditions and chlorophyll a levels indicated nutrient related stress throughout Little Pond with a moderate improvement with decreasing distance to the tidal inlet. Oxygen depletions below 5 mg/L were common in both upper and lower reaches, 19% and 13% of deployment time respectively, and depletions below 3 mg/L were observed (5% and 2% of deployment, respectively). The observed chlorophyll a levels and oxygen depletions within Little Pond waters during summer is consistent with the high level of total nitrogen found throughout the Pond's waters. Falmouth PondWatch data indicates average summer total nitrogen levels ranging from 0.745 in the lower basin nearest the tidal inlet to 0.942 mg N/L in the upper portion of the upper estuarine reach. These are relatively high total nitrogen values and when compared to the adjacent offshore waters (0.28 mgN/L) the extent of nitrogen loading to the estuarine waters of Little Pond is clear. The levels and distribution of chlorophyll a, dissolved oxygen and total nitrogen within Little Pond is consistent with the observed eelgrass losses (above) and the significantly impaired infaunal animal communities (below).

Infaunal Communities: The Infauna Study indicated that all areas are presently significantly impaired to severely degraded (Table VII-4). The upper reach of Little Pond is currently

impoverished in infaunal species (~4 per site), has relatively low numbers (~250 per sample) and is dominated by stress indicator species. The lower reach of Little Pond is only moderately better having more individuals (~600 per sample) and more species (~7 per sample). However, the lower reach, like the upper reach, is dominated by organisms indicative of high organic matter loading, stressful conditions and impaired habitat. The gradient from upper to lower estuary is only sufficient to classify the upper region as significantly impaired/severely degraded to significantly impaired in the lower basin. The infaunal habitat classification within Little Pond is supported by all of the infaunal criteria (numbers of individuals, numbers of species, diversity, evenness and habitat indicator species). The limited infaunal species in Little Pond were dominated by small polychaete worms (*Capitella*, *Streblospio*, etc.). These species are adapted to conditions of high organic matter loading and sulfidic sediments and generally are good indicators of nitrogen enrichment (eutrophic conditions). As is typical when conditions support these opportunistic stress tolerant species, they can occur in relatively high densities. Both the upper and lower reaches of Little Pond supported an infaunal community dominated by opportunistic stress tolerant species, but with lower numbers of organisms distributed among fewer species in the upper reach, indicating a higher level of stress in this region. The infaunal community based classification in the upper and lower reaches of Little Pond is fully supported by the water quality and eelgrass data discussed in the text above.

Table VIII-1. Summary of Nutrient Related Habitat Health within the Little Pond, Estuary on the south shore of Falmouth, MA., based upon assessment data presented in Chapter VII.		
Health Indicator	Estuary	
	Little Pond	
	Upper	Lower
Dissolved Oxygen	SI/SD ¹	SI/SD ¹
Chlorophyll	SI	SI
Macroalgae ²	SI	SI
Eelgrass	SI ³	MI/SI ⁴
Infaunal Animals	SI/SD ⁵	SI ⁵
Overall:	SI/SD	SI
1 – periodic oxygen depletions to <3 mg/L and frequently <4 mg/L. 2 – macroalgal floating accumulations during summer in lower basin periodically occur. 3 – no evidence that upper region of this estuarine reach is supportive of eelgrass. 4 – estuarine reach is supportive of eelgrass, but shift from beds in 1951 to only sparsely distributed plants by 2001/2002. 5 – low diversity, modest numbers of individuals dominated by stress indicator species. H = healthy habitat conditions; MI = Moderate Impairment; SI = Significant Impairment; SD = Severe Degradation -- = not applicable to this estuarine reach		

VIII.2 THRESHOLD NITROGEN CONCENTRATIONS

Threshold Conclusion: The approach for determining nitrogen loading rates, which will maintain acceptable habitat quality throughout and 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.

The restoration goal for Little Pond based upon the present and historical conditions is to restore eelgrass habitat to the lower basin and infaunal community habitat to the upper estuarine reach. The nitrogen loading threshold for Little Pond was developed from the habitat indicator information in Section VII and thresholds development from adjacent Great Pond, Green Pond and Bournes Ponds which are structurally similar to Little Pond. In particular, Bournes Pond is very similar in its basin depths and shares the common tidal waters of Vineyard Sound. Little Pond has both historic evidence of eelgrass beds (1951) and recent surveys indicating sparsely distributed eelgrass within the lower basin. The historic presence of eelgrass beds and the present survival of eelgrass plants supports the restoration of eelgrass as the management target for Little Pond. However, eelgrass appears to have been confined mainly to the lower basin with fringing beds in the shallows up to PondWatch sampling station LP-2 (Figures VI-1, VIII-1). The distribution of eelgrass in the 1951 and 1995 data indicate that eelgrass beds were found primarily within the ~1 meter depths and not in the small basin at ~2 meters depth. This is similar to the findings for Bournes Pond where a threshold at the sentinel station to achieve the fringing beds at similar depths to Little Pond was set at 0.45 mg N L^{-1} . The restoration of the full lower basin of Little Pond should also be achieved when the sentinel station reaches 0.45 mg N L^{-1} as the lower basin will have lower nitrogen levels than the sentinel station. At present, the lower basin has moderately higher quality habitat than in the upper reach in which the sentinel station is located and this moderate gradient of improvement moving toward the tidal inlet will persist as future nitrogen management is implemented. Since the sentinel station is about 1/2 of the distance from the headwaters of the Pond, the region above this station is targeted for restoration of infaunal animal habitat (i.e. the reach above the upper limit of the 1951 eelgrass distribution). In studies of Great Pond, Green Pond and Bournes Ponds and Popponesset Bay, infaunal animal habitat quality was found to be moderate to high at $0.5 - 0.6 \text{ mg N L}^{-1}$ and excellent at $\leq 0.5 \text{ mg N L}^{-1}$. Achieving the threshold level at the sentinel station will produce a level of total nitrogen in the upper estuarine reach (Station LP-1 to LP-2) of $<0.5 \text{ mg N L}^{-1}$ supportive of high quality benthic animal habitat.

Discussion: Within the Little Pond Estuary the most appropriate sentinel station (LP-2) was about 1/2 of the distance from the headwaters to the tidal inlet (Figure VIII-1). This location was selected because (1) it was in the upper region where eelgrass bed coverage was documented in the 1951 analysis, (2) restoration of nitrogen conditions supportive of eelgrass at this location will necessarily result in even higher quality conditions throughout the entire lower basin, and (3) restoration of nitrogen concentrations at this site should result in conditions similar to 1951 within the upper tributary, which will be supportive of high quality habitat for benthic infaunal communities (confirmed as described below). For embayment restoration, an additional requirement within the upper 1/2 of the estuary was to ensure that TN in this region has been reduced to levels supportive of healthy infaunal community habitat when the eelgrass threshold was met for the lower 1/2 of the embayment.



Figure VIII-1. Contour plot of modeled average total nitrogen concentrations (mg/L) in the Little Pond system, for threshold conditions (0.45 mg/L at water quality monitoring station LP2). The approximate location of the sentinel threshold station for Little Pond (LP2) is shown.

The target nitrogen concentration for restoration of eelgrass in this system was determined to be 0.45 mg TN L⁻¹ for Station LP2 and TN <0.45 mg TN L⁻¹ in the lower basin. This threshold level is consistent with the findings that (1) eelgrass beds have been lost in the lower basin which currently supports a tidally averaged TN of 0.837 mg TN L⁻¹ at LP2 and 0.705 mg TN L⁻¹ in the lower basin (LP3), (2) sparse eelgrass can be still be found within the lower

basin at tidally averaged TN of $0.61 \text{ mg TN L}^{-1}$, and (3) the eelgrass beds in Bournes Pond (threshold $0.45 \text{ mg TN L}^{-1}$) at water depths similar to those in the lower basin of Little Pond, which is important for light penetration. Based upon these data, the threshold TN level at the sentinel station was set at $0.45 \text{ mg TN L}^{-1}$ to achieve eelgrass habitat recovery throughout the lower basin and to re-establish the marginal beds seen in 1995 near LP-2. These marginal beds along the edges of the basin where the estuary narrows existed outside of the relatively deeper basins within this portion of Little Pond. Due to the shallow depths of these margins and the small tide range within the system, eelgrass restoration likely will occur at slightly higher TN values than observed regionally (e.g. Stage Harbor in Chatham). The small tide range increases the duration of light penetration to the bottom compared to similar estuaries with larger tide ranges. Therefore, restoration of eelgrass beds along the margins immediately north of where the estuary narrows down should occur when TN levels are lowered to $0.45 \text{ mg TN L}^{-1}$.

Given the lack of healthy infaunal habitat in Little Pond, the infaunal requirements are based upon Great Pond and Bournes Pond, where TN levels below $0.45 \text{ mg TN L}^{-1}$ support moderate to healthy habitat, with healthy infauna habitat requiring $\text{TN} < 0.5 \text{ mg TN L}^{-1}$. This result also is the same found to support moderate to healthy habitat by MEP for Popponeset Bay. The significantly impaired upper and mid reaches of Little Pond currently have very high TN levels, $> 0.8 \text{ mg TN L}^{-1}$. Based upon sequential reductions in watershed nitrogen loading in the analysis described in the section below (VIII-3), the sentinel station achieved an average TN level of 0.45 mg L^{-1} . This indicates that significant eelgrass habitat restoration would occur within the regions of the 1951 coverage which will achieve even lower TN levels, TN levels generally thought to be highly supportive of eelgrass beds. Although infaunal habitat is not the primary habitat restoration driving thresholds development for Little Pond, restoration of infaunal habitat throughout Little Pond should be achieved upon reaching the threshold TN level at the sentinel station. The result will be high quality infaunal habitat system wide and restoration of eelgrass habitat in the lower basin. Upon reaching the TN threshold at the sentinel station, the upper tributary (LPHEAD), which is currently showing signs of significant impairment bordering on severely degraded infaunal habitat ($> 2.0 \text{ mg TN L}^{-1}$) and located in the immediate mixing zone just below the entrance of Little Pond Stream (at LPHEAD), will have TN levels $< 1.1 \text{ mg L}^{-1}$. In the uppermost portion of the upper reach of Little Pond, LP-1 will be below the nitrogen level associated with high quality infaunal habitat, $< 0.5 \text{ mg TN L}^{-1}$. This yields a range of TN in the upper reach of 0.45 mg N/L at LP-2 and $< 0.5 \text{ mg N/L}$ at LP-1. This indicates that upon reaching the threshold nitrogen level, restoration of infaunal habitat throughout the upper reach will be achieved. It should be emphasized that these infauna values were not used for setting nitrogen thresholds in this embayment system. These values merely provide a check on the acceptability of conditions in the tributary systems when the threshold level is attained at the sentinel station. The results of the Linked Watershed-Embayment modeling, when the nitrogen threshold is attained (Section VIII-3), yield TN levels in these regions within the acceptable range. Therefore, it appears that achieving the nitrogen target at the sentinel location is restorative of eelgrass habitat throughout the lower Little Pond basin and marginal beds along the narrowing edges of the estuary and restorative of infaunal habitat throughout the estuary.

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 Little Pond. Tidally averaged total nitrogen thresholds derived in Section VIII.1 were used to adjust the calibrated constituent transport model developed in Section VI. Watershed nitrogen loads were sequentially lowered, using reductions in septic effluent discharges only, until the nitrogen levels reached the threshold level at the sentinel stations

chosen for Little Pond. 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 100% removal of septic load (associated with direct groundwater discharge to the embayment) for the systems' lower watersheds. In addition, a portion of the septic load entering the pond from the fresh water stream also must be removed to meet the threshold nitrogen concentrations. For the load reduction scenario evaluated, the Little Pond Stream sub-watershed required removal of approximately 60% of the septic load. 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 <i>septic loads</i> (attenuated) used for modeling of present and threshold loading scenarios of the Little Pond 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
Little Pond	10.419	0.000	-100.0%
Surface Water Sources			
Little Pond Stream	5.496	2.198	-60.0%

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 100% of the septic load from the lower watershed of Little Pond results in an 80% reduction in total nitrogen load. For the Little Pond Stream, septic load reduction of 60% resulted in total attenuated watershed load reduction of 55%. 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 Vineyard 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 Little Pond 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
Little Pond	13.022	2.603	-80.0%
Surface Water Sources			
Little Pond Stream	6.052	2.755	-54.5%

Table VIII-4. Threshold sub-embayment loads and attenuated surface water loads used for total nitrogen modeling of the Little Pond 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)
Little Pond	2.603	0.584	0.670
Surface Water Sources			
Little Pond Stream	2.755	-	-

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 50% is required for Little Pond.

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 consistent finding of the MEP has been the need for in depth 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. Conversion of abandoned cranberry bogs to a more “natural” state, other freshwater wetland resources, and freshwater ponds provide opportunities for enhancing natural attenuation of associated 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 Little Pond system. Sentinel threshold stations are in bold print.

Sub-Embayment	monitoring station	present (mg/L)	threshold (mg/L)	% change
Little Pond Head (fresh water)	LPHEAD	2.236	1.036	-53.7%
Little Pond - upper	LP1	0.955	0.492	-48.5%
Little Pond - mid	LP2	0.837	0.449	-46.3%
Little Pond - lower	LP3	0.705	0.408	-42.1%

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.