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

VIII.1. ASSESSMENT OF NITROGEN RELATED HABITAT QUALITY

Determination of site-specific nitrogen thresholds for an embayment requires the integration of key habitat parameters (infauna and eelgrass), sediment 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 Oyster Pond System by the 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 water quality monitoring program. At present the bulk of the Oyster Pond is showing moderately to significantly impaired habitat quality (Chapter VII).

Eelgrass: There is no evidence that the Pond has supported eelgrass from 1947 to present. If the pond supported eelgrass prior to the construction of the railroad embankment (1872), then as the tidal exchange became restricted due to the embankment and the subsequent failure of the tidal culvert and the pond freshened, eelgrass was lost. A likely estimate is that the Pond lost eelgrass more than 100 years ago as a result of freshening (not nutrients) and can no longer support eelgrass at “present” pond salinities (Section VII). Since Oyster Pond cannot support eelgrass at or near its present salinity status, eelgrass cannot be used as either an indicator of habitat health or as a target for habitat restoration. Therefore, in keeping with the MEP thresholds approach, restoration of infaunal habitat will be used as the restoration target.

Water Quality: At present, the waters of Oyster Pond generally support a moderate level of water quality as evidenced by the moderate levels of phytoplankton biomass (indicated by chlorophyll a) in summer (mean 4.9 ug/L). However, given the limited tidal flushing of the system most of the primary production remains in the Pond, to decompose and consume oxygen and regenerate nitrogen. The keystone water quality issue in Oyster Pond involves the interaction between nitrogen enrichment (through its produced organic enrichment) and dissolved oxygen in bottomwaters as also influenced by periodic vertical stratification. The ecologically significant result of this interaction is the periodic depletion of oxygen in bottom waters (4 meters) overlying significant areas of pond bottom. In this system, this periodic hypoxia is most likely the cause of the poor infaunal habitat, as evidenced by the present infaunal communities structure.

Infaunal Communities: The Infaunal Study showed communities consistent with it oligohaline condition, namely a mixture of estuarine species and species more typical of “fresh” water. Under present conditions, the community within the pond shows signs of nutrient related stress, in that while in some areas (typically at 2 meters) there are relatively large populations, the species numbers are very low, hence diversity (H’) and evenness (E) are low. The loss of benthic communities at 4 meters appears to be due to low oxygen and at 1 meter potentially due to accumulations of macrophytes. However, the macrophytes themselves provide habitat for invertebrates, which was not assessed. This suggests that the 1 meter samples may not represent the “resident” invertebrate community at this depth. The 2 meter and 4 meter samples are not compromised by macrophyte effects and therefore will be used in the development of the nitrogen threshold for restoration. The overall results indicate a system almost certainly capable of supporting diverse healthy communities but which currently has infaunal habitat that is significantly impaired under present nitrogen loading conditions.

Overall, all of the indicators show a consistent pattern of moderate to significant impairment throughout the basins of Oyster Pond. While the Pond does not show strong gradients in salinity or water quality parameters, the enclosed nature of the northern basin appears to increase the duration of stratification and subsequent hypoxia. The deep southern basin (~6 m) is salinity stratified for months to years at a time and is generally anoxic as a result of this natural process. Based primarily on the infaunal communities and the bottomwater hypoxia, it was concluded that Oyster Pond habitat is presently moderately to significantly impaired. Since the ultimate cause of the low dissolved oxygen (≤4m) results from nitrogen enrichment, it can also be concluded that the system is nitrogen overloaded at present.

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.

As stated above, Oyster Pond differs from most other estuaries in its lack of horizontal gradients in salinity, nitrogen, and nitrogen related parameters (chlorophyll a, D.O., transparency, etc.). Therefore, selection of the sentinel station was not based on horizontal gradients and their response to changing nitrogen loads. Instead, the sentinel station was selected to best capture the overall conditions of the Pond waters. Stations OP-1, OP-2, OP-3 could all be used as the sentinel station, but if a single point needs to be monitored, then OP-3 appears to be the most representative of the pond waters. In addition, since Oyster Pond is vertically stratified, the surface mixed layer (0-4 m) is the target for setting the nitrogen threshold level, as this is the zone in the pond which impinges on potentially usable benthic habitat.

The nitrogen threshold for Oyster Pond is based upon restoring benthic habitat for infaunal animals. Given the natural stratification of Pond waters, sediments < 4 meters depth representing ~80% of the pond bottom were targeted. This depth is based upon the depth distribution of the bottom and the depth of the mixed layer. Since the present nitrogen levels result in periodic hypoxia at 4 meters depth, the nitrogen threshold was set to improve and maintain oxygen levels ≥6 mg/L at 4 meters depth in the main basin (OP-3). At present, the minimum dissolved oxygen at this station is most likely 3 mg/L, although a single reading of 2 mg/L was recorded. Given the uncertainties in determining minimum D.O. in any estuary, the nitrogen threshold was set using 2 mg/L as the current minimum D.O. level. This adds a level of safety to the analysis.

The concept underpinning the linkage of nitrogen levels (threshold) to bottom water dissolved oxygen minimum is based upon the fact that during brief stratification events (as opposed to the prolonged salinity stratification), oxygen is taken up in respiration and oxygen resupply by ventilation or photosynthesis is trivial. Since the rate of oxygen uptake is directly proportional to the amount of organic matter in the system and the amount of organic matter in this tidally restricted brackish kettle pond is proportional to the amount of nitrogen input, then decreasing nitrogen inputs should result in proportional decreases in the rate of oxygen uptake in the hypolimnion during stratification. In other words, since the pond and its watershed are operating nearly completely as a biogeochemically “closed” system, reductions in nitrogen inputs should result in proportional reductions in oxygen uptake in bottom waters.

Since at summer temperatures (25^{o}C) and salinities (2 ppt), dissolved oxygen saturation is 8.2 mg/L and current oxygen minimum is 2 mg/L then raising the minimum oxygen level to 6 mg/L would require 4/6.2 or 65% reduction in the rate of oxygen uptake during stratification. This assumes that the present duration and frequency of stratification of waters overlying sediments 4 meters or less deep will remain as at present. This is a safe assumption as long as the management plan does not allow the pond salinity levels to climb above target 2-4 ppt range. Given the link between nitrogen load and oxygen uptake rate, this 65% reduction in oxygen uptake would require a 65% reduction in nitrogen loading to Oyster Pond. Using a similar analysis, raising the periodic minimum dissolved oxygen to 3.8 mg/L (Chesapeake Bay value) or the SB criteria of 5 mg/L would require reductions in nitrogen loading of 29% and 48%, respectively. These translate into the total nitrogen threshold levels in the mixed layer of Oyster Pond shown in Table VIII-5.

Table VIII-1. Average total N concentrations to achieve target bottom water oxygen minima. Based upon modeled nitrogen reductions for the Oyster Pond system. Selected sentinel station is **OP-3**.

Sub-Embayment	monitoring station	threshold (mg/L)
3.8 mg/L Minimum D.O. Threshold		
Oyster Pond – upper	OP1	0.635
Oyster Pond – mid	OP2	0.634
Oyster Pond – lower	**OP3**	**0.633**
5.0 mg/L Minimum D.O. Threshold		
Oyster Pond – upper	OP1	0.589
Oyster Pond – mid	OP2	0.588
Oyster Pond – lower	**OP3**	**0.588**
6.0 mg/L Minimum D.O. Threshold		
Oyster Pond – upper	OP1	0.549
Oyster Pond – mid	OP2	0.548
Oyster Pond – lower	**OP3**	**0.548**

Stratification and Oxygen Transport to Bottom waters: Given the importance to the thresholds development of negligible oxygen input from the surface mixed layer to the bottom waters (hypolimnion), the MEP examined the potential rate of diffusion (eddy diffusion) to supply oxygen to bottom waters during stratification. This analysis was conducted in collaboration with SMAST scientists (Dr. M. Sundermeyer). The analysis revealed that during periods of light winds, enhanced stratification in the upper-most few meters of the water column can significantly reduce, or even halt ventilation of deeper waters. The duration of such events can have a significant influence on subsurface D.O. levels. Consider an event in which the upper few meters of the water column go from a uniform, well-mixed layer of temperature 20^{o} C, to the upper 2 m having a temperature of 22^{o} C, capping a 20^{o} C layer below. Assuming a surface heat flux into the water during daylight hours of order 400 W/m^2, the time required to heat the upper 2 m of water by 2^{o} C is: $\Delta t = \Delta T \cdot \rho \cdot c_p \cdot \Delta z / Q_{net}$, where Δt is time, ΔT is change in temperature, $\rho \approx 1020$ kg/m^3, is the density of seawater, $c_p \approx 0.95$ cal/g/C is the specific heat of water, Δz is 2 m, and Q_{net} is the mean heat flux over the time of interest. This suggests that it would take approximately 12 hours, or about 1 day (sunrise to sunset) to heat the upper 2 m by this amount. Such stratification events can thus occur as the result of only a single day of such conditions. Assuming a "worst-case" scenario, in which vertical eddy diffusivity is completely suppressed by such stratification events, so that the vertical diffusivity of dissolved oxygen is reduced to its molecular value of $\kappa = 2 \times 10^{-9}\ m^2/s$, the characteristic time to ventilate the deeper waters by molecular diffusion alone can be estimated. Assuming a D.O. concentration of 8 mg/l at a depth of 3.25 m, decreasing to 2 mg/l at 4 m, the characteristic diffusion time scale to bring the 4 m D.O. level up to the 3.25 m value is $T_{diffusion} = \Delta z^2/\kappa = (0.75\ m)^2 / 2 \times 10^{-9}\ m^2/s \approx 3{,}255$ days ≈ 9 yrs; i.e., much too long to be relevant on the timescales of these events. Put another way, considering the same D.O. values from the perspective of vertical fluxes, the downward flux of D.O. by molecular diffusion under such conditions would be of order, Vert. D.O. Flux = $\kappa \cdot \Delta D.O./\Delta z = 2 \times 10^{-9}\ m^2/s \times 6\ mg/l / 0.75\ m = 1.6 \times 10^{-5}\ mg/m^2/s = 1.4\ mg/m^2/day$. Put another way, this would amount to a rate of increase of DO of $\kappa \cdot \Delta DO/\Delta z^2 = 2 \times 10^{-9}\ m^2/s \times 6\ mg/l / (0.75\ m)^2 = 2.1 \times 10^{-8}\ mg/l/s = 1.8 \times 10^{-3}\ mg/l/day$; i.e. much too small to be relevant compared to respiration and/or generation by photosynthesis.

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 Oyster Pond to a series of dissolved oxygen values. Due to the existing salinity levels in the Pond (historically between 0 and 4 ppt), eelgrass cannot be established within this brackish water body. Instead, development of an appropriate threshold to restore infaunal habitat was based on minimum dissolved oxygen within the lower basin of Oyster Pond. It was determined that a linear relationship was appropriate to assess the expected changes in dissolved oxygen relative to total nitrogen for the site-specific conditions within the main basin of the Pond. Minimum dissolved oxygen thresholds derived in Section VIII.1 were used to adjust the calibrated constituent transport model developed in Section VI. Watershed nitrogen loads were lowered by the percentage derived by the following equation:

$$\%\,\text{N Reduction} = \frac{(\text{Target D.O. - Min Observed DO})}{(\text{Max Saturation - Min Observed DO})} * 100\%$$

It is important to note that load reductions can be produced by reduction of any or all sources or by increasing the natural attenuation of nitrogen within the freshwater systems to the embayment. The load reductions presented below represent only one of a suite of potential reduction approaches that need to be evaluated by the communities.

As shown in Table VIII-2, the nitrogen load reductions within the system necessary to achieve the threshold dissolved oxygen concentrations were higher for higher minimum dissolved oxygen levels. Since the nitrogen concentrations are generally uniform across the entire surface of Oyster Pond (i.e. there is virtually no spatial gradient in nitrogen concentration), the nitrogen load was removed uniformly. Distributions of tidally-averaged nitrogen concentrations associated with the above thresholds analysis are shown in Figures VIII-1 through VIII-3 for each pond separately.

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. 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.

Comparison of model results between existing loading conditions and the selected loading scenarios to achieve the target D.O. concentrations within Oyster Pond are shown in Table VIII-5. To achieve the threshold dissolved oxygen concentrations at the sentinel stations, a reduction in TN concentration of approximately 9%, 15%, and 21% is required for dissolved oxygen concentrations of 3.8 mg/l (based on the EPA's Chesapeake Bay limit), 5.0 mg/l (Massachusetts SB waters), and 6.0 mg/l (Massachusetts SA waters), respectively.

Although the above modeling results provide one manner of achieving the selected threshold levels within the Oyster Pond system, the specific examples do 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-2. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Oyster 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
3.8 D.O. threshold			
Oyster Pond	3.477	2.192	-37.0%
Oyster Pond Lagoon	0.230	0.230	+0.0%
Mosquito Creek (surface water)	0.110	0.068	-37.5%
5.0 D.O. Threshold			
Oyster Pond	3.477	1.332	-61.7%
Oyster Pond Lagoon	0.230	0.230	+0.0%
Mosquito Creek (surface water)	0.110	0.041	-62.5%
6.0 D.O. threshold			
Oyster Pond	3.477	0.619	-82.2%
Oyster Pond Lagoon	0.230	0.230	+0.0%
Mosquito Creek (surface water)	0.110	0.019	-82.5%

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 Oyster 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
3.8 D.O. threshold			
Oyster Pond	4.066	2.781	-31.6%
Oyster Pond Lagoon	0.293	0.293	+0.0%
Mosquito Creek (surface water)	0.115	0.074	-35.7%
5.0 D.O. Threshold			
Oyster Pond	4.066	1.921	-52.8%
Oyster Pond Lagoon	0.293	0.293	+0.0%
Mosquito Creek (surface water)	0.115	0.047	-59.5%
6.0 D.O. threshold			
Oyster Pond	4.066	1.208	-70.3%
Oyster Pond Lagoon	0.293	0.293	+0.0%
Mosquito Creek (surface water)	0.115	0.025	-78.6%

Table VIII-4. Threshold sub-embayment and surface water loads used for total nitrogen modeling of the Oyster 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)
3.8 D.O. threshold			
Oyster Pond	2.781	0.773	-1.342
Oyster Pond Lagoon	0.293	0.027	-0.037
Mosquito Creek (surface water)	0.074	-	-
5.0 D.O. Threshold			
Oyster Pond	1.921	0.773	-1.080
Oyster Pond Lagoon	0.293	0.027	-0.030
Mosquito Creek (surface water)	0.047	-	-
6.0 D.O. threshold			
Oyster Pond	1.208	0.773	-0.863
Oyster Pond Lagoon	0.293	0.027	-0.024
Mosquito Creek (surface water)	0.025	-	-

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

Sub-Embayment	monitoring station	present (mg/L)	threshold (mg/L)	% change
3.8 D.O. threshold				
Oyster Pond – upper	OP1	0.696	0.635	-8.7%
Oyster Pond – mid	OP2	0.694	0.634	-8.7%
Oyster Pond – lower	OP3	0.693	0.633	-8.7%
5.0 D.O. Threshold				
Oyster Pond – upper	OP1	0.696	0.589	-15.4%
Oyster Pond – mid	OP2	0.694	0.588	-15.3%
Oyster Pond – lower	OP3	0.693	0.588	-15.2%
6.0 D.O. threshold				
Oyster Pond – upper	OP1	0.696	0.549	-21.1%
Oyster Pond – mid	OP2	0.694	0.548	-21.0%
Oyster Pond – lower	OP3	0.693	0.548	-21.0%

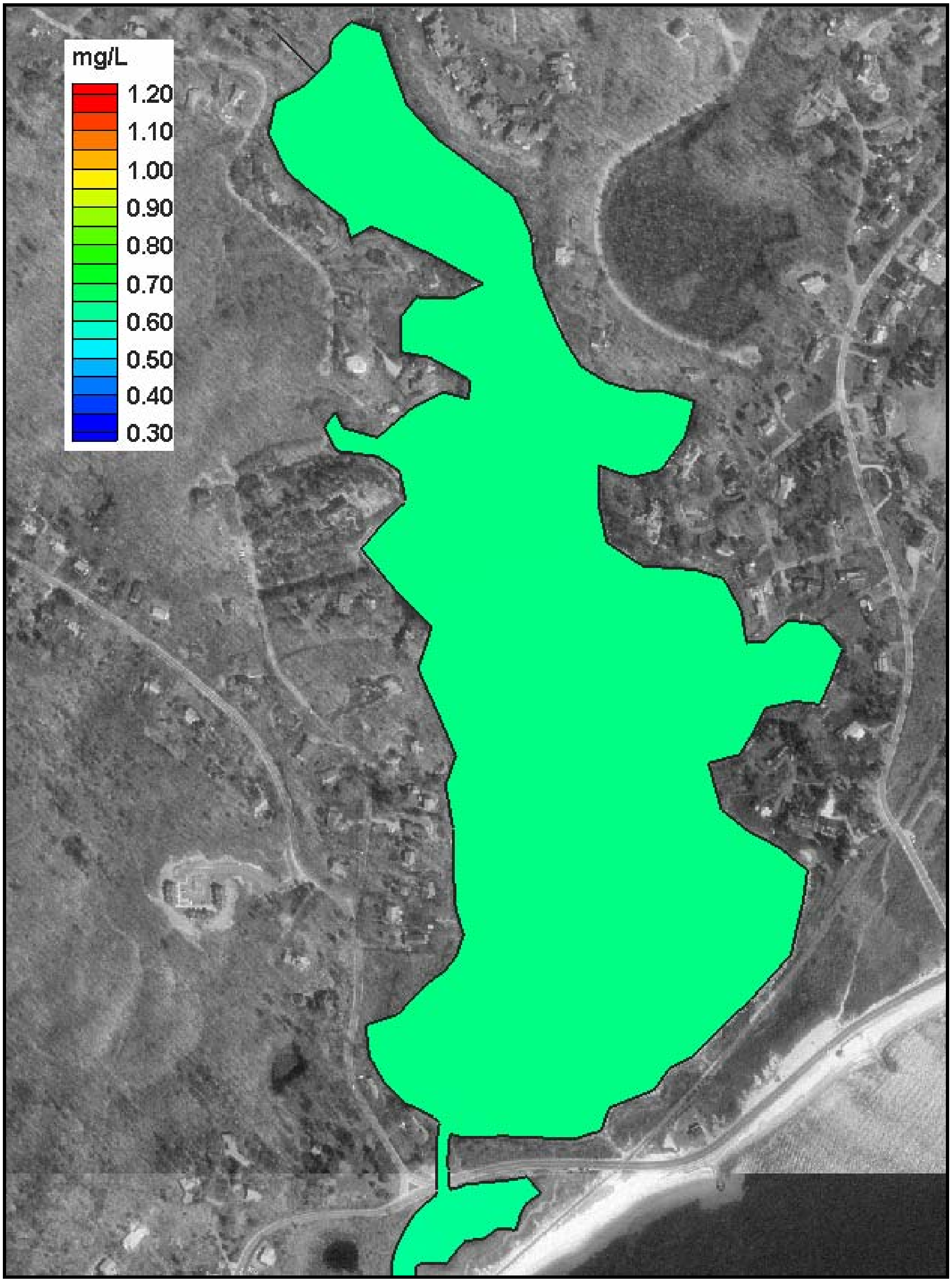

Figure VIII-1. Contour plot of modeled average total nitrogen concentrations (mg/L) in the Oyster Pond system, for threshold conditions (minimum 3.8 mg/L Dissolved Oxygen pond-wide).

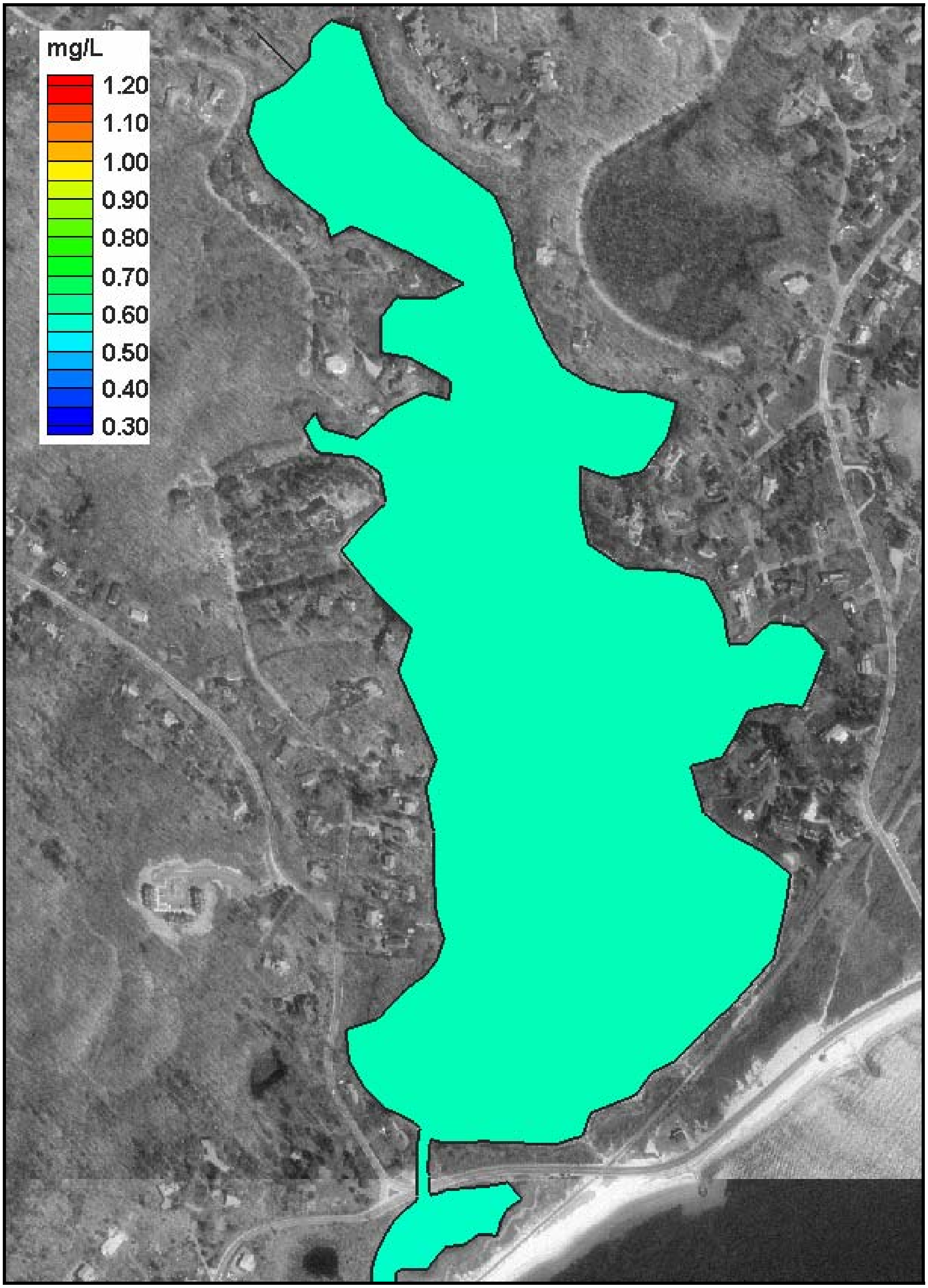

Figure VIII-2. Contour plot of modeled average total nitrogen concentrations (mg/L) in the Oyster Pond system, for threshold conditions (minimum 5.0 mg/L Dissolved Oxygen pond-wide).

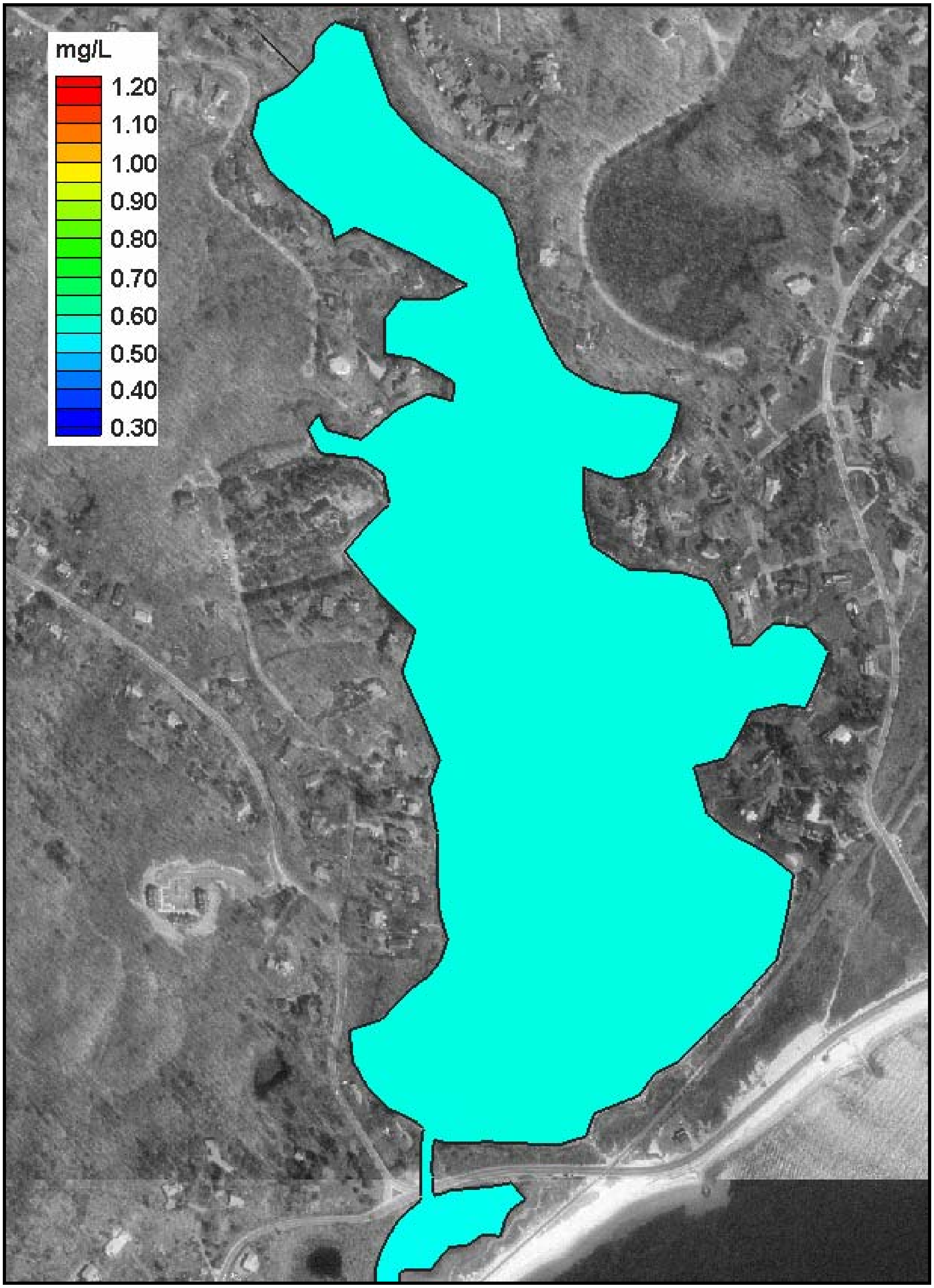

Figure VIII-3. Contour plot of modeled average total nitrogen concentrations (mg/L) in the Oyster Pond system, for threshold conditions (minimum 6.0 mg/L Dissolved Oxygen pond-wide).