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 Popponesset Bay 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 water quality monitoring program. At present the bulk of the Popponessett Bay System is showing significantly impaired habitat quality (Chapter VII).

Eelgrass: Since the system once supported eelgrass beds (~100 acres in 1951) and now has lost all eelgrass coverage, the highest habitat evaluation currently possible is moderate impairment (Howes et. al 2003). The level of impairment after the loss of eelgrass can be determined from the dissolved oxygen and phytoplankton biomass (chlorophyll) and infaunal communities. The current lack of eelgrass beds is expected given the high chlorophyll a and low dissolved oxygen levels and watercolumn nitrogen concentrations within this system. However, it appears that a substantial area of the central basin supported eelgrass beds in 1951. In addition, there were smaller beds within the upper region of the main basin, at the mouth to Shoestring Bay. The pattern of these beds is consistent with the pattern of nitrogen related habitat quality, which is currently observed within the System. It appears that as the Bay became nutrient enriched, that these sites could no longer support eelgrass beds. However, it is likely that if nitrogen loading were to decrease, eelgrass could first be restored in the lower portion of the main basin and with further reductions, be restored to the 1951 pattern.

It is significant that eelgrass was not detected in Shoestring Bay and Ockway Bay in the 1951 data. It appears that these systems are not supportive of this type of habitat. Given the structure of these sub-embayments and their sediment types, it appears that these are natural depositional basins and may not be conducive to supporting rooted macrophytes. It is also possible that the tidal flushing of the Popponesset Bay System has historically varied from unrestricted to restricted as the inlet has migrated. This variation may have created nutrient related habitat quality issues within Ockway and Shoestring Bays, even under the low watershed nitrogen loading levels generally associated with the 1951 population. The lack of eelgrass in the Mashpee River is consistent with its role as a salt marsh system, which drains completely at low tide in the upper regions and which is “naturally” organic rich. For these reasons, salt marshes typically do not support eelgrass beds within their main channels.

Water Quality: At present, the central basin of Popponesset Bay supports relatively healthy habitat conditions of consistently high bottom water dissolved oxygen and modest phytoplankton blooms during summer. In contrast, the other regions of the System have moderate to high levels of nitrogen related impairment. Shoestring Bay shows both periodic oxygen declines and significant phytoplankton blooms, while Ockway Bay has similar oxygen declines, but apparently less phytoplankton biomass. Dissolved oxygen measurements in the Mashpee River also indicate nutrient impairment, with extreme oxygen excursions and night-time oxygen depletion on a consistent basis, and significant phytoplankton blooms. The major issue with the Mashpee River is the extent to which its structure as a salt marsh system ameliorates the impact of these water quality features. However, even as a salt marsh, these

levels of chlorophyll a and oxygen excursion indicate a moderate level of impairment. Based upon the dissolved oxygen and chlorophyll data the ranking of the Popponesset Bay System components is as follows:

- Popponesset Bay Central Basin – high quality
- Popponesset Bay upper/confluence, Shoestring & Ockway Bays – significantly impaired
- Mashpee River – significantly impaired to degraded (relative to embayments)
  -- moderately to significantly impaired (relative to salt marshes).

Infaunal Communities: The Infauna Study indicated that all areas, except for the lower station within the central basin of Popponesset Bay, are presently moderately to severely degraded (Table VII-5). Upper Ockway Bay was found to support the poorest infaunal communities within the system, based upon the very low number of species and individuals. Although the 2 species found (compared to 31 in the central basin) were indicative of healthy conditions, the low numbers (20's compared to 400-500 typically) indicated that this system is not supporting a productive or diverse benthic community. The indication of better habitat, although listed as significantly impaired, is seen in the Mashpee River results. The River is currently supporting a community indicative of a riverine salt marsh. However, the total numbers of individuals and diversity tend to be low, indicative of an impaired resource (significant impaired on the overall classification scale). Shoestring Bay and the uppermost portion of the Popponesset Bay central basin both showed a resource between moderate and significant impairment. The numbers of individuals was generally high and were distributed among a moderate number of species. Diversity was also moderate to high and distributed between indicators of healthy and stressed conditions (Table VII-5), again indicative of moderate impairment. In contrast the Lower Popponesset Bay station supports a relatively healthy infaunal community, with nearly double the species of other sites and high numbers of individuals. The high diversity (H') and general evenness (E) are consistent with a healthy community. The indication of moderate impairment stems from the presence of stress indicator species. The overall results indicate an embayment system capable of supporting diverse healthy communities in the region nearest the tidal inlet, with most of the system having infaunal habitat that is significantly impaired under present nitrogen loading conditions.

Overall, all of the indicators show a consistent pattern of moderate impairment of the lower portion of the central basin of Popponesset Bay, primarily based upon its loss of eelgrass. While the upper central bay and Shoestring Bay are moderately to significantly impaired and Ockway Bay is significantly impaired to severely degraded based primarily upon the infaunal community data and the extent and duration of bottom water dissolved oxygen depletion. The Mashpee River appears to be functioning as a riverine salt marsh. However, due to its impoverished benthic community in the upper reach and the extreme dissolved oxygen excursions and phytoplankton blooms, it appears to be nutrient overloaded at present.

VIII.2. THRESHOLD NITROGEN CONCENTRATIONS

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 is

determined, the Linked Watershed-Embayment Model is used to sequentially adjust nitrogen loads until the targeted nitrogen concentration is achieved.

Within the Popponesset Bay System the region between the upper portion of the central basin to Popponesset Bay and the mouth of Shoestring Bay was selected as the sentinel region (PBh in Figure VI-1). This location was selected because (1) it was the upper extent of the eelgrass coverage in 1951, (2) restoration of nitrogen conditions supportive of eelgrass at this location will necessarily result in even higher quality conditions throughout the whole of the central basin, and (3) restoration of nitrogen concentrations at this site should result in conditions similar to 1951 within Shoestring and Ockway Bays. Shoestring Bay and Ockway Bay should then be supportive of high quality habitat for benthic infaunal communities (confirmed as described below).

The target nitrogen concentration for restoration of eelgrass in this system was determined to be 0.38 mg TN L^{-1}. It was not possible to make this determination based upon an analysis of the relationship of measured nitrogen levels to existing eelgrass beds in Popponesset Bay, as all beds have been lost. Instead, the value stems from (1) the analysis of Stage Harbor, Chatham which also exchanges tidal water with Nantucket Sound (for which a MEP target has already been set), (2) analysis of nitrogen levels within the eelgrass bed in adjacent Waquoit Bay, near the inlet (measured TN of 0.395 mg N L^{-1}, tidally corrected <0.38 mg N L^{-1}), and (3) a similar analysis in West Falmouth Harbor. The sentinel station under present loading conditions supports a measured nitrogen level at mid-ebb tide of 0.581 mg TN L^{-1} and a tidally corrected average concentration of 0.451 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 0.371 mg L^{-1} , the mouth of Ockway Bay, 0.376 mg TN L^{-1} and the whole of the Popponesset Bay basin <0.331 mg TN L^{-1}. This indicates that significant eelgrass habitat restoration would occur within the regions of the 1951 coverage. It is possible also to evaluate the response in benthic infaunal habitat. At present, the regions supporting the highest quality infaunal habitat have tidally averaged concentrations (mg TN L^{-1}) from 0.692 in the moderate-significantly impaired Shoestring Bay sites, to 0.451 in the similar upper Popponesset Bay site to 0.325 at the watercolumn site closest to the infaunal sampling site in the lower Bay basin. This latter concentration is likely too low and results from the fact that the model results are at the lower end of the allowable fit to the measured data at this site. The measured TN concentration is currently 0.456 mg TN L^{-1}. In any case, the data suggest that there is likely a range of total nitrogen that can support healthy infauna within this system. Based upon the infaunal analysis (Chapter VII) coupled with the nitrogen data (measured and modeled), nitrogen levels on the order of 0.4 to 0.5 mg TN L-1 are likely supportive of high infaunal habitat quality in this system. It should be noted that these values were not used for setting nitrogen thresholds in this embayment system. These values merely provide a check on the acceptability of conditions in Shoestring and Ockway Bays, as well as Lower Mashpee River, at the point that 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: upper to lower Shoestring Bay, 0.522 to 0.412 mg TN L^{-1}; upper Ockway Bay, 0.421 mg TN L^{-1}; and mid to lower Mashpee River, 0.525 to 0.422 mg TN L^{-1}. Therefore, it appears that achieving the nitrogen target at the sentinel location is restorative of eelgrass habitat throughout the Popponesset Bay central basin and restorative of infaunal habitat throughout Shoestring and Ockway Bays, as well as the lower portion of the Mashpee River.

VIII.3. DEVELOPMENT OF TARGET NITROGEN LOADS

The 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 region for the Popponesset Bay System. 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. 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-1, the nitrogen load reductions within the Popponesset Bay System necessary to achieve the threshold nitrogen concentrations were relatively high, 100% removal of septic load (associated with direct groundwater discharge to the embayment) required within four sub-embayments (Popponesset Creek, Ockway Bay, Mashpee River, and Shoestring Bay). In addition, a portion of the septic load entering the estuarine system via Mashpee and Santuit Rivers also must be removed to meet the threshold nitrogen concentrations. For the load reduction scenario evaluated, the Mashpee River and Santuit River required removal of approximately 41% and 35% of their septic load, respectively. The distribution of tidally-averaged nitrogen concentrations associated with the above thresholds analysis is shown in Figures VIII-1 and VIII-2.

Tables VIII-2 and VIII-3 provide additional loading information associated with the thresholds analysis. Table VIII-2 shows the change to the total watershed loads, based upon the removal of septic loads depicted in Table VIII-1. In general, removal of 100% of the septic load from Popponesset Creek, Ockway Bay, Mashpee River, and Shoestring Bay results in an 80% to 85% reduction in total nitrogen load from these sub-watersheds. Table VIII-3 shows the breakdown of threshold sub-embayment and surface water loads used for total nitrogen modeling. For Table VIII-3, 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 Nantucket Sound.

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 sub-embayments 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 to ensure the most cost-effective nitrogen reduction strategies. However, "planned" use of natural systems has to be done carefully and with the full analysis to ensure that degradation of these systems will not occur. One clear finding of the MEP has been the need for analysis of the potential of 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 systems, as well. The

lower freshwater and salt water reaches of the Mashpee and Santuit Rivers 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 streams discharging to estuaries is 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.

Although the above modeling results provide one manner of achieving the selected threshold levels for the sentinel site within this estuarine 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. As the restoration process continues, the MEP will work with the Towns of Mashpee and Barnstable to develop additional specific water quality modeling scenarios, to be run to evaluate other nitrogen removal strategies. One such proposed scenario, removing the discharges from the existing wastewater facilities from the watershed (pipeline), was partially evaluated by the MEP Team. At present only a tiny fraction (<0.5%) of the watershed nitrogen loading is discharged by the existing treatment facilities. Removing this load would have a very small impact. However, with increased sewering and treatment of wastewater, discharge within the groundwatershed directly discharging to Nantucket Sound has merit. The existing MEP analysis and model provides for the determination of potential discharge sites and the concomitant improvement of the nutrient related habitat quality within the Popponesset Bay System.

Table VIII-1. Comparison of sub-embayment watershed ***septic loads*** (attenuated) used for modeling of present and threshold loading scenarios of the Popponesset Bay system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms.

sub-embayment	present septic load (kg/day)	threshold septic load (kg/day)	threshold septic load % change
Popponesset Bay	1.58	1.58	0.0%
Popponesset Creek	4.00	0.00	-100.0%
Pinquickset Cove	0.58	0.58	0.0%
Ockway Bay	2.39	0.00	-100.0%
Mashpee River	9.61	0.00	-100.0%
Shoestring Bay	6.94	0.00	-100.0%
Surface Water Sources			
Mashpee River	9.96	5.85	-41.3%
Santuit River (Shoestring Bay)	11.69	7.58	-35.2%
Quaker Run River (Shoestring Bay)	4.69	4.69	0.0%
TOTAL	51.12	19.96	-61.0%

Table VIII-2. Comparison of sub-embayment ***total watershed loads*** (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Popponesset Bay system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Popponesset Bay	1.82	1.82	0.0%
Popponesset Creek	4.94	0.95	-80.7%
Pinquickset Cove	0.76	0.76	0.0%
Ockway Bay	3.15	0.76	-76.0%
Mashpee River	12.11	2.50	-79.4%
Shoestring Bay	9.21	2.26	-75.5%
Surface Water Sources			
Mashpee River	15.56	11.45	-26.4%
Santuit River (Shoestring Bay)	15.58	11.47	-26.4%
Quaker Run River (Shoestring Bay)	5.98	5.98	0.0%
TOTAL	69.11	37.95	-45.2%

Table VIII-3. Threshold sub-embayment and surface water loads used for total nitrogen modeling of the Popponesset Bay 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 (kg/day)
Popponesset Bay	1.82	4.01	-4.91
Popponesset Creek	0.95	-	-0.62
Pinquickset Cove	0.76	0.29	-0.33
Ockway Bay - lower	-	-	-1.13
Ockway Bay - upper	0.76	1.09	2.24
Mashpee River	2.50	0.66	9.47
Shoestring Bay	2.26	2.23	-8.73
Surface Water Sources			
Mashpee River	11.45	-	-
Santuit River (Shoestring Bay)	11.47	-	-
Quaker Run River (Shoestring Bay)	5.98	-	-
TOTAL	37.9	8.28	

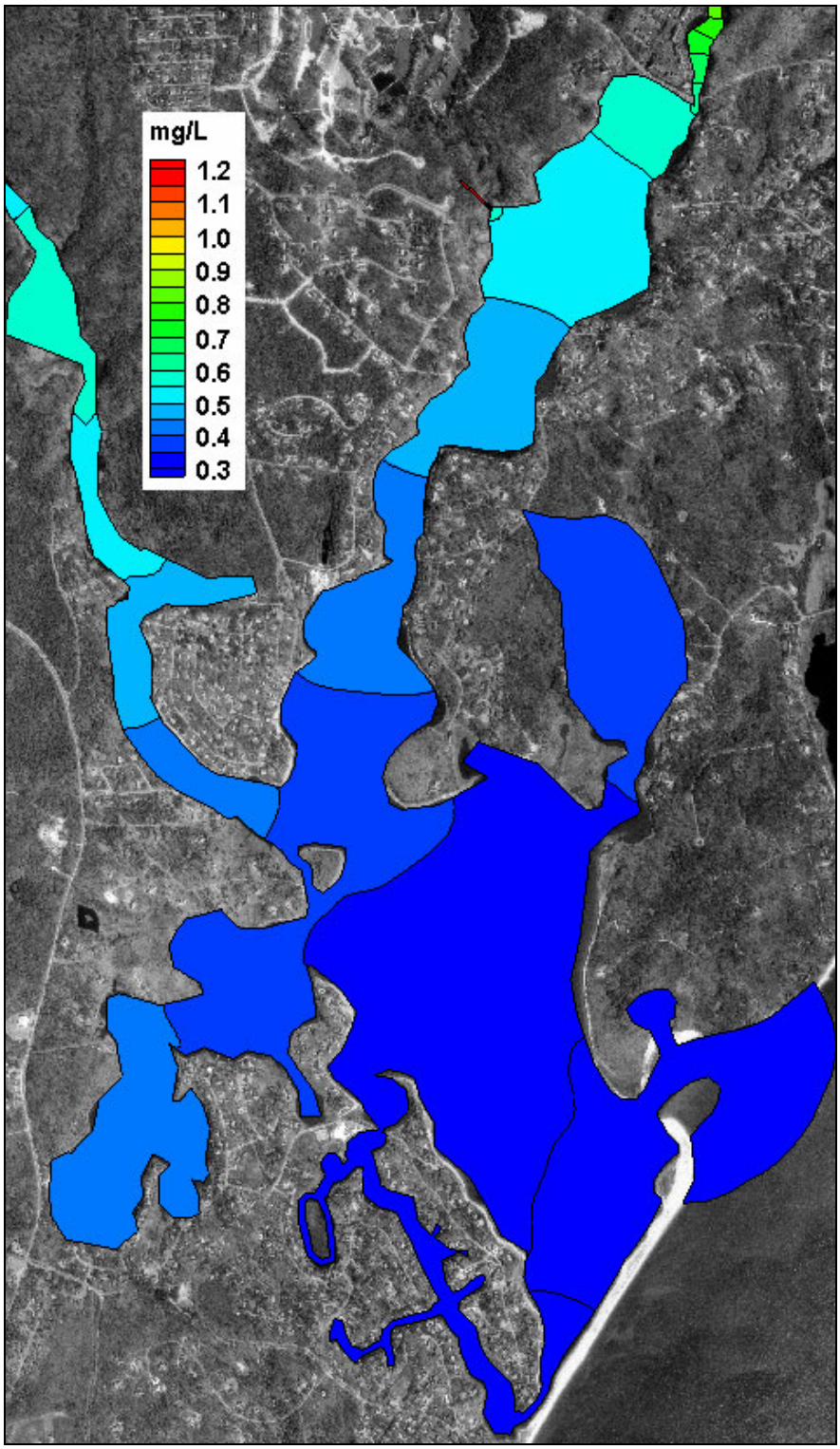

Figure VIII-1. Contour plot of modeled total nitrogen concentrations (mg/L) in the Popponesset Bay system, for threshold conditions (0.38 mg/L at lower Mashpee River, Lower Shoestring Bay, and mid Ockway Bay).

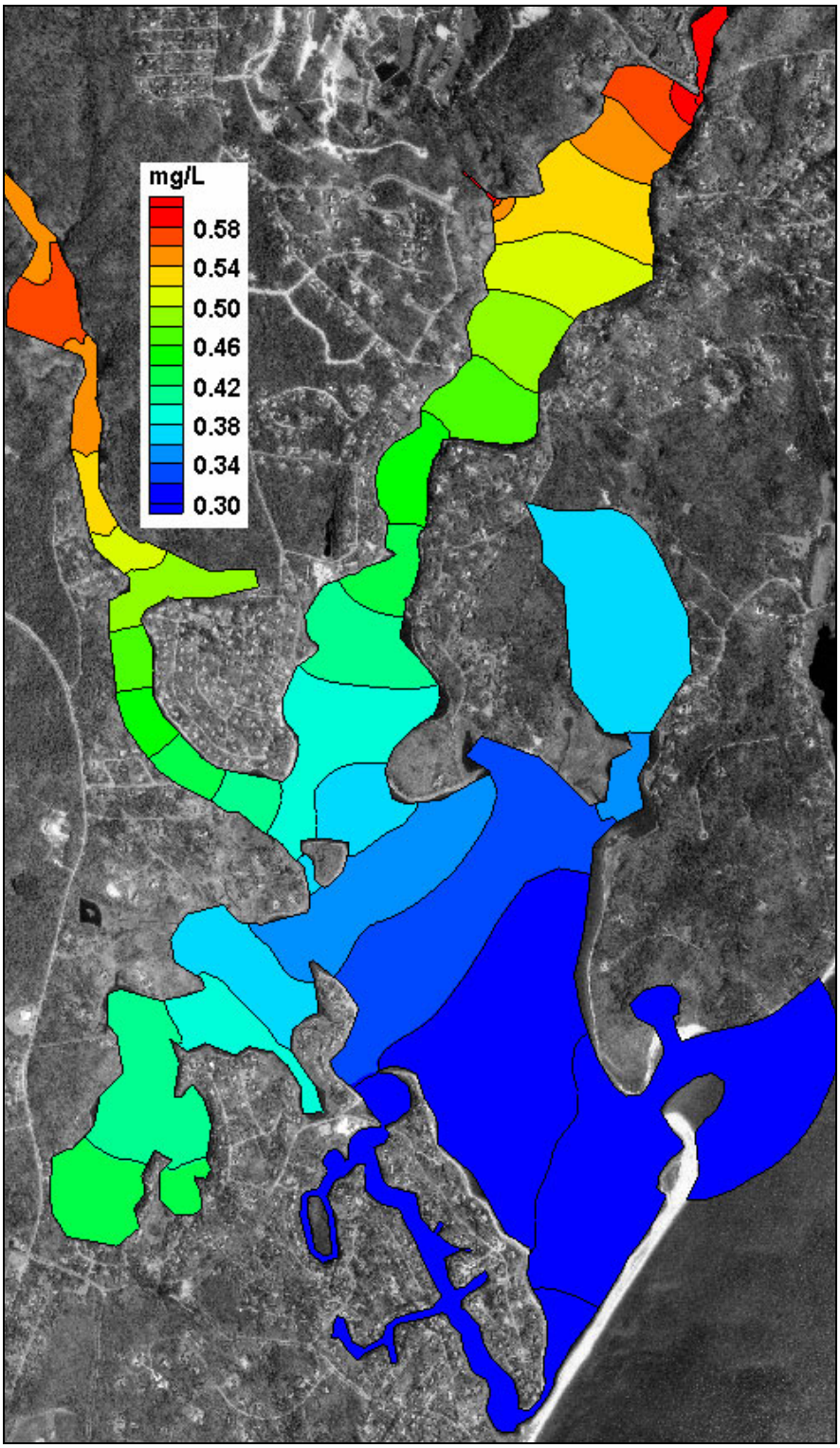

Figure VIII-2. Same results as for Figure VIII-1, but shown with finer contour increments for emphasis. Contour plot of modeled total nitrogen concentrations (mg/L) in the Popponesset Bay system, for threshold conditions (0.38 mg/L at lower Mashpee River, Lower Shoestring Bay, and mid Ockway Bay).