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 strengthens the analysis. These data were collected to support threshold development for the Edgartown Great Pond System by the MEP Technical Team and were discussed in Chapter VII. Nitrogen threshold development builds on this data and links habitat quality to summer water column nitrogen levels obtained from the long-term baseline Water Quality Monitoring Program conducted by the Town of Edgartown and the MV Commission (technical guidance from the Coastal Systems Program at SMAST). At present, the Edgartown Great Pond System is generally showing moderately to significantly impaired habitat for infauna with the lower basin also supporting moderately impaired eelgrass habitat. There is a slight gradient in the infaunal habitat quality with the upper basin and its tributary coves showing greater impairment than he large lagoonal basin running parallel to the barrier beach. All of the habitat indicators are consistent with this evaluation of the whole of system (Chapter VII).

Eelgrass:

At present, eelgrass beds are not present in the Edgartown Great Pond System, although sparse patches of eelgrass can still be observed within the lower basin. The current lack of eelgrass beds and the remaining sparse patches are consistent with the elevated chlorophyll-a concentrations, the low dissolved oxygen levels and water column nitrogen concentrations within this system. That the remaining patches are found within the shallow margins versus within the "deeper" regions of the lower basin (1951 versus 1997-2002) also supports the contention that the mechanism of loss is nitrogen enrichment.

Total nitrogen levels (TN) within the lower basin have mean summer time levels of ~0.59 mg N L^{-1} compared to the levels in other southeastern Massachusetts estuaries supporting eelgrass, 0.35-0.45 mg N L^{-1} (range of Cape Cod systems). Other key water quality indicators such as dissolved oxygen and chlorophyll-a show similar levels of moderate enrichment with periodic oxygen depletions below 5 mg/L and chlorophyll levels in blooms reaching 10-20 ug/l. Given the sensitivity of eelgrass to declining light penetration resulting from nutrient enrichment and secondary effects of organic enrichment and oxygen depletion, impairment of eelgrass habitat is expected within this system.

While water quality parameters, primarily related to nitrogen, chlorophyll and oxygen are the major factors causing shifts in eelgrass habitat quality within this system, water depth is also important in determining potential habitat locations for restoration. All of the locations with eelgrass (1951-2006) are <1.5 meter depth. The more recent field observations suggest eelgrass at depths of 0.5 - 1.0 meters, with the shallower depth potentially related to low water stand when the inlet is opened and the deeper depth being determined by light penetration when the inlet is closed. The depth of the upper main basin (above Swan Neck) appears to have historically limited eelgrass colonization of this basin. The absence of eelgrass within the Coves, most likely relates to their shallow depth, organic rich sediments and periodic salinity declines.

Relative to setting a benchmark for restoration, it is unfortunate that the density of the historical 1951 beds have not been quantified. While it is certain that eelgrass habitat at that time was of a higher quality than at present, it was likely not a high quality habitat due to the systems periodic tidal exchange and "naturally" nitrogen enriched condition. Routine opening of this salt pond was initiated in the 1940's and would have been required for habitat maintenance at that time, as well as today. Therefore, habitat restoration in this nutrient enriched system should focus on improving eelgrass habitat within the lower main basin, and on full restoration of infaunal habitat quality pond-wide. It should be noted that there is no evidence of eelgrass within the upper main basin or within the major tributary coves.

The overall results indicate that eelgrass habitat within Edgartown Great Pond is presently impaired and the eelgrass coverage has declined. While it is not possible to determine the density of the eelgrass beds in 1951, it does appear the coverage has declined and that recent eelgrass areas support only sparse colonization by eelgrass plants. The decline of eelgrass beds relative to historical distributions is expected given the elevated nitrogen levels and resulting chlorophyll a and dissolved oxygen depletions within this embayment system.

Based upon the 1951 eelgrass coverage data it appears that on the order of 30 acres of eelgrass habitat might be recovered if nitrogen management alternatives were implemented (Table VII-3). It is likely that a greater area of eelgrass habitat would be restored, as the 1951 coverage is likely an underestimate as a result of mapping issues and observed, consistent records of eelgrass from the western region of the lower basin, not observed in the 1951 analysis. Note that restoration of this eelgrass habitat will necessarily result in restoration of other resources throughout the Edgartown Great Pond Embayment System, specifically the tributary coves which have traditionally only supported infaunal habitats (see below). However, given the uncertainty in the quality of the 1951 eelgrass habitat (e.g. eelgrass density), improvement of eelgrass habitat within the lower basin, coupled to embayment-wide restoration of infaunal habitat, should be used to set the nitrogen threshold for management of this salt pond.

Water Quality:

Overall, Edgartown Great Pond is showing a moderate level of habitat impairment (eelgrass and infaunal animals) from summer oxygen depletion and organic enrichment primarily from phytoplankton production, parameters directly related to nutrient inputs. The level of oxygen depletion and the magnitude of daily oxygen excursions and chlorophyll-a levels indicate moderately nutrient enriched waters and impaired habitat quality within the upper and lower basins (Figures VII-3 through VII-8). The oxygen data is consistent with organic matter enrichment, primarily from phytoplankton production as seen from the parallel measurements of chlorophyll-a. The periodic elevated oxygen levels observed in Edgartown Great Pond provides additional evidence that this system is presently receiving nitrogen inputs above the threshold required to maintain high quality estuarine habitat.

The measured levels of oxygen depletion in the bottom waters of Wintucket Cove and the lower main basin to Edgartown Great Pond indicate that this Great Salt Pond is currently organic matter enriched, primarily through in situ production by phytoplankton. Moreover, the system periodically experiences moderate levels of oxygen stress, consistent with nitrogen enrichment (Table VII-1). While the levels of oxygen depletion are relatively modest, the phytoplankton blooms in the lower basin are moderate to high (chlorophyll-a, >15 µg/L 1%, 49% and 54% of the time) for the east and west regions, respectively (Table VII-2). The level of chlorophyll is relatively high compared to other embayments in the MEP study region, for example Lewis Bay (<12 ug L-1) or East Bay (<10 ug L^{-1}) on the Nantucket Sound shore of the

Town of Barnstable. The larger bloom in the lower basin may be related to the higher rates of nitrogen release from the sediments in this versus the Wintucket Cove basin (Section IV.3). Except for 3 brief (few hours) depletion events at the western site (lower basin), oxygen conditions were generally >5 mg L^{-1} indicating only a moderate level of oxygen related habitat impairment within this system. This was consistent with the grab sample data from the Water Quality Monitoring Program for Wintucket Cove and also for the upper main basin, Janes Cove, and Slough Cove.

The relatively uniform moderate level of habitat impairment is consistent with the small range in observed total nitrogen levels throughout this estuary, 0.582 mg N L^{-1} in the lower basin to 0.650 mg N L^{-1} in upper Mashacket Cove. The relative uniformity of total nitrogen results from the non-tidal nature of this system, the lack of major surface water discharges and the absence of major restrictions separating the coves from the main basin. As discussed below, the level of water column TN during summer has been documented to cause moderate (0.5 - 0.6 mg N L^{-1}) to significant (>0.6 mg N L^{-1}) impairment of infaunal animal communities in southeastern Massachusetts estuaries.

Infaunal Communities:

Overall, the infauna survey indicated that most areas within Edgartown Great Pond are supporting moderate nutrient related infaunal habitat quality. Also, consistent with the lack of large horizontal gradients in water quality within this mainly non-tidal coastal salt pond, there was only a relatively small spatial variation in infaunal habitat quality. It appears that the upper main basin (above Swan Neck) supports the poorest habitat, moderately to significantly impaired, with similar impairment in the major tributary coves (Janes Cove, Wintucket Cove, Mashacket Cove). The lower large lagoonal basin and one of the small associated tributary coves (Jobs Neck Cove) supported slightly higher quality habitat, although moderate impairment by nitrogen and organic enrichment was clearly observed in these basins as well. Both of the lower eastern coves (Turkeyland Cove and Slough Cove) support infaunal animal habitats of intermediate quality between upper and lower basin conditions (Table VIII-1).

The underlying structure of Edgartown Great Pond and its watershed supports the observed spatial variation in infaunal habitat quality. The upper tributary coves receive almost three-quarters of the total watershed nitrogen load to this system, which stimulates organic matter enrichment of the sediments. The upper main basin is deep, creating a depositional environment for organic matter created in situ or entering by transport from its associated basins. The semi-separate lower basin is moderately impaired by organic enrichment, but receives much less direct input of watershed nitrogen. This pattern is reflected in the bottom sediments of each basin, with the predominance of unconsolidated mud in the upper basin and more oxidized mud and sand in the lower basin. While data is limited, it is nearly certain that the upper deep basin periodically undergoes oxygen depletion. As a deep depositional area, the upper basin sediments are enriched in fine organic matter with resulting impacts to its benthic habitats. This contention is supported by the pond-wide oxygen sampling data from the Water Quality Monitoring Program, which showed depletions to <4 mg L^{-1} only in Janes Cove and the upper main basin (7% and 3% of samples, respectively). The observations of iron accumulation at the sediment surface in the upper main basin also indicate periodic hypoxia. In general, the observed distribution of significantly to moderately impaired infaunal animal habitat in the upper basin and Janes Cove and only moderate impairment in the lower basin compares well with these water quality and sediment data.

Table VIII-1. Summary of Nutrient Related Habitat Health within the Edgartown Great Pond Embayment System (Town of Edgartown, MA.), based upon assessment data presented in Chapter VII. The main basin of Edgartown Great Pond and its major tributary sub-embayments (Coves) experience only periodic tidal exchange with ocean waters during managed breaching of the barrier beach. Some basins were approximated using monitoring data coupled to instrument mooring data.

Health Indicator	Edgartown Great Pond Embayment System							
	Main Basin		**Tributary Coves**					
	Upper[1]	**Lower**	**Jobs Neck Cove**	**Janes Cove**	**Wintucket Cove**	**Mashacket Cove**	**Turkeyland Cove**	**Slough Cove**
Dissolved Oxygen	H-MI[2,3a]	MI[2,3]	--[10]	MI[3a]	H-MI[2]	H-MI[5a]	--[10]	H[2a]
Chlorophyll	MI[5,6]	MI[5]	MI[5]	--[10]	H-MI[6]	--[10]	--[10]	MI[5]
Macroalgae	--[7]	--[7]	--[7]	--[7]	--[7]	--[7]	--[7]	--[7]
Eelgrass	--[9]	MI[8]	--[9]	--[9]	--[9]	--[9]	--[9]	--[9]
Infaunal Animals	SI-MI[11]	MI[12]	MI[12]	SI-MI[14]	SI-MI[14]	SI-MI[13]	MI[12]	MI[12]
Overall:	**SI-MI[15]**	**MI[16]**	**MI**	**SI-MI**	**SI-MI**	**SI-MI**	**MI**	**MI**

a -- analysis of Water Quality Monitoring Program data
1 -- monitoring data and Wintucket Cove & Lower Basin moored instruments, as appropriate.
2 – oxygen levels generally >6 mg/L, with periodic depletions 6-5 mg/L.
3 – oxygen levels generally >6 mg/L, with oxygen depletions rarely 4-3 mg/L.
4 -- oxygen levels generally >6 mg/L, with periodic depletions 5-4 mg/L..
5 – moderate to high chlorophyll a levels generally 10-25 ug/L, generally >15 ug/L
6 – moderate chlorophyll a levels 2-12 ug/L, generally <8 ug/L.
7 -- drift algae sparse or absent, little surface microphyte mat, no visible accumulations
8 -- eelgrass beds (1951); now very sparse eelgrass in easternmost & westernmost lower main basin (2002), observed during MEP surveys, also in 2006 by MVC and Edgartown Shellfish.
9 – no evidence this basin is supportive of eelgrass.
10 -- insufficient data for assessment on this Health Indicator
11 -- low - # species, moderate # individuals, mainly polychaetes, some amphipods, moderate-low diversity and Eveness, organic enrichment indicators
12 -- moderate # species, moderate # individuals, moderate diversity and Eveness, dominated by polychaetes and crustaceans
13 -- low # species, moderate # individuals, dominated by disturbance species (e.g. Ampelisca).
14 -- moderate # species, high # individuals, dominated by organic enrichment species (Streplospio) with Capitella, Mediomastus, Ampelisca.
15 -- regions of basin significantly impaired infaunal habitat, other areas only moderately impaired, eelgrass habitat not used in assessment based upon historical data and MassDEP analysis.
16 -- eelgrass has declined since 1951 and between 1995 - 2003, but evidence of historically dense eelgrass beds is lacking. The decline in eelgrass patches indicates moderate impairment and that nitrogen management to improve this key habitat type should be undertaken.

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

Overall, the infaunal habitat quality was consistent with the gradients in dissolved oxygen, chlorophyll, nutrients and organic matter enrichment in this system. Classification of habitat quality necessarily included the structure of the specific estuarine basin. Based upon this analysis it is clear that the tributary sub-embayment basins are presently supporting moderately to significantly impaired benthic habitat while the lower main basin generally shows moderate quality. Impairment in these basins is through nitrogen and organic matter enrichment. These results indicate that the nitrogen management threshold analysis (see below) needs to include a lowering of the level of nitrogen enrichment throughout this salt pond for restoration of nitrogen impaired benthic habitats. However, it is important to note that the non-tidal nature of this embayment and the depositional nature of the upper main basin (deep) make benthic habitat within that region of the system particularly sensitive to nitrogen enrichment.

VIII.2 THRESHOLD NITROGEN CONCENTRATIONS

The approach for determining nitrogen loading rates that will maintain acceptable habitat quality throughout an embayment system, is to first identify the critical spatial distribution and secondly, to determine the nitrogen concentration within the water column which will restore specific locations to a desired habitat quality. The sentinel location(s) are selected such that their restoration will necessarily bring the other regions of the system to acceptable habitat quality levels. Once the sentinel site(s) and the target nitrogen level are determined, the Linked Watershed-Embayment Model is used to sequentially adjust nitrogen loads until the targeted nitrogen concentration is achieved.

Since the Edgartown Great Pond System does not support strong horizontal gradients (range in total nitrogen levels from 0.58 mg N L^{-1} in the lower basin to <0.63 mg N L^{-1} in the coves, with 0.65 mg N L^{-1} in upper Mashacket Cove), the MEP Technical Team decided to use the average of the five long-term water quality stations to determine a pond-wide threshold (EGP 2,3,5,6,9). This distributed "location" for the threshold stems from the variability at individual sites and the non-tidal nature of this system. These stations are presently showing an average TN level of 0.596 mg N L^{-1} (range = 0.587-0.613 mg N L^{-1}). As noted in previous sections, the average concentrations at these stations approximate concentrations throughout the pond waters (i.e. it is representative of other pond locations).

Relative to setting a benchmark for restoration, it is unfortunate that the density of the historical 1951 beds has not been quantified. While it is certain that eelgrass habitat at that time was of a higher quality than at present, it was likely not a high quality habitat due to the systems periodic tidal exchange and "naturally" nitrogen enriched condition. Routine opening of this salt pond was initiated in the 1940's and would have been required for habitat maintenance at that time as well as today. Therefore, habitat restoration in this nutrient enriched system should focus on improving eelgrass habitat within the lower main basin and on full restoration of infaunal habitat quality pond-wide. It should be noted that there is no evidence of eelgrass within the upper main basin or within the major tributary coves.

Since the infaunal community at all sites with the Pond are either dominated by organic matter enrichment species or are depleted, comparisons to the muddy basins of other estuarine systems in the MEP study region were relied upon. This type of comparative analysis suggests that a healthy infaunal habitat would clearly be achieved at an average nitrogen level of TN <0.5 mg TN L^{-1}. This level was found for Popponesset Bay, where based upon the infaunal analysis coupled with the nitrogen data (measured and modeled), nitrogen levels on the order of 0.4 to 0.5 mg TN L^{-1} were found to be supportive of high infaunal habitat quality in that system. Similarly, in the deeper basins of Three Bays System, healthy infaunal areas are found at nitrogen levels of TN <0.42 mg TN L^{-1} (Cotuit Bay and West Bay) and in Eel Pond (Bourne) at a TN level of 0.45 mg TN L^{-1}. Conversely, moderate impairment of infaunal habitat has routinely been documented by the MEP in areas where nitrogen levels of TN >0.5 mg TN L^{-1} were observed. By example, the moderately impaired infaunal habitat in Hyannis Inner Harbor (Barnstable) was found at concentrations of 0.518-0.574 mg N L^{-1} and in Bournes Pond and Great Pond (Falmouth) at concentrations >0.6 mg N L^{-1}.

Based on the line of evidence provided above, the MEP Technical Team determined that infaunal habitat quality within Edgartown Great Pond is responding to nitrogen levels in a manner consistent with other embayments within the MEP study region, as seen by the present TN level of ~0.6 mg TN L^{-1} supporting a moderately impaired infaunal community. The integration of all information available clearly supports a nitrogen threshold for restoration of healthy infaunal habitat within Edgartown Great Pond of 0.5 mg N L^{-1} (time averaged). The modeling simulations in Section VIII-3 targeted the 0.5 mg TN L^{-1} for healthy habitat. This significant lowering of average TN levels within the lower basin of Edgartown Great Pond will also improve eelgrass habitat within the historic 1951 coverage area and likely in the western portion of the lower basin as well.

VIII.3 DEVELOPMENT OF TARGET NITROGEN LOADS

After developing the dispersion-mass balance model of Edgartown Great Pond to accurately simulate the nitrogen conditions that exist under present nitrogen loadings and periodic openings to tidal exchange, various management alternatives were examined as to their efficacy in restoring the observed nitrogen related habitat impairments (Section VIII.1). In addition, the model was used to simulate a modified management approach that could be followed to improve water quality conditions in the pond year-round.

The effect of alterations to nitrogen loads and/or pond-opening practices on habitat quality was gauged from predicted changes in water quality conditions pond-wide (Stations EGP 2,3,5,6,9 Chapter VI). The main goal of this proposed management scenario is to prevent time averaged pond-wide TN concentrations in the pond from rising above 0.50 mg/L during the summer months, when benthic regeneration and algae production is greatest. One effective alternative to achieving these goals was found to be to reduce the watershed loading to the pond, together with an additional mid-summer breach. This potential mid-summer breach would be in addition to the present 2 successful breachings per year.

Watershed loading was reduced from present (2007) conditions until time averaged pond-wide TN concentrations would remain below 0.50 mg/L during a 45-day period[1]. The threshold modeling assumptions include 1) a successful early summer breach, which lowers the average pond TN concentration to 0.35 mg/L; 2) a successful mid-summer breach that remains open for 11-days, and which again lowers pond-averaged TN concentrations to 0.35 mg/L; 3) the mid-summer breach is in addition to the current practice of 2 successful breaches per year; and 4) a combined freshwater input rate (groundwater + precipitation) of 11.0 ft^3/sec, which is the lower range of summertime groundwater flow rates to the pond. Though it is true that the period between the fall breach and the spring breach is a bit longer than the period between the others, it is not significant in the sense that this longer period occurs during the winter time when there are extremely low rates of N-regeneration and therefore little N would be accumulating in the watercolumn. Moreover, it is not likely that much N is accumulating over the sediments during that 2 month "gap" in the winter time as the accumulation would typically be occurring through the settling of particulate organic N out of the water column to the sediments. The

[1] The time-averaged total nitrogen level of 0.5 mg L^{-1}, means that the average total nitrogen level from just after the tidal inlet closes until the next inlet is opened equals 0.5 mg N L^{-1} across the 6 long-term water quality monitoring stations within Edgartown Great Pond (EGP 1-6; Chapter VI). In the alternative, a 45 day period was used in the average.

winter time is when water quality is typically at its best and when there is the least paticulate in the water column available to settle out to the sediments. Additionally, it should be noted that the rate of freshwater recharge was only used to predict changes in pond elevation. In addition, it appears that the concentration (0.35 mg/L) after the spring breach is reasonable, given the breach modeling of an 11 day opening (Figure VI-1) and the most likely TN level prior to the breach in the year following the implantation of a mid-summer breach. During the late 1990's the top 25% of spring TN concentrations averaged ~0.70 mg/L. However, in the year following a mid-summer breach, these highest levels would be 0.2 mg/L lower (figure VIII-1) or ~0.50 mg/L. It should be noted further that these measured highest quartile values were during years generally with only 1 successful breach.

One of the MEP management alternatives which resulted in a lowering of the nitrogen levels within Edgartown Great Pond to meet the nitrogen threshold for improving eelgrass habitat and restoring high quality infaunal animal habitat combines watershed nitrogen management and a modification of the present opening regimen. This alternative can be further modified by increasing nitrogen reduction and lengthening the period between pond openings, or doing less nitrogen management with a shorter interval between pond openings. The intermediate alternative was based upon the history of successful pond openings and a moderate level of watershed nitrogen management. The resulting threshold septic loading is presented in Table VIII-2. A 30% reduction in the present (2003-06) septic load to the pond, in combination with the plume of treated effluent from the "new" WWTF replacing the historical N load from the "old" WWTF discharge (pre-1996) was sufficient to achieve the threshold requirements. This septic load change results in a 17.8% change in the total watershed load to the pond, as shown in Table VIII-3. A tabulation of all the loads to the pond is provided in Table VIII-4. The benthic loading term is effected by the change in watershed load. The same method described in section VI.2.5.1 was used to adjust the benthic regeneration load to the pond for threshold conditions. The 30% reduction in present septic loading coupled with a mid-summer pond opening, 45 days after the late spring opening, achieved the target of a time averaged pond-wide TN concentrations below 0.50 mg L^{-1} over the summer period.

Table VIII-2. Comparison of sub-embayment septic loads used for modeling of present 2003-06 and modeled threshold loading scenarios of Edgartown Great Pond. Septic loads are from existing residential and commercial properties. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.

sub-embayment	Present Septic N Load (kg/day)	Threshold (kg/day)	Threshold change
Edgartown Great Pond	15.167	10.617	-30.0%

Table VIII-3. Comparison of sub-embayment watershed loads used for modeling of present 2007 and modeled threshold loading scenarios of Edgartown Great Pond. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms. The threshold level reflects the lowered septic loading (threshold) in Table VIII-2 and the "new" WWTF nitrogen load (2007). (Loading in 2007 less than 2003 due to "new" WWTF Plume.)

sub-embayment	Present N Load (kg/day)	Threshold (kg/day)	Threshold Change
Edgartown Great Pond	25.608	21.058	-17.8%

Table VIII-4. Sub-embayment and surface water loads used for total nitrogen modeling of threshold conditions for Edgartown Great Pond, with total watershed N loads, atmospheric N loads, and benthic flux.

sub-embayment	Threshold N Load (kg/day)	direct atmospheric deposition (kg/day)	benthic flux net (kg/day)
Edgartown Great Pond	21.058	11.445	13.559

Through the course of the summer, the effect on TN concentrations of the threshold management scenario suggested for Edgartown Great Pond is presented in Figure VIII-1. For the 101-day period shown in Figure VIII-1, the time averaged TN concentration is 0.50 mg/L. A similar plot of salinities is presented in Figure VIII-2. In each plot, results are also shown for the case where the first, early summer breach is made, but the mid-summer one is not. The average salinity during the course of this 101-day simulation is 25.5 ppt.

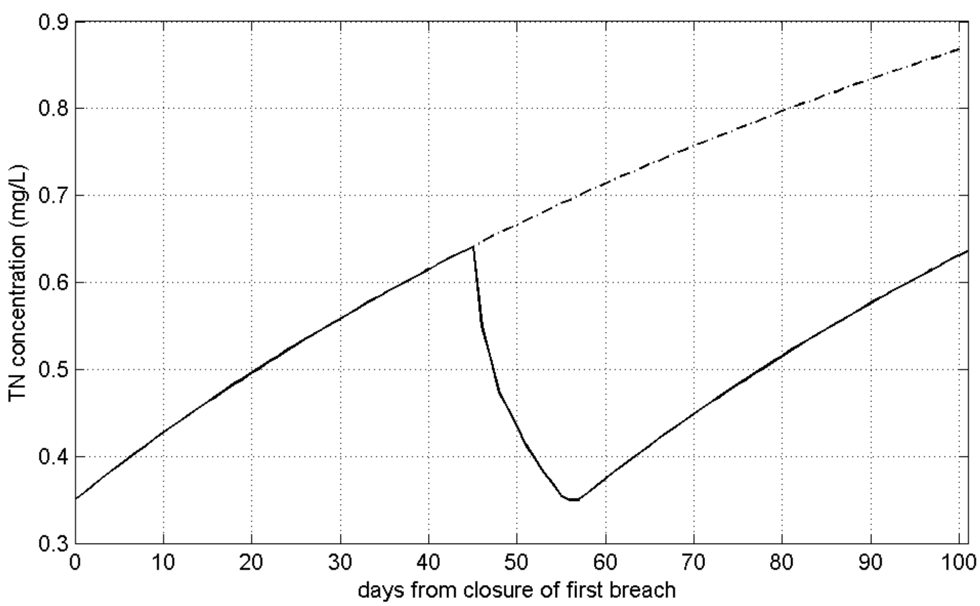

Figure VIII-1. Comparison of modeled pond-averaged TN concentrations for case where the pond is breached only in the early summer (thick black dot-dashed line) and also when it is breached an additional time mid-summer.

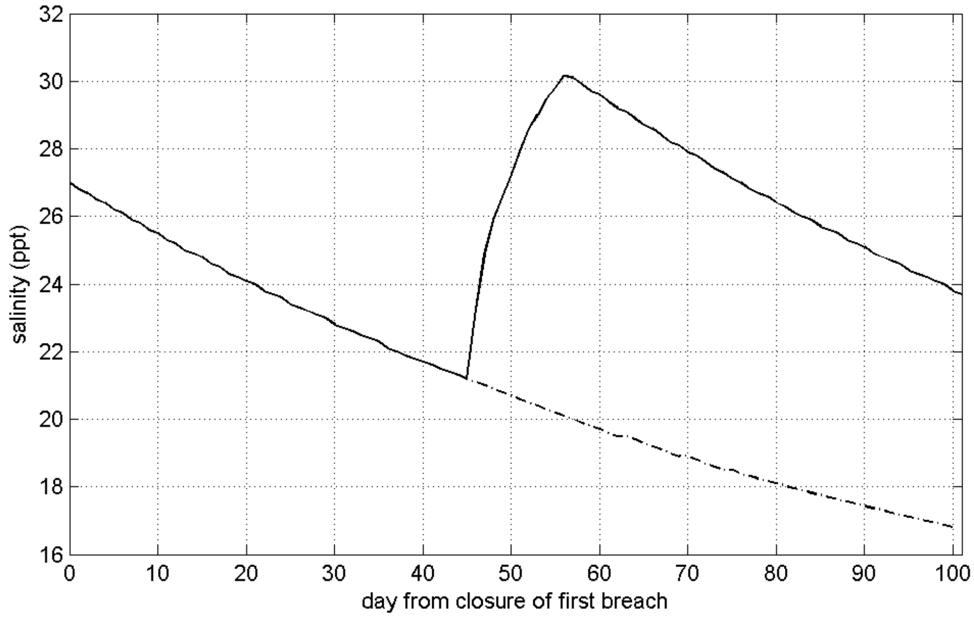

Figure VIII-2. Comparison of modeled pond-averaged salinities for case where the pond is breached only in the early summer (thick black dot-dashed line) and also when it is breached an additional time mid-summer.