Determination of Nitrogen Thresholds and Nitrogen Load Reductions for Green Hill and Ninigret Ponds

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I INTRODUCTION

The addition of excessive amounts of nitrogen from anthropogenic sources is contributing to water quality degradation and habitat loss in coastal waters throughout the world, and in many areas nitrogen loading is one of the most significant long-term threats that must be managed (Costa et al. 1999). Non-point source loading of nitrogen to coastal waters has increased with the intensification of land uses on watersheds (Valiela et al. 1997; Bowen and Valiela 2001). Nitrogen typically limits the growth of producers in estuarine systems (Howarth 1988) consequently, increases in nitrogen results in higher phytoplankton production, hence organic matter load in waters and sediments. The higher organic matter load results in increased oxygen consumption and therefore an increased likelihood for bottom water oxygen depletion (Howes et al. 2003).

Nitrogen enters Green Hill and Ninigret Ponds from individual sewage disposal systems, stormwater runoff, fertilizers, atmospheric deposition, and internal recycling from bottom sediments. It is widely believed that excessive nitrogen (N) originating primarily from septic systems has led to significant decreases in the habitat quality of Green Hill Pond and eastern Ninigret Pond. In both waterbodies, the problems include:

- Loss of some eelgrass beds, which are critical habitats for macroinvertebrates and fish
- Undesirable increases in macro algae, which are much less beneficial than eelgrass
- Documented periodic extreme decreases in dissolved oxygen concentrations that threaten aquatic life in Green Hill Pond
- Reductions in the diversity of benthic animal populations
- Periodic algae blooms

In order to restore and protect Green Hill and Ninigret Ponds, nitrogen loadings, and subsequently the concentrations of nitrogen in the water column, must be reduced to levels below the 'thresholds' that cause undesirable changes in biological (eelgrass, macroalgae, benthic animals), chemical (dissolved oxygen, organic and inorganic nitrogen, phytoplankton pigments), physical (water clarity, temperature), and or geochemical (sediment characteristics) habitat measures.

DEM-OWR has evaluated several methods of determining nitrogen "thresholds" for Green Hill and Ninigret Ponds. These are presented in Sections III, IV and V of this technical report. Much of the current research is focused on developing nitrogen load-response models in an effort to translate ecological effects into quantitative nutrient inputs.

Section III summarizes results from the URI Mesocosm studies, and draws conclusions as they relate to the objectives of this project. The method preferred by DEM-OWR is to use the Buzzards Bay Project Approach (Section IV), which was originally developed in 1999 by the Buzzards Bay Project National Estuary Program (Costa et al. 1999). A nitrogen- 'concentration reduction' approach is evaluated in Section V. In this approach, DEM calculated nitrogen reductions using in-pond concentration data coupled with nitrogen thresholds and coastal water classifications taken from the Massachusetts Estuaries Project.

II CURRENT AND HISTORIC WATER QUALITY CONDITIONS

It is widely believed that excessive amounts of nitrogen (N) originating primarily from septic systems has led to significant decreases in the habitat quality of Green Hill Pond and, to a lesser extent, eastern Ninigret Pond. Examination of historic and current in-pond water quality data shows notable increases in nitrate-N concentrations in both ponds with less notable increases in Chlorophyll-a concentrations.

A comparison of historic and current chlorophyll a and nitrate-nitrogen concentrations in Green Hill and Ninigret Pond are presented in Figures 1 and 2. Water quality data collected by Salt Pond Coalition volunteers at several sites in Green Hill and Ninigret Pond during 1985-1993 were compared to more recent data collected by the same organization during 2000-2005. Laboratory methods for analyzing nitrate-N were the same for both data sets. Chlorophyll-a was determined by analog in the first dataset and digital for the second dataset. Both methods have been proven to provide comparable data.

It is likely that the primary form of nitrogen entering Green Hill and eastern Ninigret Pond is nitrate-nitrogen. Therefore, it is expected that levels of nitrate-nitrogen in the ponds would increase with the incremental development of their watersheds (i.e. incremental increase in nitrate loading from ISDS). Although total nitrogen (TN) concentration is a better indicator of the amount of nitrogen in the system, comparisons of the in-pond nitrogen species concentrations is limited to Nitrate-N. Both total and nitrate-N data are available for the more recent dataset however only nitrate-N data exist for the 1985-1993 dataset.

The intent of presenting these data is to show that: 1) Average nitrate-N concentrations have increased markedly in both ponds since 1985, and 2) Average chlorophyll-a concentrations are similar in both datasets, even though average in-pond NO3-N concentrations doubled in Green Hill Pond and increased nearly 7-fold in Ninigret Pond.

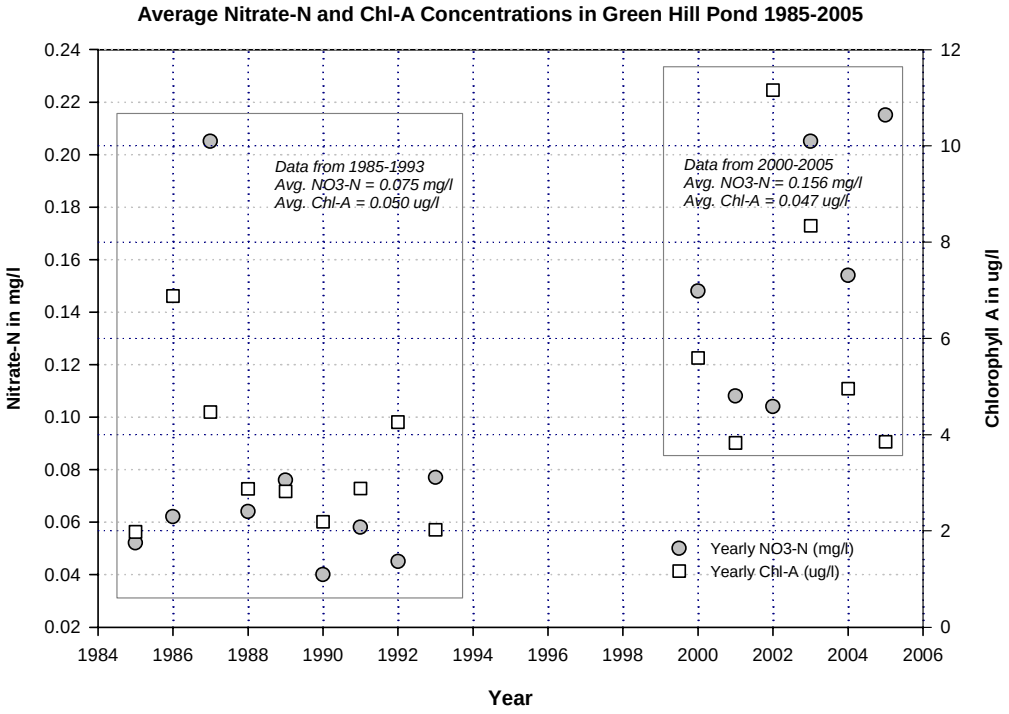

Figure 1. Comparison of nitrate-N and chlorophyll-a concentrations in Green Hill from 1985-2005.

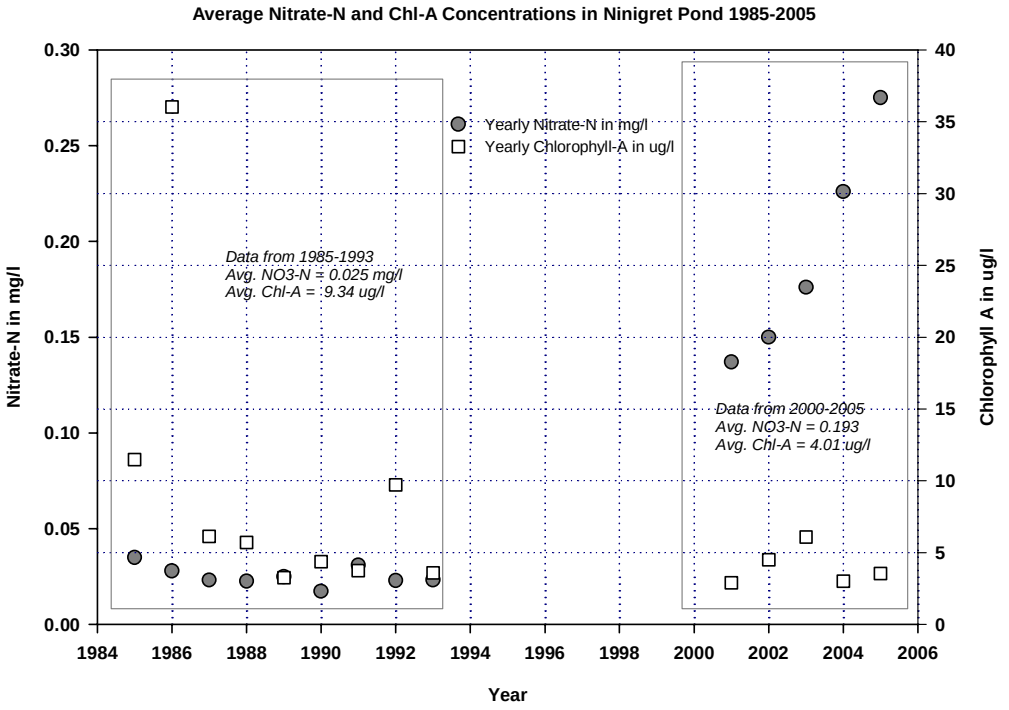

Figure 2. Comparison of nitrate-N and chlorophyll-a concentrations in Green Hill from 1985-2005.

III NITROGEN TARGETS AND THE URI-MESOCOSM N-ENRICHMENT STUDY

URI researchers conducted experiments to quantify the effects of different levels of nutrient enrichment on the plant communities of temperate coastal lagoons, specifically the lagoons of the northeast U.S (Taylor et al. 1999). The lagoon mesocosms have been described in the literature (e.g. Taylor et all 1995a, b, c; 1999; Lin et al. 1996). Briefly, ten mesocosms, each containing coastal water, lagoon sediments, and plants and animals found in natural lagoons, were subjected to five levels of enrichment and plant community response was evaluated.

A significant finding of the mesocosm experiments was that the unpredictable ranges in phytoplankton chlorophyll from year to year were not related to differences in inorganic nutrient loading. Examination of time-weighted mean water column chlorophyll concentration and inorganic nutrient input during summer (May-Sept) revealed large interannual variations that weaken any trend with nutrient enrichment. During one summer when the "brown tide" organism bloomed in the control mesocosms, high concentrations of chlorophyll developed with very low inputs of inorganic nutrients (Nixon et al. 1994).

Since no strong relationship between dissolved inorganic nitrogen loading and chlorophyll a exists, the mesocosm study is of limited use when attempting to evaluate nitrogen thresholds for Green Hill and Ninigret ponds. The studies do indicate that there are measurable water quality impacts from even small increases in nitrogen concentrations above that found in seawater, suggesting that the carrying capacity of the ponds is low. These studies may in the future be useful in refining a nitrogen target for the ponds.

IV ESTABLISHING NITROGEN TARGETS USING A MODIFIED BUZZARDS BAY APPROACH

The relationship between nutrient loadings and water quality response of an estuary is complex for a number of reasons. These complicating factors include the size and shape of the estuary, the flushing time, the indirect nature of the connection between dissolved oxygen response and loadings, the temporal variability of dissolved oxygen, phytoplankton, and macroalgae. The Buzzards Bay Program (BBP) in nearby Massachusetts has addressed many of these factors by extracting empirical relationships between nitrogen loadings and eutrophication response from observations made in a number of estuaries.

In 1991, the Buzzards Bay Project National Estuary Program (BBP) developed a Total Maximum Annual Limits (TMAL) nitrogen management strategy to protect "nitrogen sensitive embayments" using a watershed mass loading approach to manage nitrogen inputs to protect and restore water quality and living resources in the more than 30 embayments that surround Buzzards Bay, MA.

The BBP approach uses land use information from the State GIS or from parcel information to estimate present and potential future nitrogen loads. Loading rates and calculation procedures are outlined in Costa et al (1999) and Costa et al (1994). Recommended embayment TMAL limits were established by incorporating existing regulatory water quality classifications, together with embayment volume and hydraulic turnover time.

The BBP approach is considered by DEM to offer a number of advantages for use in Rhode Island based on physical and biological similarities outlined below that made the use of loading-estuarine response relationships for Buzzards Bay, appropriate for shallow Rhode Island estuaries, such the coastal salt ponds in southern RI:

1. The BBP approach has been developed for estuaries that are physically similar to RI estuaries. These similarities include:

    - geometry (depth and size),
    - tidal regime,
    - drainage area characteristics (land use and size),
    - climatic conditions such as rainfall and seasonal temperature variations, and
    - ambient seaward water chemical and thermal conditions

2. Plant and animal communities affecting water quality in and around Buzzards Bay, including the plankton and macroalgal species are similar to those in Rhode Island, including Green Hill Pond and Ninigret Pond.

3. The nature of nitrogen sources to Green Hill and Ninigret Pond is similar to those in Buzzards Bay, with a prevalence of low intensity uses.

The BBP approach characterizes estuarine response as a Eutrophication Index (EI) that is a function of five factors: the mean value of the lowest 20% of dissolved oxygen percent saturation values, mean dissolved inorganic nitrogen (DIN) concentration, mean Secchi depth, mean chlorophyll a concentrations, and mean total organic nitrogen (TON).

Estimates of existing nitrogen loading for each embayment studied in the BBP were related to existing summertime water quality through the use of site specific data collected by the Buzzards Bay Citizens' Water Quality Monitoring Program, a joint project of Buzzards Bay Project, the Coalition for Buzzards Bay (a local citizens group), and the Woods Hole Oceanographic Institution Biology Department. The citizens measure dissolved oxygen concentrations with Hach Kits™, secchi depth, salinity, and temperature) approximately 15 times between June 1 and September 30. The citizens also collect 2-4 water samples during summer which were analyzed for dissolved and particulate organic nitrogen, nitrate+nitrite, ammonia, orthophosphate, and chlorophyll.

Data for four years (1992 to 1996) were used to develop Eutrophication Indices for each of the embayments. Generally 2 to 4 sites within each embayment were monitored in each embayment. In some smaller embayments only one site was monitored; in larger embayments 5 or more sites were sampled. Samples for nutrient analyses were taken on outgoing tides, while oxygen and secchi data included both incoming and outgoing tides because the oxygen measurements were needed in the early morning hours, generally taken between 6-9 AM.

Mean summertime values of dissolved oxygen percent saturation, secchi disk depth, chlorophyll a, total organic nitrogen (TON), and dissolved inorganic nitrogen (DIN) were combined in a EI. Because the focus of the Buzzards Bay Eutrophication Index was on the effects of nitrogen loading, BOD and coliforms were omitted from the index, and DIN and DON were included instead of TKN because of problems associated with measuring low levels of nitrogen in seawater using the TKN methodology.

The 100 and 0 point values for each parameter is shown in Table 1. All summertime means of the five parameters were applied to the equation above. The end points shown in Table 1 were chosen for Buzzards Bay based on knowledge of conditions typically found in a range of southern New England embayments. During the course of the water Citizen Monitoring Program, 100 and 0 point values changed somewhat, and Table 1 reflects the current values employed. Most notably,

at inception, mean summertime oxygen concentrations were used in the index. This was later changed to the mean of the lowest 20% of all summertime values with a concurrent change in the 0 point and 100 point values.

The Eutrophication Index equals the mean of the scores for the five parameters (i.e. all parameters were equally weighted). The local level of each parameter for each estuary was compared to a range expected for eutrophic to pristine conditions. When the level meets the pristine condition, a score of 100 points is assigned. When the level is considered eutrophic, a score of 0 points is assigned. The final index is taken as the average of the indices for the five parameters. The index ranges used by the BBP are presented in Table 1 below for the determination of an Eutrophication Index.

Table 1. Buzzards Bay Project Eutrophication Index Endpoints.

Parameter	0 Points	100 Points
Summer % dissolved oxygen saturation (mean lowest 20%)	40%	90%
Secchi depth in meters	0.60	3.0
Dissolved inorganic nitrogen (DIN) in uM	10.0	1.0
Chlorophyll-a (ug/l)	10.0	3.0
Total organic nitrogen (TON) in mg/l	0.60	0.28

Eutrophication Indices were calculated for Green Hill and Ninigret Ponds using available physical and chemical data collected from the Salt Ponds Coalition Volunteer Water Quality Monitoring Program (Pond Watchers) and DEM. Indices were calculated for four stations in Green Hill Pond using data collected in 2000 and 2001 and for two stations in Ninigret Pond using data collected in 2001. Data collected by the Pond Watchers was analyzed for chlA, DIN, and TON. DEM-OWR collected continuous dissolved oxygen data in both ponds during 3-week periods in August of 2000 and 2001. Secchi data were obtained from previous datasets from years 1985-1994, as well as current data collected in 2004 and 2005. Eutrophication Index spreadsheets are shown in Table 2 below. These spreadsheets were provided by the Buzzards Bay Project and are available online at: http://www.buzzardsbay.org/nitrmang/eutroind.xls

Table 2. Eutrophication Index Calculations for Green Hill and Ninigret Ponds (2000 and 2001).

Buzzards Bay Project **2000**
Eutrophication Index*

	lowest	depth m	ug/l	ug/l	ppm
0 Pts:	0.4	0.6	10.00	10.0	0.60
100 Pts:	0.9	3.0	1.00	3.0	0.28

summer O_2 % sat (mean lowest 1/5)	mean secchi (m)	Mean DIN (uM)	acid corr. Chl A (ug/l)	TON** (mg/l)	Oxsat SCORE	secchi SCORE	DIN SCORE	CHL-A SCORE	TON SCORE	EUTRO INDEX	Station	Waterbody
91%	1	7.86	9.7	0.385	100.0	31.7	10.5	2.5	58.2	40.6	Sea Lea	GH Pond
16%	1	20.71	6.8	0.38	0.0	31.7	0.0	32.0	59.9	24.7	Teal Road	GH Pond
69%	1	13.93	3	0.395	67.2	31.7	0.0	100.0	54.9	50.8	Indigo Pt.	GH Pond
69%	1	7.14	2.85	0.56	67.2	31.7	14.6	100.0	9.1	44.5	Twin Peninsula	GH Pond

* This index uses "good" (100 point) and "bad" (0 point) water quality values based on local conditions for what is considered unimpacted to near pristine conditions for 100 point and those conditions considered eutrophic for 0 points. Application of this index for other geographic regions may require adjustment of the 0 and 100 point values.

** IF TON is not available, PON may be substituted using 0.1 and 0.2 ppm for 100 and 0 point criteria respectively.

40 Average GH Pond EI

Buzzards Bay Project **2001**
Eutrophication Index*

	lowest	depth m	ug/l	ug/l	ppm
0 Pts:	0.4	0.6	10.00	10.0	0.60
100 Pts:	0.9	3.0	1.00	3.0	0.28

summer O_2 % sat (mean lowest 1/5)	mean secchi (m)	Mean DIN (uM)	acid corr. Chl A (ug/l)	TON** (mg/l)	Oxsat SCORE	secchi SCORE	DIN SCORE	CHL-A SCORE	TON SCORE	EUTRO INDEX	Station	Waterbody
43%	1.45	13.43	2.56	0.132	8.9	54.8	0.0	100.0	100.0	52.7	Sea Lea	GH Pond
43%	1.45	20	3.05	0.29	8.9	54.8	0.0	98.6	95.4	51.6	Teal Road	GH Pond
43%	1.45	14.5	5.2	0.207	8.9	54.8	0.0	54.3	100.0	43.6	Indigo Pt.	GH Pond
43%	1.45	12.57	2.51	0.224	8.9	54.8	0.0	100.0	100.0	52.7	Twin Peninsula	GH Pond
72%	1.75	13.21	1.51	0.065	72.5	66.5	0.0	100.0	100.0	67.8	Tockwotten	Ninigret Pond
72%	1.5	11.43	2.85	0.18	72.5	56.9	0.0	100.0	100.0	65.9	Pond St.	Ninigret Pond

* This index uses "good" (100 point) and "bad" (0 point) water quality values based on local conditions for what is considered unimpacted to near pristine conditions for 100 point and those conditions considered eutrophic for 0 points. Application of this index for other geographic regions may require adjustment of the 0 and 100 point values.

** IF TON is not available, PON may be substituted using 0.1 and 0.2 ppm for 100 and 0 point criteria respectively.

50 Avg Green Hill Pond EI
67 Avg Ninigret Pond EI

EI scores for each station were averaged to provide a single EI score for both Green Hill and Ninigret Ponds. The average EI score for Green Hill Pond is 45 and the average EI score for Ninigret Pond is 67.

Eutrophication Index Scores of 65 to 100 are considered “good to excellent” water quality, 35 to 65 are considered “fair to good” water quality, and <35 are considered typical of eutrophic conditions. The BBP has assigned endpoints to the EI scale that correlate to the designated uses specified in the MA WQ regulations. The EI goal for Massachusetts waters designated as “Outstanding Natural Resource Waters” (ONRW) is a score of 65 or better. Class SA waters must meet an EI score of 50 or better, and class SB waters must score 40 or higher.
Many embayments along Buzzards Bay are designated as “Outstanding Natural Resource Waters”, or ONRWs. Massachusetts water quality regulations define these waters as “constitute(ing)” an outstanding resource as determined by their outstanding socio-economic, recreational, ecological and/or aesthetic values”. Rhode Island has not designated any waters as ONRWs, but instead has designated a number of its waters as Special Resource Protection Waters, whose designated uses are essentially equivalent to those of ONRWs. Both Green Hill and Ninigret Ponds have been designated as Special Resource Protection Waters and should therefore should have an EI goal of 65 or better.

Special Resource Protection Waters (SRPWs) are defined as:

“…high quality surface waters identified by the Director as having significant ecological or recreational uses, which may include but is not limited to: wildlife refuge or management areas; public drinking water

supplies; State and Federal parks; State and Federal designated Estuarine Sanctuary Areas; waterbodies containing critical habitats, which may include but is not limited to waterbodies identified by the RIDEM Natural Heritage Program as critical habitat for rare or endangered species; wetland types or specific wetlands listed as rare, threatened, endangered, of special interest or of special concern by the RI Natural Heritage Program; waterbodies identified by the U.S. Department of the Interior on the Final List of Rivers for potential inclusion in the National Wild and Scenic Rivers System." (RIDEM, 2004)

The relationship between the nitrogen loading rate and Eutrophication Index (EI) for Buzzards Bay estuaries is presented in Figure 3 using data provided by the Buzzards Bay Project. As the figure shows, the BBP quantified environmental response (EI) as a function of the loading rate per unit estuary volume per Vollenweider flushing term, defined as $\tau_w/(1+ \tau_w^{½})$, and where τ_w is the hydraulic turnover time, commonly defined as the flushing time, in years. The regression in Figure 3 was visually approximated through the dataset (n=23). N Loading rates for ONRW, SA, and SB waters were taken from the corresponding Eutrophication Indices for 65, 50, and 45.

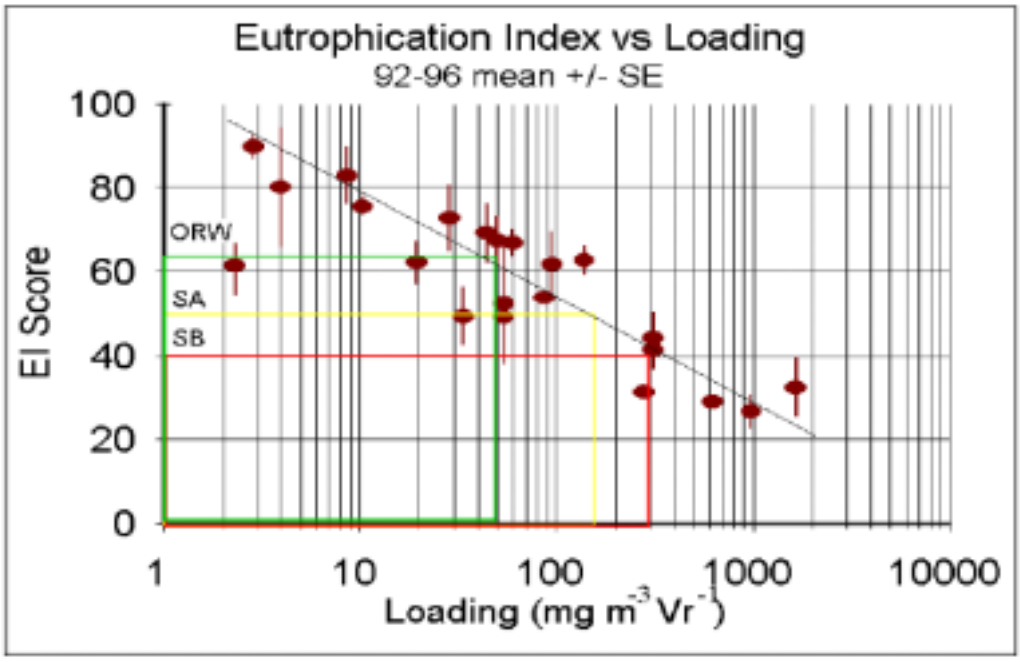

Figure 3. Use of Eutrophication Index scores to establish nitrogen loading limits for Buzzards Bay embayments. Regression visually approximated.

The Buzzards Bay Project adopted watershed nitrogen loading limits rather than water quality standards as the basis of nitrogen management for two fundamental reasons. First, evaluation of existing conditions of receiving waters fails to account for nitrogen in transit from new sources. Because average time of groundwater transit in any particular watershed may exceed 10 years or more, an evaluation of loadings based on watershed loading models was viewed as a more reliable basis for decision making than existing water quality conditions, especially in watersheds with considerable new development away from shore. Second, the use of water quality measurements in receiving waters has difficulties, especially in the context of regulatory decisions.

BBP adopted a land-use based approach to quantify loadings in its methodology. A 30% attenuation loss term was incorporated as an average for "upper" watershed loadings to account for uptake by wetlands streams, and ponds. Loadings are therefore quantified in terms of total nitrogen values into the water column. Nitrogen loads from all sources are calculated in the BBP from land use-specific nitrogen load coefficients that pool nitrogen loads from each source. The land use data to which the loading coefficients are applied are derived from literature and from information specifically collected by the BBP.

The BBP set EI goals of 50 and 65 for its SA and ONRW waters, respectively. The corresponding loading rates for SA and ONRW, assuming a shallow estuary having a mean depth less than 2 m are 150 and 50 mg m^{-3} per Vollenweider residence time (Vr) (Figure 1).

To translate this loading rate into an annual load, the calculation below developed by the Buzzards Bay Project was used. This calculation was designed to determine the annual load (in kg/year) for specific water bodies using a specific loading rate. It is presented in spreadsheet format at the following website: http://www.buzzardsbay.org/nitrmang/embnlim.xls

The calculation for annual load is:

$$\text{Annual Load (in kg yr}^{-1}) = \frac{\text{Loading rate x volume at half tide (in m}^3) \times (1+ \tau_w^{1/2})}{\tau_w \div 1{,}000{,}000}$$

Where τ_w is the hydraulic turnover time in years.

DEM-OWR has evaluated and accepted the BBP methodology for use in determining nitrogen loading rates to Green Hill and Ninigret Ponds. Current EI values for each pond were determined from available data as described above. EI values were plotted along the regression developed in Figure 1 and corresponding loading rates were then estimated for each pond. These loading rates were compared to loading rates which would support Eutrophication Indices of 65 for each waterbody (i.e. a target EI for each pond yields a corresponding loading rate in mg/m^3-Vr). A percent reduction in either annual nitrogen load or nitrogen loading rate was then calculated.

Using the above-equation, the allowable load for Green Hill Pond is 2,757 kg/yr and the allowable load for Ninigret Pond is 38,306 kg/yr. EI scores and allowable annual loads and loading rates are tabulated below in Table 3.

Table 3: Allowable nitrogen loadings to Green Hill and Ninigret Ponds.

Waterbody	Current EI Index	Corresponding Loading Rate (mg/m3-Vr)	Current Annual Load (kg)	EI Goal	Loading Rate Goal (mg/m3-Vr)	Allowable Load	Required Percent Reduction
Green Hill	45	250	13,783	65	50	2,757	80%
Ninigret	67	47	36,008	65	50	38,306	None

The EI for Green Hill Pond was calculated using 2 years of data collected at five different sites, resulting in a current EI score of 45, which corresponds to a loading rate of 250 mg/m^3-Vr. With a flushing time of 10.8 days and a mean volume of 1.4 x 10^6 m^3, the corresponding current annual load is estimated to be 13,783 kg/yr.

Based on the EI goal of 65 for RI SRPW waters, and a corresponding loading rate goal of 50 mg/m^3-Vr, the allowable annual load for Green Hill Pond is 2,757 kg/yr. An 80% reduction in either the loading rate or the total nitrogen load is required to meet this goal.

The EI for Ninigret Pond was calculated using 1 year of data collected at three different sites. For Ninigret Pond, with a current EI score of 67, the corresponding loading rate is 47 mg/m^3-Vr. The pond has an estimated flushing time of 4.6 days and a mean volume of 8.75 x 10^6 m^3, which corresponds to an estimated annual load of 36,008 kg/yr. Since the current estimated EI of 67 is only slightly higher than the EI goal of 65 for RI SRPW waters, no reduction in total nitrogen load is necessary.

V CALCULATION OF NITROGEN REDUCTIONS USING IN POND CONCENTRATION DATA COUPLED WITH NITROGEN THRESHOLDS AND COASTAL WATER CLASSIFICATION TAKEN FROM THE MASSACHUSETTS ESTUARIES PROJECT (MEP)

The MA Estuaries Project is attempting to develop site-specific nitrogen thresholds that can be used as a management tool to identify corrective and protective measures to protect water quality in 89 embayments in southeastern Massachusetts. The intent of the project is to link measured nitrogen concentrations to the more diagnostic biological and chemical indicators of habitat quality. Analysis of preliminary data collected in several Falmouth estuaries suggest that quantitative nitrogen criteria can be developed. The total nitrogen target levels in Table 4 are loosely based on the previous Buzzards Bay Program results, but also include site-specific consideration of nitrogen concentrations and indicators of embayment health (dissolved oxygen, phytoplankton densities, water clarity, sediment type and carbon concentrations, macroalgae, eelgrass and benthic communities).

Two significant results of the MA work are that mean chlorophyll levels of 10 ug/l and TN values of 0.39 mg/l appear to represent the threshold between suitable and impaired waters. Table 4 summarizes threshold TN concentrations and the resulting observations of embayment health.

Table 4. MA guidelines for TN and environmental health.

Condition	Threshold Nitrogen Concentrations (mg/l)	Observations
Excellent	< 0.30	[1] Block Island Sound and other offshore N concentrations less than 0.30 mg/l
Good	0.30-0.39	Eelgrass beds present, benthic animal diversity and shellfish productivity high, oxygen depletions to < 4mg/L are rare, chlorophyll 3-5 ug/l.
Moderate Quality	0.39-0.50	Above this TN range, loss of diverse animal communities and replacement by smaller, shorter-lived animals of intermediate burrowing capabilities, and shellfisheries may shift to more resistant species. Oxygen levels do not generally fall below 4 or 5 mg/l, phytoplankton blooms raise chlorophyll at levels to around 10 ug/l. Macro-algae may be present.
Significant Impairment	0.50-0.70	Large phytoplankton blooms, chlorophyll a of approximately 20 mg/l. Stressful oxygen conditions, major phytoplankton blooms, complete loss of eelgrass, periodic fish kills, macro-algal accumulations and aesthetic (odor) problems are observed. Stress tolerant species persist.
Severe Degradation	>0.70	Complete or near complete loss of oxygen periodically in bottom waters. Macro-algal accumulations and fish kills are observed periodically. Drift algae, lift-off mats and near complete loss of benthic animal communities occurs during a portion of the summer.

[1]Dissolved inorganic nitrogen concentrations of 0.5 *u*mol/l (0.007 mg/l) have been reported in Block Island Sound by Nixon and Lee (1981). The average total nitrogen in Nantucket Sound is reported as 33ppb (0.033 mg/l) (Nantucket Harbor Water Quality 2002 Annual Report).

Table 5 summarizes available total nitrogen and chlorophyll-a data collected in Green Hill and Ninigret Ponds by Salt Pond Watcher volunteers. Data were collected between 2000 and 2005 and are comprised of approximately 6-8 measurements of TN and chlorophyll (among other parameters) between the months of May and November.

Comparison of TN data in Table 5 with the MA TN guidelines in Table 4 suggests that current water quality in Green Hill Pond falls approximately midway between the MA conditions of "Moderate Quality" and "Severe Impairment". Current water quality in Ninigret Pond falls into the "Moderate Quality" condition.

Evaluation of Table 5 suggests that a TN target of 0.31 mg/l may be appropriate for both Green Hill and Ninigret Pond. Average TN and chlorophyll-a data were lowest at all stations in 2001 and likely reflect the best water quality conditions during the 6-year sampling period. The TN goal of 0.31 corresponds to best-year conditions in Ninigret Pond when the calculated EI index was 67. Required TN reductions needed to reach the 0.31mg/l TN goal are presented below.

Table 5. Summary of TN, NO3-N, and chlorophyll-a data for Green Hill and Ninigret Pond.

*******Total Nitrogen in mg/l*******								
Location	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**6-yr average**	**Avg**
Sea Lea	0.495	0.318	0.651	0.799	0.572	0.557	**0.579**	
Teal Road	0.670	0.573	0.515	0.701	0.752	0.751	**0.642**	
Indigo Point	0.662	0.413	0.649	0.587	0.607	0.751	**0.613**	
Twin Peninsula	0.658	0.403	0.504	0.643	0.745	0.631	**0.615**	**0.612**
GH Pond avg.	0.621	0.427	0.580	0.683	0.669	0.673	0.612	
Crawford Dock		0.343	0.494	0.403	0.472	0.619	**0.472**	
Tockwotten Dock		0.248	0.504	0.437	0.502	0.407	**0.441**	
Pond Street		0.338	0.369	0.410	0.514	0.458	**0.422**	**0.445**
Ninigret Pond avg.		0.310	0.456	0.416	0.496	0.494	0.445	

******Chlorophyll a******							
Location	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**6-yr average**	
Sea Lea	9.710	2.722	3.684	14.278	6.345	3.456	**5.881**	
Teal Road	6.822	3.926	6.970	8.643	5.161	4.581	**6.164**	
Indigo Point	2.968	5.861	25.197	4.866	3.804	4.422	**7.587**	
Twin Peninsula	2.880	2.806	8.790	5.572	4.517	2.935	**4.690**	**6.081**
GH Pond avg.	5.595	3.829	11.160	8.340	4.957	3.848	6.081	
Crawford Dock		3.610	5.692	4.513	3.570	4.034	**4.170**	
Tockwotten Dock		2.080	3.269	5.226	2.635	3.530	**3.485**	
Pond Street		2.976	4.540	8.515	2.824	3.099	**4.217**	**3.957**
Ninigret Pond avg.		2.889	4.500	6.085	3.010	3.554	3.957	

*******Nitrate Nitrogen in mg/l*******								
Location	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**6-yr average**	**Avg**
Sea Lea	0.050	0.077	0.089	0.318	0.063	0.177	**0.129**	
Teal Road	0.243	0.210	0.056	0.091	0.241	0.185	**0.171**	
Indigo Point	0.268	0.085	0.224	0.286	0.186	0.334	**0.230**	0.156
Twin Peninsula	0.033	0.058	0.049	0.127	0.128	0.164	**0.093**	
GH Pond avg.	0.148	0.108	0.104	0.205	0.154	0.215	0.156	
Crawford Dock		0.030	0.038	0.036	0.045	0.165	**0.063**	
Tockwotten Dock		0.044	0.044	0.081	0.120	0.207	**0.099**	0.193
Pond Street		0.338	0.369	0.410	0.514	0.451	**0.416**	
Ninigret Pond avg.		0.137	0.150	0.176	0.226	0.275	0.193	

Green Hill Pond

- Current GH Pond mean TN concentration (6yrs data, approx 6-8 values per year) = 0.612 mg/l TN.
- Corresponds to “Significant Impairment” according to MA guidelines for TN and environmental health.
- “Good” WQ concentrations = 0.31 mg/l TN = Target Value based on 2001 TN data from Table 6.
- Required Reduction = (0.61-0.31)/0.61 = 51%

Ninigret Pond

- Current Ninigret Pond TN concentration (6yrs data, approx 6-8 values per year) = 0.45 mg/l TN.
- Corresponds to “Moderate Quality” according to MA guidelines for TN and environmental health. Worst-case data correspond to borderline moderate quality-significant impairment.
- “Good” WQ concentrations = 0.31 mg/l TN = Target Value based on 2001 TN data from Table 6.
- Required Reduction = (0.45-0.31)/0.45 = 31%.

VI LOAD REDUCTION SUMMARY

Table 7 summarizes the different approaches for evaluating nitrogen targets for Green Hill and Ninigret Pond. Required nitrogen reductions in Green Hill Pond vary from 51% using the concentration approach to 80% using the Buzzards Bay Approach. Nitrogen reductions in Ninigret Pond range from none (utilizing the Buzzards Bay approach) to 31% (utilizing the concentration-based approach), as shown below.

Table 7. Summary of approaches for evaluating nitrogen targets for Green Hill and Ninigret Ponds.

APPROACH- Green Hill Pond	**ESTIMATED CURRENT LOAD or CONC.**	**TARGET CONDITION**	**REQUIRED REDUCTION**
BUZZARDS BAY APPROACH	13,783 kg/yr	2,757 kg/yr[1]	80%
CONCENTRATION BASED APPROACH	0.61 mg/l average	0.31 mg/l[3]	51%
Ninigret Pond	**ESTIMATED CURRENT LOAD or CONC.**	**TARGET CONDITION**	**REQUIRED REDUCTION**
BUZZARDS BAY APPROACH	36,008 kg/yr	38,306 kg/yr[1]	None
CONCENTRATION BASED APPROACH	0.45 average	0.31 mg/l[3]	31%

[1]Target Condition equals annual load back-calculated from the EI goal of 65 (Loading Rate of 50mg/m3-Vr).
[2]Target Condition equals annual load back-calculated from EI goal of 65 (DEM-OWR modified regression). Corresponding Loading Rate of 14.5 mg/m3-Vr.
[3]Target Condition equals concentration of 0.31 mg/l TN. Based on available data, DEM-OWR has determined that, for Green Hill and Ninigret Ponds, a TN concentration of 0.31 mg/l is protective.

As stated earlier, DEM-OWR recommends the use of the BBP approach to evaluating nitrogen targets for Green Hill and Ninigret Ponds. DEM has modified the approach slightly by calculating the Eutrophication Index first, based on available data, and back-calculating the loading rate along the regression line in Figure 1. Because the BBP's nitrogen loading limits take into account the depth, flushing time, and volumes of bays, they are bay specific and nitrogen loading is a result of specific assumptions used in the BBP loading model.

This approach is still a general model, and ultimately sophisticated computer models may be developed that will take into account a more wide range of features of bays and provide more exact numerical limits. However, until these models have been developed and refined, DEM-OWR believe these limits combined with a sound management approach will establish an objective set of performance standards on which permitting decisions or new bylaws and regulations can be based.

VI References

Bowen, J.L., and I. Valiela. 2001. The ecological effects of urbanization of coastal watersheds: Historical increases in nitrogen loads and eutrophication of Waquoit Bay estuaries. *Can. J. Fish Aquat. Sci.* 58:1489-1500.

Costa, J. E., B.L. Howes, D. Janik, D. Aubrey, E. Gunn, A.E. Giblin. 1999. Managing anthropogenic nitrogen inputs to coastal embayments: Technical basis and evaluation of a management strategy adopted for Buzzards Bay.

Costa, J. E., D. Janik, N. MacGaffey, and D. Martin. 1994. Use of a geographic information system to estimate nitrogen loading to coastal watersheds. Buzzards Bay Project Technical Report. Draft, March 2, 1994, 21p.

Ernst, L. (ed), Miguel, L.K(ed)., and Willis, J.(ed). 1999. Rhode Island's Salt Pond Region: Special Area Management Plan. Coastal Resources Management Council.

Howarth, R. W. 1988. Nutrient limitation of net primary production in marine ecosystems. *Annu. Rev. Ecol. Syst.* 19:89-110.

Howes, B., Samimy, R., Dudley, B. 2003. Site Specific Nitrogen Thresholds for Southeastern Massachusetts Embayments: Interim Report. Massachusetts Department of Environmental Protection.

Lin, H.J., Nixon, S.W., Taylor, D.I., Granger, S.L., and Buckley, B.A. 1996 Responses of epiphytes on eelgrass, *Zostera marina* L., to separate and combined nitrogen and phosphorus enrichment. Aquat. Bot. 52: 243-258.

Nixon, S.W., Granger, S.L., Taylor, D.I., Johnson, P.W. and Buckley, B.A. 1994. Subtidal volume fluxes, nutrient inputs, and the Brown Tide-an alternate hypothesis. Est. Coast. Shelf Sci. 39: 303-312.

Nixon, S. W. 1995. Coastal marine eutrophication: a definition, social causes, and future concerns. *Ophelia* 41:199-219.

RIDEM. 2004. State of Rhode Island and Providence Plantations Department of Environmental Management. Office of Water Resources. Water Quality Regulations. Draft. November 2004.

Taylor, D.I., Nixon, S.W., Granger, S.L., and Buckley, B.A. 1999. Responses of coastal lagoon plant communities to levels of nutrient enrichment: A mesocosm study. Estuaries. 22(4): 1041-1056.

Taylor, D.I., Nixon, S.W., Granger, S.L., and Buckley, B.A, McMahon, J.P., and Lin, H.J. 1995a. Responses of coastal lagoon plant communities to different forms of nutrient enrichment: A mesocosm experiment. Aquatic Botany. 52:19-34.

Taylor, D.I., Nixon, S., Granger, S., and Buckley, B.A. 1995b. Nutrient limitation and the eutrophication of coastal lagoons. Mar. Ecol. Prog. Ser. 127: 235-244.

Taylor, D. I., S. W. Nixon, S.L. Granger, and B.A. Buckley. 1995c. Impacts of different forms of nutrients on the roles of coastal lagoons as nutrient sources or sinks: A mesocosm study. Ophelia. 42: 353-370.

Valiela, I., G. Collins, J. Kremer, K. Lajtha, M. Geist, B. Seely, J. Brawley, and C.H. Sham. 1997 Nitrogen loading from coastal watersheds to receiving estuaries: New method and application. *Ecol. Appl.* 7:358-380.