The allowable DIN loads due to WWTFs and river base flow for each reach of the Providence and Seekonk Rivers based on the limit of technology, and not accounting for sources such as stormwater directly discharging to the rivers become:

Element 1, Seekonk River:	526 kg/day
Element 2, Areas north of Fields Point	877 kg/day
Element 3, Areas north of Bullocks Point	1073 kg/day
Element 4, Entire area	1073 kg/day

Experimental data indicate that the 2X and 4X conditions (8.06E-05 kg/m2/day and 1.61E-04 kg/m2/day, respectively) are the likely goal from the perspective of consistency with the State's water quality standards. Specifically, the enrichment status of the Seekonk River would be expected to be consistent with the 4X condition, and the remaining area of the Providence River would be at the 2X or a lower condition. Information from other agencies and researchers indicates that maximizing the area of the Providence and Seekonk Rivers at the 2X level is beneficial from the standpoint of supporting the designated uses of the area for fisheries habitat. The following points underscore this decision:

- Historical data indicate that eelgrass beds were once present in the Providence River, extending northward to Green Jacket Shoal opposite Fox Point (www.edc.uri.edu/ Eelgrass). Eelgrass restoration efforts to date have determined that future restoration efforts north of Prudence Island are water quality limited. The goal of supporting fish and shellfish populations in the Providence River is compatible with the return of eelgrass, at least in the southern reaches of the Providence River and upper Narragansett Bay. Dennison et al. (1993) reported the following habitat criteria for SAV: DIN of 0.15 mg/l (10.7 μM), DIP of 0.33 μM; N:P (atomic) of 32; and chlorophyll *a* of 15 μg/L. The MERL experiment means at the 2X case are 0.26 mg/l for DIN and 12 ug/l for chlorophyll, which compare well with these guidelines.

- Locally, Massachusetts has established environmental general guidelines for total nitrogen concentrations in estuaries. Guidelines began with those developed by the Buzzards Bay Program that rated the condition of a water body based on ambient water quality parameters (Table 7). Each estuary was scored on the basis of a suite of parameters that included mean DIN, Chlorophyll, and DO concentrations. Impaired estuaries received a score of zero if mean DIN levels were greater than 10 uM (0.14 mg/l) or chlorophyll levels exceeded 10 ug/l. The 40% saturation DO levels would correspond to a concentration slightly greater than 3 mg/l in estuarine waters during the summer. Under the Buzzards Bay approach, SB waters would have to meet a score of 40%; SA waters would need to meet 50%.

- Massachusetts has recently refined its approach to incorporate a land-use loading model, and a receiving water quality model that simulates the TN response to loading. The TN target levels (Table 8) 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

Table 7: Buzzards Bay Project Eutrophication Index endpoints

	0 Points:	100 Points:
Summer % Dissolved Oxygen saturation (mean lowest 1/3)	40%	90%
Secchi depth, (m)	0.6	3.0
Dissolved inorganic nitrogen (DIN), (uM)	10.00	1.00
Chlorophyll-a (ug/l)	10.0	3.0
Total organic nitrogen (TON), (mg/l)	0.60	0.28

significant results of the MA work are that mean chlorophyll levels of 10 ug/l and DIN of 10 uM (0.14 mg/l) appear to represent the threshold between suitable and impaired waters. Table 8 summarizes threshold TN concentrations and the resulting observations of embayment health. The 2X case meets the mean chlorophyll a concentration of 10 ug/l (Figure 10) target established by Massachusetts.

Table 8: MA guidelines for TN and environmental health

Condition	Threshold Nitrogen Concentrations	Observations
Excellent	<0.30	
Good	0.30-0.39	Eelgrass beds present, benthic animal diversity and shellfish productivity high, oxygen depletions to <4 mg/L are rare, chlorophyll 3 to 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.

Our summary of this analysis is that considerable reductions of existing loads to the Providence and Seekonk Rivers are needed. In the context of existing information on water quality conditions needed to support State water quality standards and the designated uses of the area, a loading scenario consistent with the 2X-4X condition represents the goal for the area. The WWTF scenario that produces loads consistent with this goal would require WWTFs in the watershed to implement reductions to the limit of technology. DEM's interpretation of this limit is the TN=3 scenario, with plant flows at 90% of present design values.

Phased Implementation of Nitrogen Controls

Based upon the MERL enrichment gradient experiment, minimum DO levels of approximately 3.0 and 2.7 mg/l are anticipated from the no treatment plant and LOT cases, respectively. Lower values are expected for the Providence River since it is stratified and the MERL experiment was conducted under unstratified conditions. This analysis indicates that the limit of technology is required but will not fully meet existing water quality standards (minimum of 5.0 mg/l "except as naturally occurs") and may not meet EPA guidelines recently recommended for waters from Cape Cod to Cape Hatteras (EPA 2000). The EPA guidelines allow instantaneous values below 4.8 mg/l provided the cumulative exposure to low DO levels do not exceed the duration criteria established to ensure that the cumulative percentage of larvae affected shall not exceed a 5% reduction in larval recruitment over the recruitment season.

While we believe that the MERL tank results provide an adequate representation of the relationship between nitrogen and oxygen levels in the Providence and Seekonk Rivers, some uncertainty remains regarding predicted water quality improvements and loading reductions necessary to meet water quality standards. As noted above, significantly lower mean DIN concentrations were observed in the Providence and Seekonk Rivers as compared to the MERL experiment for an equivalent loading rate, which may be the result of large differences between the field and experimental flushing times, uptake by macroalgae and denitrification in the bottom waters. Also the MERL experiment DO sampling protocol does not provide sufficient data to fully assess compliance with the recently established EPA guidelines regarding cumulative periods of low dissolved oxygen. However, it is clear that the Providence and Seekonk Rivers are impacted by low dissolved oxygen levels and high phytoplankton levels related to excessive nitrogen loadings. For these reasons, evaluation of phased implementation is indicated. Implementation of a phased approach is consistent with the EPA TMDL guidance (EPA 1991) which states: "For certain non-traditional, problems, if there are not adequate data and predictive tools to characterize and analyze the pollution problem, a phased approach may be necessary."

Evaluation of Implementation Alternatives

For the reasons noted above, RIDEM has evaluated implementation costs, analysis of the performance of available technology, and estimates of water quality improvement to developed a phased plan for implementation of WWTF improvements which maximizes the DO levels relative to implementation cost.

Nine different cases, representing various combinations of nitrogen reduction at 3 MA and 7 RI facilities were examined. The facilities included in this analysis are: Upper Blackstone Water Pollution Abatement District ("UBWPAD" or "UB"), located in Worcester, MA, North Attleboro ("NA"), Attleboro ("A"), Woonsocket ("W"), Bucklin Point ("BP"), Fields Point ("FP"), East Providence, Cranston, West Warwick and Warwick. Estimates were developed for capital costs, including allowances for planning, design, construction and administration, to modify a secondary treatment facility to achieve the target levels on a seasonal basis. Table 9 lists the alternatives evaluated and the estimated implementation costs. Costs shown must be considered "Order-of Magnitude" cost estimates, since specific facility characteristics were not available for many alternatives. The cost are based on estimates which were developed for control of point sources in the Chesapeake Bay watershed (Nutrient Reduction Technology Cost Task Force, 2002), with the exception of a few facilities for which planning estimates or construction bid costs were available. A comparison of the cost to water quality benefits are presented both in terms of the resulting loading gradient (Figure 21) and loading gradient improvement (Figure 22).

Table 9: Estimated cost of WWTF nitrogen reduction alternatives.

WWTF Effluent TN Concentrations (mg/l)	Estimated Cost ($M)
All WWTFs 8 mg/l	104.1
All WWTFs 5 mg/l	192.8
All WWTFs 3 mg/l	337.1
FP, BP 5 mg/l rest 8	120.1
UB, W, FP, BP 5 rest 8 mg/l	156.7
FP, BP 3, UB, W 5 rest 8	212.6
W, FP, BP 5, Rest RI 8, MA - 95-96 levels	85.5
FP, BP, UB, W 5: Rest RI 8: NA, A 95-96 levels	141.1
FP, BP 3, Rest 8	176
FP, BP 3 Rest 5	248.7

As noted in Figures 21 and 22, the following WWTF reductions maximize the water quality improvements relative to costs, 5 mg/l at UBWPAD, Woonsocket, Bucklin Point and Fields Point and 8 mg/l at North Attleboro, Attleboro, East Providence, Cranston, West Warwick and Warwick. Reductions in loading are expressed as the mean 95-96 summer conditions compared to conditions resulting from nitrogen loadings at the target concentrations discharged at summer WWTF design flows (90% of approved design flows). The anticipated loading reduction includes estimates of nitrogen uptake in the tributary rivers (river attenuation). If nitrogen controls are not implemented, loads delivered to the Providence Seekonk system will increase by 55 % as WWTFs increase to their design flows, increasing the existing Seekonk reach loading factor from 24X to 40X. Using the analysis described above, implementation of this first phase would initially reduce the summer season WWTF loading delivered to the Providence Seekonk system by 68% dropping to 52% as WWTF flows increase to their approved design flows. The corresponding Seekonk reach loading factors would drop to 6.6 at current flows and 10X at design flows.

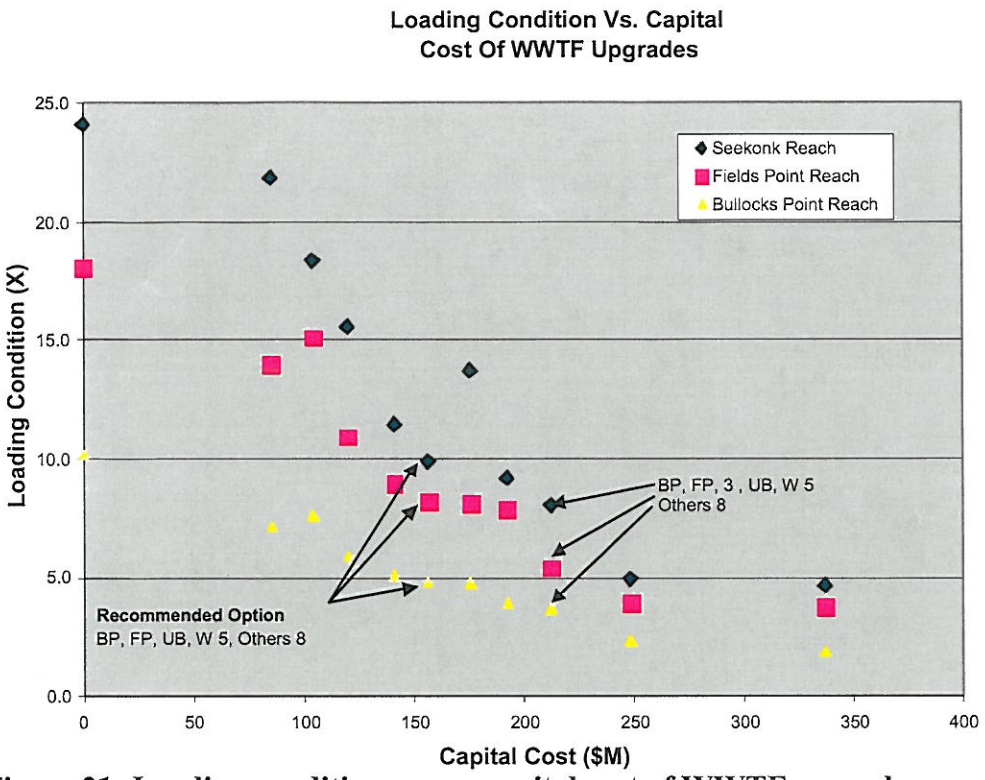

Figure 21: Loading condition versus capital cost of WWTF upgrades

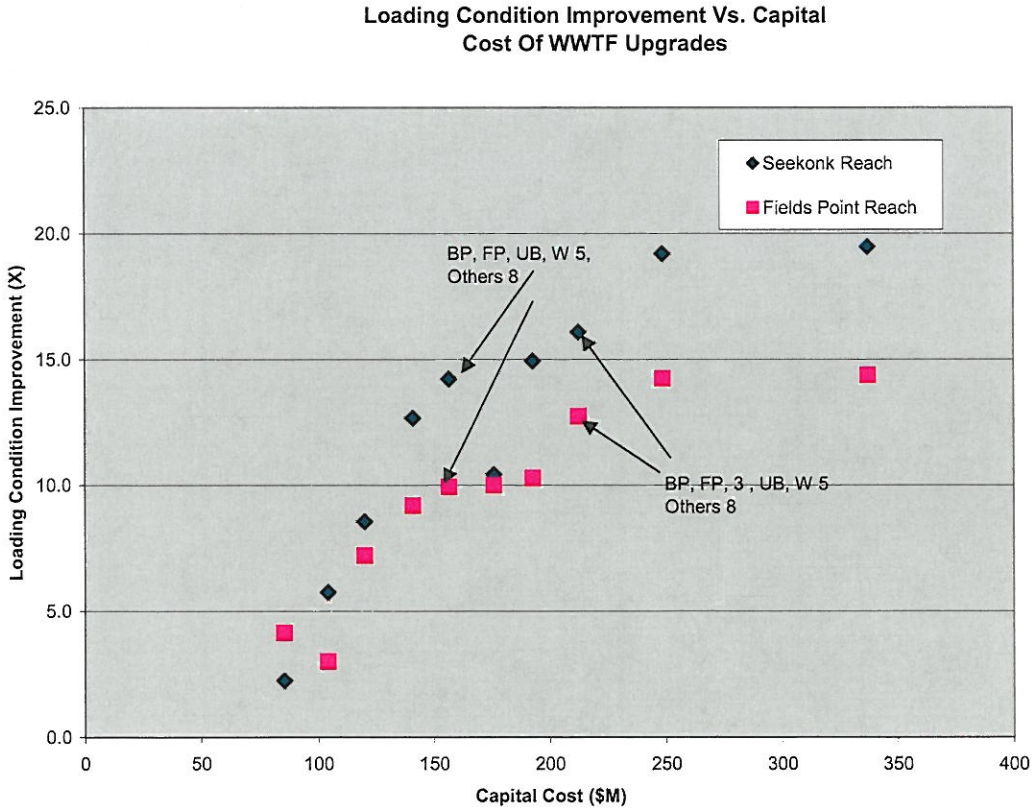

Figure 22: Loading condition improvement versus capital cost of WWTF upgrades.

Evaluation of the Significance of WWTFs in Massachusetts

If the UBWPAD, Attleboro and North Attleboro WWTFs do not implement nitrogen controls, the summer season WWTF loading delivered to the Providence Seekonk River system will decrease from 53% to 30% below current levels. The impact to the Seekonk River is much more significant; a 58% reduction with full participation (the loading factor is reduced from 24X to 10X) but only a 9% reduction (to 22X) if nitrogen loads from these MA facilities are not reduced.

There has been a suggestion that permit limits for nitrogen at MA WWTFs should not be pursued until after current upgrades are completed and further information is available to evaluate river attenuation (e.g. a river delivery factor of 85% was computed for the Blackstone River). DEM does not believe this is appropriate, since river delivery factors would have to be 17% and 7% before the UBWPAD at 95-96 concentrations and design flow would be reduced to the loading resulting from the 5 mg/l discharge proposed for Bucklin Point and Woonsocket WWTFs and at their design flows. The UBWPAD design flow is large relative to the other WWTFs impacting the Seekonk River: 1.8 times larger than Bucklin Point and 3.5 times larger than Woonsocket. Furthermore, the UBWPAD is currently planning an upgrade and it would be prudent to consider nitrogen removal options while the planning process is underway. UBWPAD, North Attleboro and Attleboro WWTFs play a significant role in the ability to improve water quality in the Providence and Seekonk River system, and efforts to reduce their nitrogen inputs should be initiated as soon as possible. RIDEM will be working with Massachusetts and the US EPA to pursue nitrogen reductions at these facilities.

Implementation of Nitrogen Reductions

As noted earlier, MERL tank experiments suggest that LOT treatment is required to meet water quality standards. However, based on a comparison of technology, costs and reductions in the nutrient loading factors for the Providence and Seekonk River Systems, RIDEM has established a phased reduction strategy. The first phase is based on achieving the following WWTF effluent concentrations: 5 mg/l at UBWPAD, Woonsocket, Bucklin Point and Fields Point and 8 mg/l at North Attleboro, Attleboro, East Providence, Cranston, West Warwick and Warwick. This analysis acknowledges that loadings will increase as WWTF flows increase to their design flows, but follow-up monitoring and possibly water quality modeling will be needed to determine whether additional reductions are required. Because LOT treatment is presently indicated, it is DEM's position that it is appropriate to express WWTF permit requirements as a concentration limit, which will enhance the near-term environmental improvement while plants are below their design flows.

The analysis presented herein evaluates the impact of current and future nitrogen loading scenarios on the Providence and Seekonk Rivers using the inputs from the most significant WWTFs. For example, summer loads measured at the mouth of Blackstone River were expressed as loading from the Woonsocket and UBWPAD WWTF inputs, attenuated to match loads measured in the river. UBWPAD is by far the single largest WWTF in the

Blackstone River Watershed. Attenuation from the state line to the mouth of the Blackstone River was established based on the following assumptions: that majority of the loadings during the 95-96 study period were from the most significant point sources (Woonsocket and UBWPAD), that Woonsocket is located close to the state line, that the load crossing the state line and Woonsocket's loading are equally attenuated and adequately represented by a single delivery factor. The first phase results in a **DIN** load at the mouth of the River of 403 kg/day or 463 kg/day combined input from Woonsocket and MA sources. Of this allowable load, 85 kg/day has been allocated to Woonsocket and 378 kg/day to MA sources.
Upper Narragansett Bay

Areas of Upper Narragansett Bay are affected by the WWTFs that impact the Providence and Seekonk River Systems. In addition, to reduce its impact on Greenwich Cove, the East Greenwich WWTF is in the process of constructing modifications to achieve a seasonal nitrogen limit of 5 mg/l as required by its RIPDES permit. It is DEM's position that the point source discharges to the Warren River will also need to reduce nitrogen to address impacts to the Palmer River.

Implementation of nitrogen removal would initially reduce the summer season nitrogen load discharged from these eleven Rhode Island WWTFs to the Upper Bay by 65%, dropping to 48% as WWTF flows increase to their approved design flows.

Monitoring Water Quality Improvements

An integral component of this phased implementation approach is adequate monitoring and assessment of water quality changes to determine if additional reductions are necessary to meet water quality standards. Of particular concern are the establishment, maintenance and data processing for a system of continuous dissolved oxygen, chlorophyll, temperature and salinity monitors strategically located throughout the Bay. DEM, in partnership with NERRS, the Narragansett Bay Commission, University of Rhode Island and Roger Williams University increased the Narragansett Bay continuous water quality monitoring system from 7 to 9 stations during the summer of 2004. DEM has obtained funding from the federal Bay Window grant to increase the number of stations to at least13 by the summer of 2005. This monitoring network will provide the data necessary to evaluate compliance with water quality standards, particularly temporal detail needed to evaluate compliance with EPA's dissolved oxygen guidelines. The United States Environmental Protection Agency (EPA), Office of Water's, Office of Science and Technology EPA is currently seeking a contractor to assist DEM with the development of methods to review continuous time series DO measurements for compliance with EPA's October 2000 recommended ambient water quality criteria. The contractor will also assess monthly transect surveys of the bay to determine whether modifications are needed to the existing and planned monitoring network based and provide technical support to establish guidelines for evaluating the response to changes in nitrogen loads .

References

Asselin, S. 1991. Flushing times in the Providence River based on tracer experiments. Thesis (M.S.). University of Rhode Island.

Chinman, R.A. and S.W. Nixon. 1985. Depth-area-volume relationships in Narragansett Bay. NOAA/Sea Grant Marine Technical Report 87. Graduate School of Oceanography, University of Rhode Island.

Dennison, W.C., R.J. Orth, K.A. Moore, J.C. Stevenson, V. Carter, S. Kollar, P.W. Bergstrom, and R.A. Batiuk. 1993. Assessing water quality with submersed aquatic vegetation. Bioscience 43:86-94.

Environmental Protection Agency, 2000. *Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras*. EPA-822-R-00-012

Environmental Protection Agency, 1991. Guidance for Water Quality Based Decisions: The TMDL Process. EPA Office of Water. EPA440/4-91-001

Liberti, A.S.1985. A waste load allocation for DO/BOD dynamics of the Pawtuxet River Rhode Island, Department of Civil and Environmental Engineering, University of Rhode Island, Kingston.

Nixon, S. B. Buckley, S. Granger, and J. Bintz. 2001. Responses of very shallow marine ecosystems to nutrient enrichment. Human and ecological Risk Assessment. V.7 No.5, pp. 1457-1481.

Nutrient and Bacteria Pollution Panel, 2004. Nutrient and Bacteria Pollution Panel Initial Report, March 3, 2004.
http://www.ci.uri.edu/GovComm/Documents/Phase1Rpt/Docs/Nutrient-Bacteria.pdf
Governor's Narragansett Bay and Watershed Planning Commission.

Nutrient Reduction Technology Cost Task Force, 2002. Nutrient Reduction Technology Cost Estimations for Point Sources in the Chesapeake Bay Watershed, November 2002. Chesapeak Bay Program.

NYDEP and CTDEP. 2000. A Total Maximum Daily Load Analysis to Achieve Water Quality Standards for Dissolved Oxygen in Long Island Sound. http://www.dec.state.ny.us/website/dow/tmdllis.pdf. 73 pp.

Oviatt, C.A., A.A. Keller, P.A. Sampou, and L.L. Beatty. 1986. Patterns of productivity during eutrophication: a mesocosm experiment. Mar. Ecol. Prog,. Ser. 28: 69-80.

WEF and ASCE. 1992. Design of municipal wastewater treatment plants / prepared by Joint Task Force of the Water Environment Federation (formerly the Water Pollution Control Federation) and the American Society of Civil Engineers. WEF Facilities Development Subcommittee of the Technical Practice Committee and ASCE Environmental Engineering Division Committee on Water Pollution Management . Alexandria, VA : Water Environment Federation ; New York, NY : American Society of Civil Engineers.1592 pp.