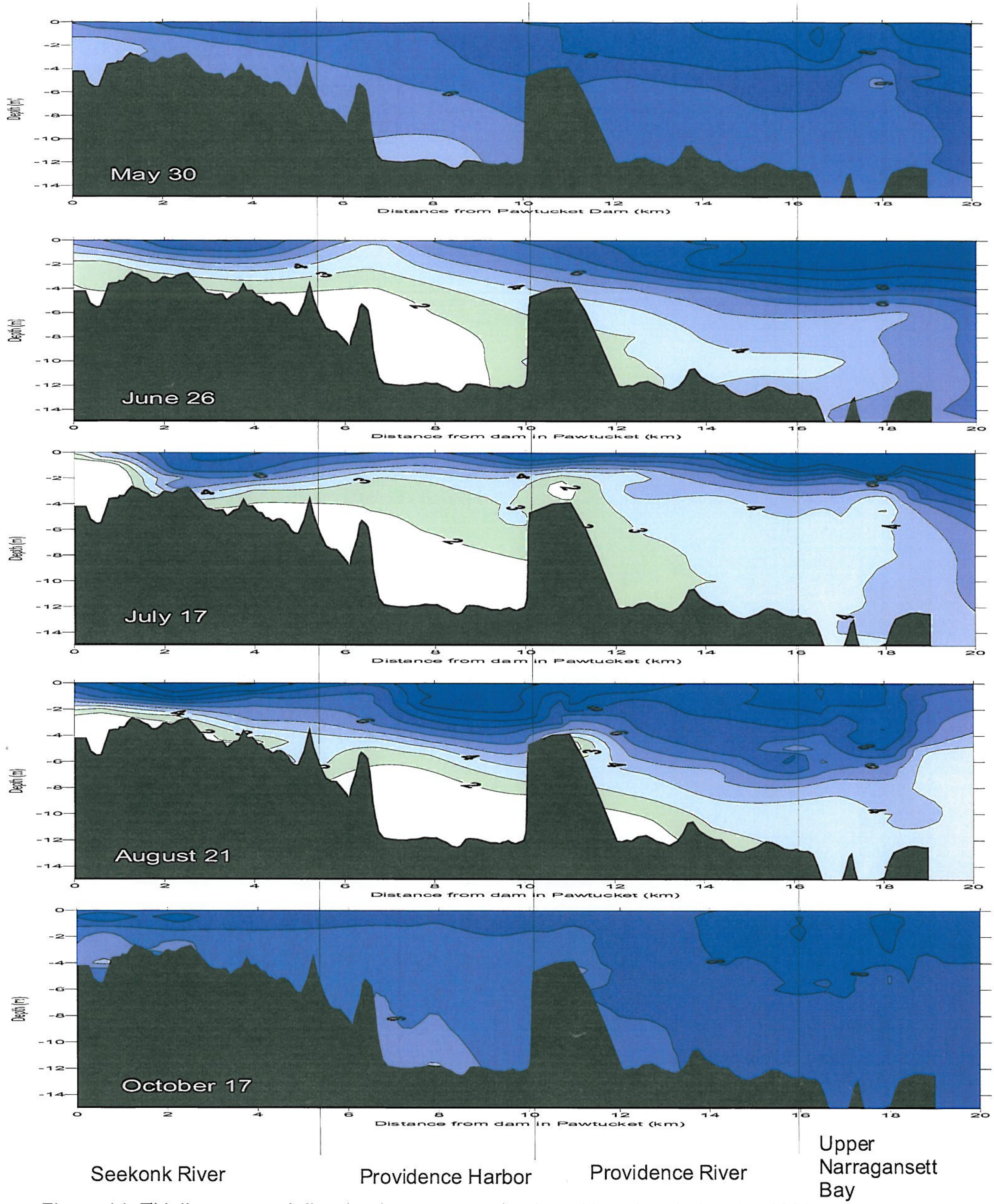

Figure 14: Tidally averaged dissolved oxygen vs. depth and location during the 1996 surveys
White areas:<2 mg/l. Green areas: 2-3 mg/l. Blue areas >3 mg/l at 1mg/l increments.

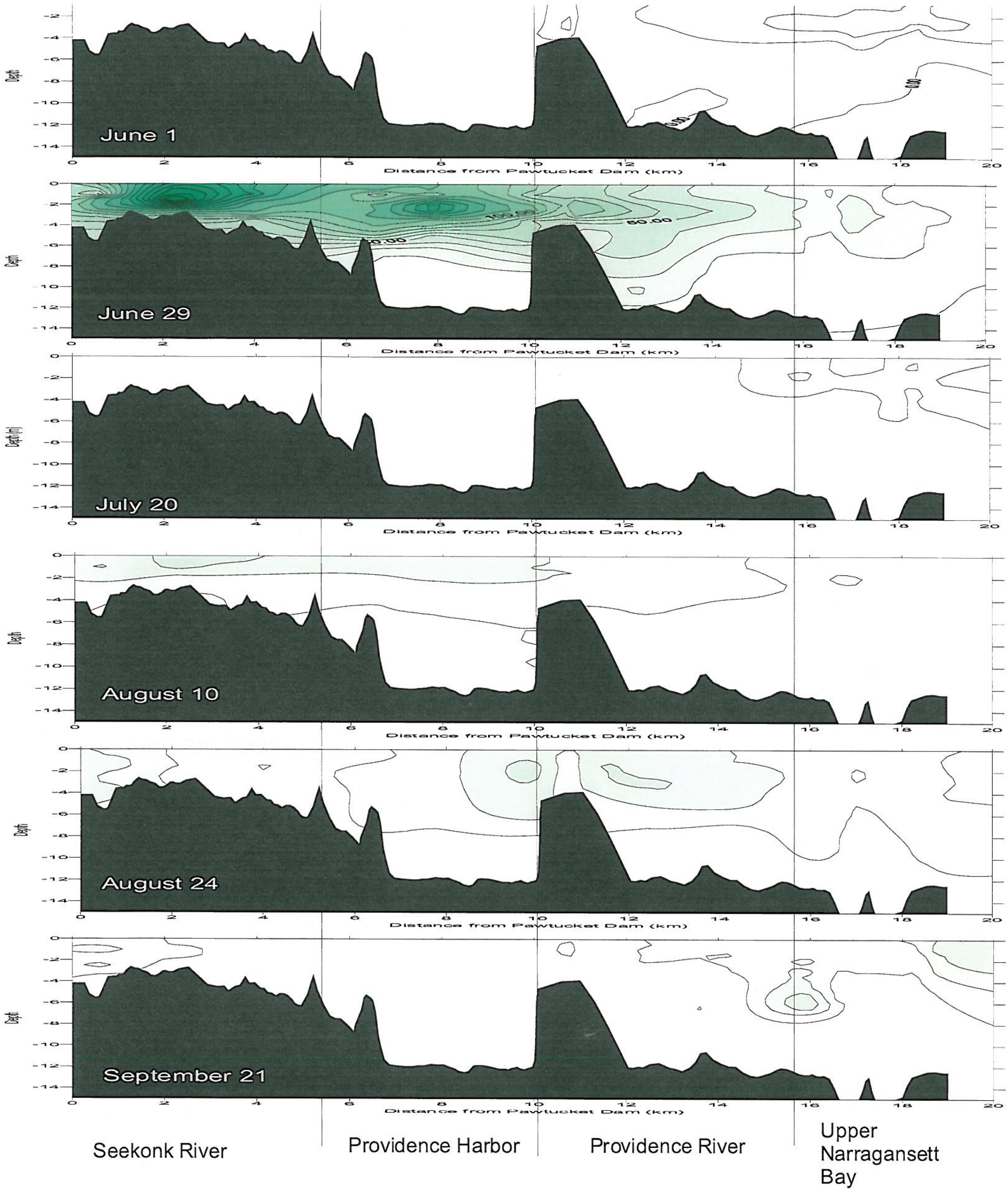

Figure 15: Tidally averaged chlorophyll-a vs. depth and location during the 1995 surveys
Isopleths are at 10 ug/l increments

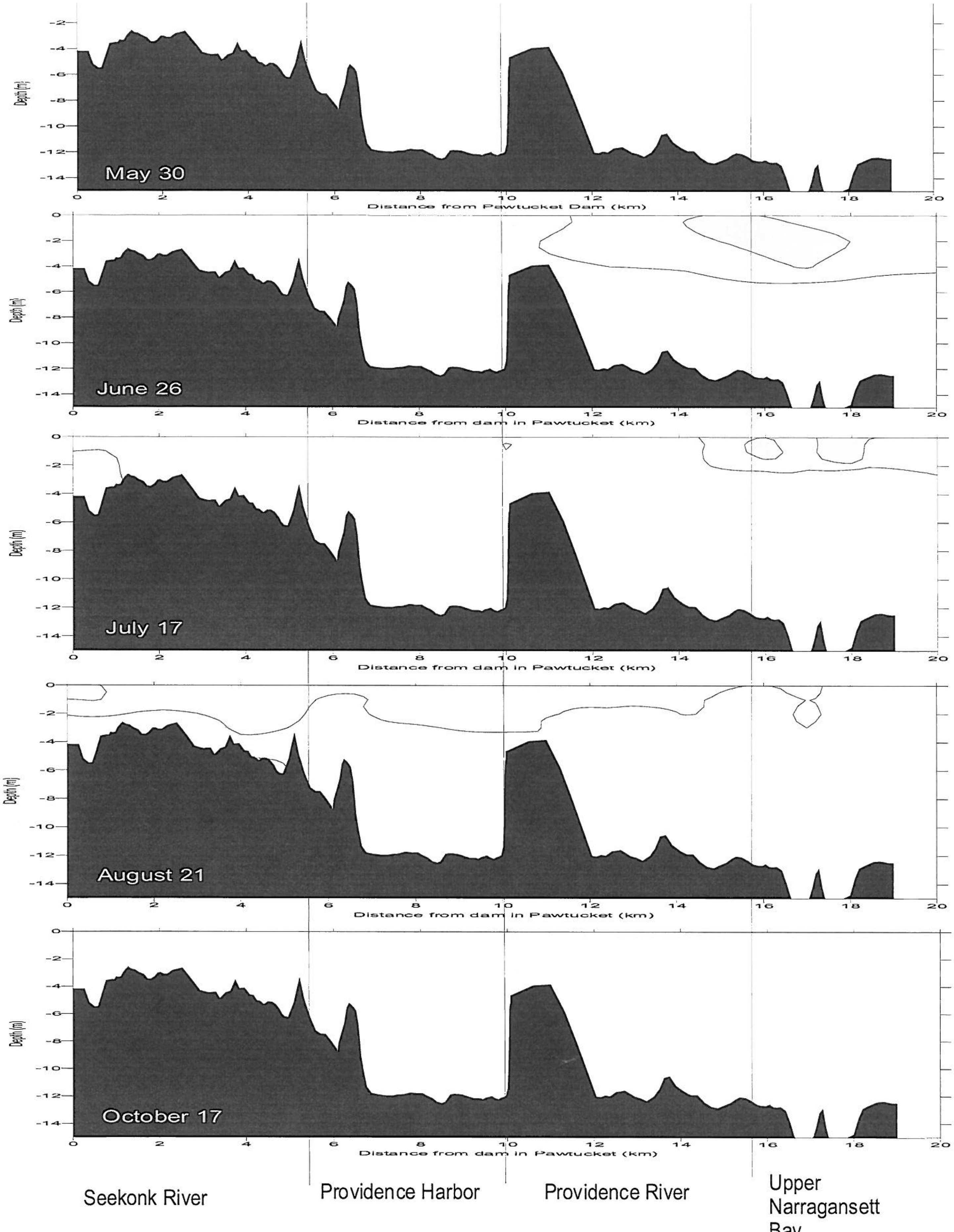

Figure 16: Tidally averaged chlorophyll-a vs. depth and location during the 1996 surveys. Isopleths are at 10 ug/l increments.

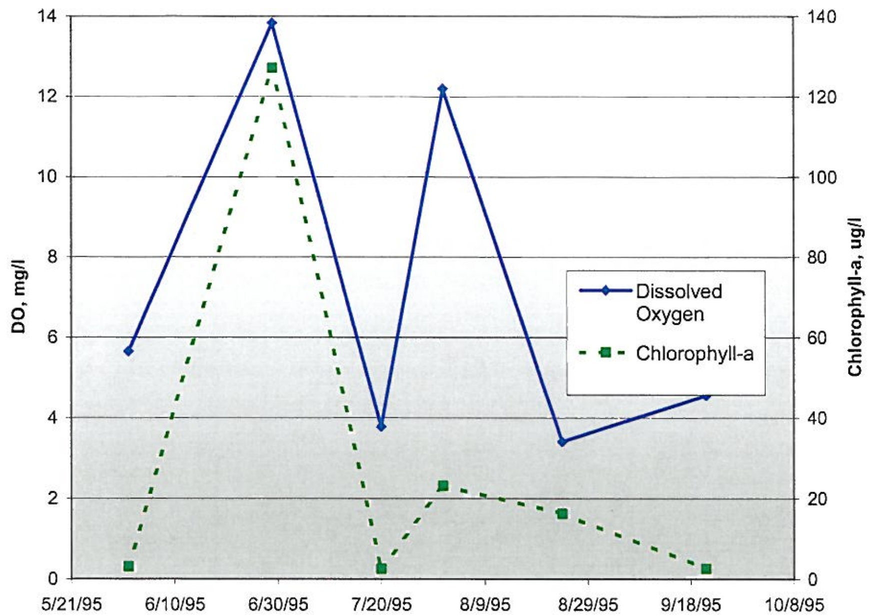

Figure 17: Tidally averaged dissolved oxygen and chlorophyll-a in the top 2m of the water column in Providence Harbor during the summer of 1995

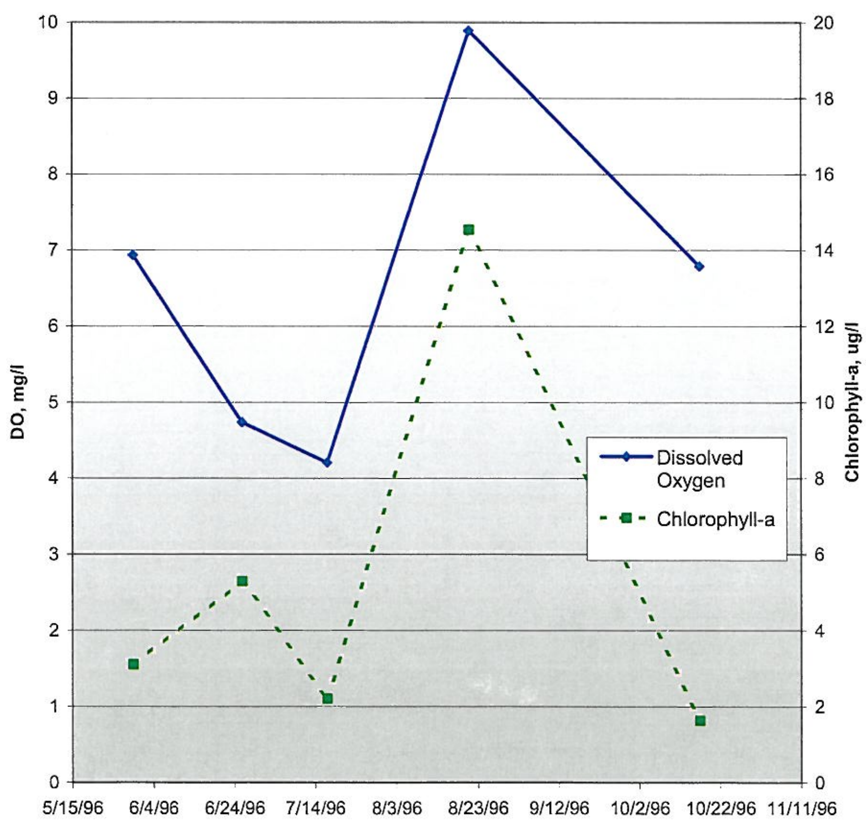

Figure 18: Tidally averaged dissolved oxygen and chlorophyll-a in the top 2m of the water column during the summer of 1996

USING THE MERL RELATIONSHIPS TO PROJECT THE IMPLICATIONS OF FUTURE NITROGEN LOAD REDUCTIONS TO THE PROVIDENCE AND SEEKONK RIVERS

As noted in the Initial Report From the Nutrient and Bacteria Pollution Panel of the Governor's Bay and Watershed Planning Commission, several analyses have been conducted which agree that wastewater treatment plants are the major source of nitrogen to Narragansett Bay (Nutrient and Bacteria Pollution Panel, 2004). This section presents a summary of an analysis that DEM has conducted to evaluate outcomes for reducing nitrogen levels.

Considerations Regarding WWTF loading reductions

The Long Island Sound TMDL for DO set the degree of nutrient reduction at a WWTF based on the relative environmental impact of each discharge. This issue was addressed in the Long Island Sound Dissolved Oxygen TMDL (NYDEC and CTDEP, 2000) by establishing two "equivalency factors" to account for the loss of nitrogen between the point of discharge and the point of impact. These were: 1) attenuation during tributary river transport, called river delivery factors, and 2) transfer efficiency from the "edge-of-Sound" to the area of most significant degradation.

River delivery factors are predicated on the idea that some degree of nitrogen removal due to permanent uptake or denitrification occurs in the river between the WWTF discharge and the mouth. It is expressed as the percentage of the point source load discharged to the river that reaches the Sound. In the Long Island Sound Study, river delivery factors ranged between 52% – 90%. River delivery factors may increase as nutrient inputs are restricted to control low dissolved oxygen and excessive algae growth in the rivers. Reductions in WWTF phosphorus inputs have been required and are in various stages of completion along the Blackstone and Pawtuxet Rivers.

Blackstone River

Detailed source and river loads (i.e. concurrent WWTF and river data) were computed as part of the 1991 interstate Blackstone River Initiative study. Based on sampling conducted during three sampling surveys (July, August and October), the load discharged from the mouth of the Blackstone River into the Seekonk River is estimated to range from 27% to 84% (average 60%) of the summed nitrogen loads from the Woonsocket WWTF and the Upper Blackstone Water Pollution Abatement District WWTFs. Based on DEM's 1995 and 1996 sampling at the mouth of the Blackstone and monthly average WWTF discharge monitoring report data, 87% of the loading from the two sources is discharged from the Blackstone River. Stated another way, reducing the total nitrogen from the WWTFs to 8 mg/l is equivalent to 7.0 mg/l discharged near the mouth of the Blackstone River. The difference is attributable to uptake and denitrification along the length of the river. Given the large range observed during the Blackstone River Initiative, and since concurrent WWTF and river data is not available for the other tributaries rivers the 1995 – 1996 data was used to calculate delivery factors for all tributaries to the Providence and Seekonk Rivers.

Pawtuxet River

Attenuation of the West Warwick, Warwick and Cranston WWTFs loading is anticipated when discharged from the mouth of the Pawtuxet River into Pawtuxet Cove which in turn discharges to the Providence River at Pawtuxet Neck. Using the method described above, it was estimated that 82% of the WWTF load is discharged from the mouth of the river.

Ten Mile River
In the Ten Mile River, the DIN discharge to the Seekonk River was found to be 61% of the concurrent load estimate from the Attleborough and North Attleborough WWTFs using 1995-1996 flows. The Attleborough facilities did not monitor nitrogen during that period, so concentrations reported in 2000-2002 discharge monitoring reports (DMRs) were used to represent the facility loads.

Consideration of the transfer efficiency from the edge of the Providence and Seekonk Rivers acknowledges that areas of the Providence and Seekonk Rivers with the most severe hypoxia are located from the mouth of the Blackstone River to Gaspee Point. Although sufficient information is not available to quantitatively evaluate this "equivalency factor", a qualitative approach is also instructive.

Edge of the Seekonk River
Sources to the edge of the Seekonk River include the Blackstone River, the Ten Mile River and the Bucklin Point WWTF. Given the close proximity of these sources it is reasonable to conclude that on a unit loading basis, these sources equally impact the Seekonk River. As such it is not appropriate to establish transfer efficiency factors for these sources.

Edge of the Providence River
Significant nitrogen sources to the edge of the Providence River include the Seekonk River, Fields Point WWTF, East Providence WWTF and Pawtuxet Cove. Based on the close proximity of the Seekonk River, Fields Point WWTF and East Providence WWTF to one another and to the areas of most severe hypoxia, it is reasonable to conclude that on a unit loading basis, all sources cause equal environmental impacts. The Pawtuxet River discharges to Pawtuxet Cove, which then empties into the Providence River at the southern extent of the area of severe hypoxia. As a result, the impact of nutrient loadings from Pawtuxet Cove would qualitatively expected to be less than that those from sources to the edge of the Providence River or to the edge of the Seekonk River.

Loads from upstream WWTFs in the Pawtuxet, Blackstone and Ten Mile Rivers
WWTF loads to the tributary rivers were calculated using Discharge Monitoring Report (DMR) data collected May – October 1995-1996. Inorganic nitrogen data were not collected by the Upper Blackstone or Ten Mile facilities during that period. As a consequence, data collected for May through October 2000 - 2002 were used to represent the facility loads from the Upper Blackstone facility (UBWPAD) in Worcester, Attleborough and North Attleborough WWTFs.

Loads reaching the mouths of the rivers from the WWTFs were calculated in two ways for this analysis. The first approach assumed that the DIN load released from the facilities reached the mouth of each river with no loss or uptake in the river. This term was assumed to be representative of the case where either no denitrification was occurring, or where nitrogen was not accumulating annually in the bottom sediments of the river. The second approach assumed that some net uptake losses were occurring in the rivers. This loss term was calculated as a percentage of the combined plant load (other watershed sources, including smaller WWTFs in the upper Blackstone are assumed to be negligible), based on observed or estimated plant loads during the summer months of 1995 – 1996, and the loads observed leaving the mouths of the rivers. The ratios (load leaving river/load introduced by WWTFs) were 87%, 82%, and 60% for the Blackstone, Pawtuxet, and Ten Mile rivers, respectively.

A component of each plant's TN load was assumed to be refractory nitrogen. A refractory nitrogen concentration of 2.0 mg/l, the upper limit of the 0.5 to 2.0 mg/l range suggested in the literature (WEF and ASCE. 1992), was used as the mean difference between TN and DIN. The mean difference measured by DEM at Bucklin, Fields, and East Providence WWTFs during its 1995 – 1996 study was 1.4 mg/l. The DIN loadings from facilities in the tributary watersheds for each reduction scenario then equaled the product of the (TN-refractory N) concentration and plant flow. As an example, for the TN=5 case, the DIN load from a facility would be (3.0 mg/l) x (mean flow). For facilities not discharging directly to the Providence or Seekonk Rivers, and where river attenuation was assumed to occur, this load would be further reduced as described in the paragraph above. DIN loads from facilities directly on the Providence and Seekonk Rivers were calculated as the product of the (TN-refractory N) concentration and the mean flow.

Calculations were also made for the case in which projected loads were based on plant flows at 90% of their approved design flows. A comparison of WWTF data revealed that the average May-October 1995-1996 flows were 90% of the January-December 1995-1996 flows. WWTF design flows are listed in Table 4.

Table 4: Approved WWTF design flows and design flows used for the load evaluations.

WWTF Name	Approved Design Flow (MGD)	Estimated May-Oct Design Flow (MGD)
CRANSTON WWTF	20.2	18.18
EAST PROVIDENCE WWTF	10.4	9.36
NARRAGANSETT BAY COMM-BUCKLIN	31	27.9
NARRAGANSETT BAY COMM-FIELDS	65	58.5
WEST WARWICK WWTF	10.5	9.45
WARWICK WWT F	7.7	6.93
WOONSOCKET WWTF	16	14.4
UBWPAD	56	50.4
ATTLEBOROUGH WWTF	8.6	7.74
NORTH ATTLEBOROUGH WWTF	4.6	4.14

Base loads

Base nutrient loads from the Blackstone, Ten Mile, and Pawtuxet tributary rivers were calculated to establish a DIN concentration that would exist in the absence of wastewater treatment facilities. This minimum DIN concentration of 0.30 mg/l was derived from data collected in the north branch of the Pawtuxet River upstream of the WWTFs (Liberti, 1987). The base loads for each river were then calculated as the product of this concentration (0.30

mg/l) and the mean daily flow on the days samples were collected for the 95-96 TMDL study.. For the Blackstone River, the base load of 370 kg/day resulted from a mean discharge of 14.3 m3/s (discharge at Woonsocket scaled up to the value at the mouth). Estimated base loads calculated in a similar manner for the Ten Mile and Pawtuxet Rivers were 50 and 161 kg/day, respectively. These values were also used whenever the contributions from WWTFs reaching the mouths of the tributary rivers were less than the base loads.

Combining loads and areas

The impact of these loads on water quality in the area is a function of both the size of the loading and the size of the area, and would be expected to increase upriver from Conimicut Point to the head of the Seekonk River. Consistent with this idea, the study area was divided into the four sub-areas presented in Figure 3 of Chinman and Nixon (1985). Surface areas and sources are presented in Table 5. Each element receives loads from WWTFs and tributaries discharging to that reach, in addition to the loads to upstream reaches. For example, element 4 in the table receives loads from all sources in elements 1 through 3. The area reported below for element 4 includes the summed areas of elements 1 through 3. Loads entering each area from the Blackstone and Pawtuxet Rivers are quantified as outlined above.

Table 5: Summary of sources and receiving areas

Element Number	Element area (m2)	Sources included: (sources also contribute to downstream elements)
1	2.81E+06	Blackstone River, Bucklin Point WWTF, and Ten Mile River
2	5.81E+06	Fields Point WWTF, Woonasquatucket River, Moshassuck River
3	1.43E+07	Pawtuxet River, East Providence WWTF
4	2.41E+07	Providence and Seekonk Rivers

Results

Figure 19 shows observed or projected loads per unit area for each of the four elements of the Providence River as a function of concentration and flow case (described on the x-axis) for three scenarios. For this example, loads from WWTFs in the tributaries are attenuated prior to reaching the Providence and Seekonk Rivers. The leftmost group of bars represents the projected loading condition of each area with no treatment plants. The remaining groups represent the conditions for the period of 1995-1996, all plants at TN of 5 mg/l and design flows, and all plants at TN of 3 mg/l and design flows.

The figure shows that in the absence of the WWTFs listed in Table 4, loading conditions in the area will range from less that the 1X condition for the area as a whole to slightly less than 4X for the Seekonk river. The second group of bars shows the present loading condition. The following two groups of bars show conditions seen under the TN=5 and TN=3 scenarios and assumed design flow conditions. For the TN=3 case, the loads per unit area drop to under 5x in the Seekonk River and to slightly more than 1X for the area as a whole. Areas north of the Gaspee-Bullock line would receive loads equivalent to the 2X case under this condition. This scenario assumes that some fraction of WWTF loads to tributaries do not reach the

Providence and Seekonk Rivers. For the assumption of no river attenuation, the projected condition of the area is shown in Figure 20. Note that the TN=3 results are identical in Figures 19 and 20 because WWTF loads delivered to the mouths of the rivers dropped below the base load values, hence the base loads were used. As expected, the TN=3 case yield the lowest enrichment scenarios throughout the area. These enrichment levels would be considered to be essentially equivalent to the no-WWTF case. The load per unit area for the TN=5 mg/l case effectively doubles the loading index for each area.

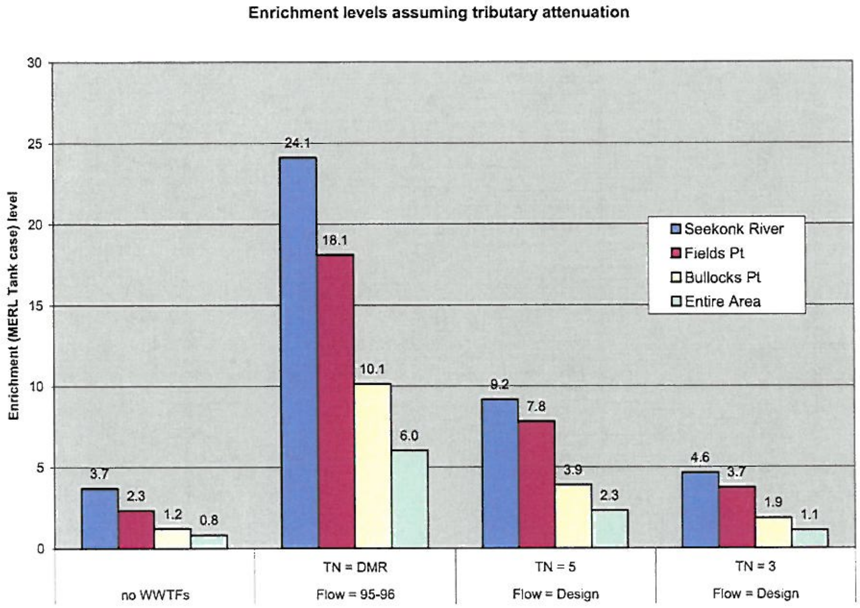

Figure 19: Summary of projected DIN loading rates to selected reaches of the Providence and Seekonk Rivers under four scenarios.

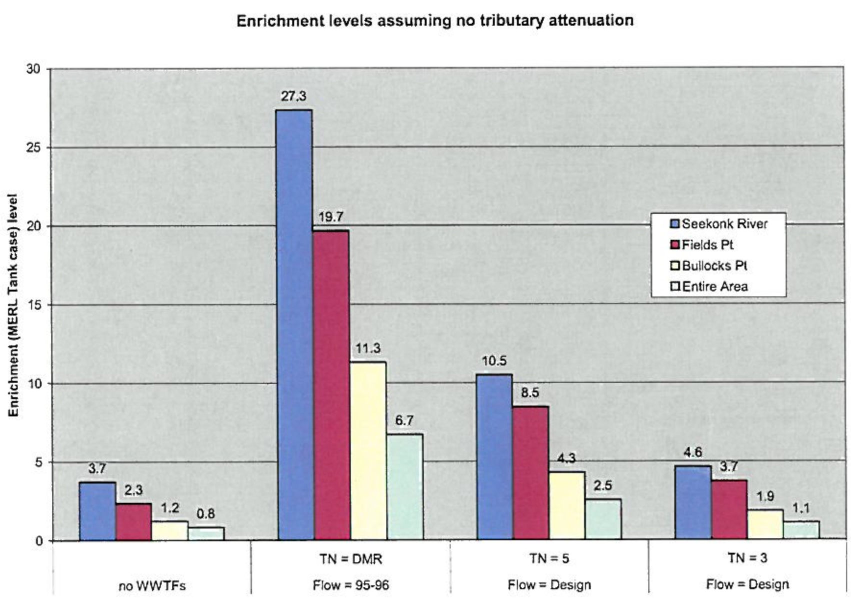

Figure 20: Summary of projected DIN loading rates to selected reaches of the Providence and Seekonk Rivers under four scenarios assuming no uptake of nitrogen along river.

WHAT GOALS SHOULD BE SET FOR THE AREA?

Table 2 in Rule 8.D of the Water Quality regulations (DEM, 1997) lists the dissolved oxygen standard for Rhode Island's Class SB marine waters:

SB waters:
Not less than 5 mg/l at any place or time, except as naturally occurs. Normal seasonal and diurnal variations which result in in situ concentrations above 5.0 mg/l not associated with cultural eutrophication will be maintained in accordance with the Antidegradation Implementation Policy.

Cultural eutrophication is defined as *the human-induced acceleration of primary productivity in a surface waterbody resulting in nuisance conditions of algal blooms and/or dense macrophytes.*

The regulations also contain a definition of low quality waters that states:

"Low quality waters" or "degraded" *means any water whose quality falls below any of the criteria of rule 8.D. in accordance with Applicable Conditions of rule 8.E. and corresponding to its classification as designated in rule 8.C., as determined by the Director, shall be considered degraded for that particular criterion and in violation of its water quality standards and, therefore, unsatisfactory for any designated uses which the Director determines are affected by the particular criterion which is violated. Waters in their natural hydraulic condition may fail to meet their assigned water quality criteria from time to time due to natural causes, without necessitating the modification of assigned water quality standard. Such waters will not be considered to be violating their water quality standards if violations of criteria are due solely to naturally occurring conditions unrelated to human activities.*

Rule 8.E mentioned above defines critical adverse conditions under which the standards apply; Rule 8.C categorizes water quality classifications.

Examination of Figure 4 shows that the water quality standard for DO cannot be met under any loading scenario, because DO minima for the three control tanks (containing un-enriched water from the mouth of Narragansett Bay) are all below 5 mg/L during the experiment. DO minima for the enriched tanks also drop further below the standard as the enrichment level increases. Although the numeric water quality standard of 5 mg/l is not met in the un-enriched tanks, they are not considered to violate the standard because of the "except as naturally occurs" clause in the standard – human activities do not contribute to an exceedence of the standard. The final sentence in the definition of low quality waters clarifies that levels below 5 mg/l are not considered a violation of standards if the violations are due "solely" to conditions "unrelated to human activities". The present regulations coupled with the analysis presented above indicate that, among other reduction actions, WWTF nitrogen contributions must be reduced to the limit of technology in the Providence and Seekonk Rivers.

EPA has issued revised guidance for DO standards in marine waters, and DEM is in the process of implementing the guidance into a revised standard for its marine waters. The revisions have not been finalized, but do allow excursions below a base value of 4.8 mg/l, down to approximately 3 mg/l for short periods of time. Although the new standards have not been established, a review of Figure 4 indicates that it is possible for the standard to be met under some of the lower enrichment cases. The regression equation in Figure 4 indicates that the DO minima for the 2X and 4X cases are 3.7 and 3.0 mg/l respectively. Under these conditions, it is possible for EPA's recommended new DO standard to be met. On the other hand, minima for the 8X and higher cases are less than 2 mg/l. The water quality standard could not be met under any of these conditions. DEM then could not propose loading allocations that were shown to meet the 8X or higher condition if lower levels could be achieved.

Referring back to Figures 19 and 20, one can see even for the projected "no WWTF" loading case, the enrichment status of the Seekonk and upper Providence Rivers varies from a high of 3.7X in the Seekonk River, down to 0.8 for the area as a whole. This "no WWTF" condition defines the best potential condition for the Providence-Seekonk River area. With WWTFs in the watershed reducing their loads to a level consistent with the limit of technology, where effluent TN is 3 mg/l, enrichment levels in the area would range from 1.1X – 4.7X. This scenario is arguably quite similar to the no-WWTF case. For the next higher (TN=5) case, levels in the upper Providence River and Seekonk River increase significantly to 8.0X above Fields Point and to 9.3X in the Seekonk River. These levels would not be acceptable as water quality goals for the area, based on the behavior observed in the MERL experiment.

The allowable plant loads are based on the estimated May – October design flows, and an effluent TN of 3 mg/l, of which 2.0 mg/l is assumed to be refractory (not DIN). These loads are listed by facility in Table 6.

Table 6: Plant TN allocations (at TN=3 mg/l and 90% design flow), and corresponding DIN loads used in this analysis.

Facility Name	TN load at TN=3 mg/l and 90% Design Flow (kg/day)	DIN load at TN=3 mg/l and 90% Design Flow (kg/day)
Cranston	206	69
East Providence	106	35
NBC - Bucklin Point	317	106
NBC Fields Point	664	221
West Warwick	107	36
Warwick	79	26
Woonsocket	164	55
Upper Blackstone, Worcester	572	191
Attleborough	88	29
North Attleborough	47	16