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HAND DELIVERED

February 7, 2005

Mr. Joseph B. Haberek, P.E.
Department of Environmental Management
Office of Water Resources, RIPDES Program
235 Promenade Street
Providence, RI 02908-5767

Dear Mr. Haberek:

This letter serves as the Narragansett Bay Commission's (NBC) response to the Rhode Island Pollutant Discharge Elimination System (RIPDES) permit modifications issued to the NBC on December 23, 2004. Pursuant to Chapter 42-17.4 of the Rhode Island General Laws, it is the NBC's intention to present these comments at the February 8, 2005 Public Hearing and enter these comments into the record.

As you are aware, the NBC is Rhode Island's largest wastewater authority and has a staff of approximately 250 individuals dedicated to providing reliable, cost-effective wastewater collection and treatment services to over 360,000 residents and 8,000 businesses in ten Rhode Island communities in the metropolitan Providence and Blackstone Valley areas. As the largest secondary wastewater treatment facility in Rhode Island and the second largest in New England, the Field's Point Wastewater Treatment Facility provides preliminary and primary treatment for up to 200 million gallons per day (MGD) of wastewater, and secondary treatment for up to 91 MGD. With new modifications scheduled to be completed by September 23, 2006, the Bucklin Point Wastewater Treatment Facility will provide preliminary and primary treatment for up to 116 MGD of wastewater, up from the current 60 MGD, and secondary treatment for up to 46 MGD.

The RIDEM has responded to public concern, state legislation, and Clean Water Act requirements and taken on the charge of developing a plan for addressing nutrient loading to Narragansett Bay. A major part of this plan involves implementing sweeping permit modifications for wastewater treatment facilities which will result in significantly more stringent nitrogen discharge limits. The Narragansett Bay Commission (NBC) is one of the agencies directly impacted by these permit modifications. The NBC is wholly committed to developing and implementing cost-effective projects that will further our efforts to improve water quality in Narragansett Bay and its tributary rivers. Improved water quality is a goal we continually strive towards in our daily operations and planning for the future. Our record clearly shows the NBC's proactive approach to improving and protecting the health of Narragansett Bay. In planning for the future, the NBC has executed, is putting into practice, and will continue to implement cost effective changes to continually improve the water quality of its receiving waters and the Bay as a whole. The NBC wishes to highlight the proactive measures it has taken to address the issue of nutrient loading in Narragansett Bay:

- In 1995, NBC began facility planning for the BPWWTF upgrade. Construction of the upgrade will be completed next year. NBC designed the facility to reduce total nitrogen by approximately 50%; our permit only mandated reduction of ammonia. In an effort to reduce nutrient levels, the NBC has expedited the nitrogen removal phase of the project so that we may have this portion of the project on line at least one year ahead of the compliance schedule.

- In 2000, NBC staff participated in a training program offered by RIDEM and the New England Interstate Environmental Training Center on nutrient optimization. This program resulted in wastewater testing and an evaluation which determined that Field's Point wastewater has insufficient carbon sources, and possibly alkalinity, to complete nitrification and denitrification, meaning chemical addition would be necessary. NBC continued these efforts by investigating how the current FPWWTF could be modified in the near-term, at limited cost to rate-payers, to improve nitrogen treatment until a TMDL is finished by the RIDEM.
- In January 2000, NBC received an Environmental Monitoring for Public Access and Community Tracking (EMPACT) grant from EPA to begin work with the late Dr. Dana Kester of URI/GSO for long-term monitoring of dissolved oxygen and the problem of hypoxia in the Providence and Seekonk Rivers. This work is continuing, well beyond the period of funding by EPA.
- In March 2001, NBC entered into a contract for facility planning at the FPWWTF for nitrogen removal at a cost of over $200,000. At that time RIDEM committed to continuing the TMDL process for nitrogen. An initial report in 2002 indicated that the treatment options ranged in capital cost from $13.5 million to $88.4 million plus annual operating costs between $1.1 million and $2.92 million, depending on final effluent permit limits for total nitrogen (TN) which were to be based on the results of RIDEM's TMDL study.
- In 2001 and 2002, NBC funded studies in the Providence and Seekonk Rivers which have led to these estuarine waters being removed from the state's 303(d) list for trace metals. Although high quality nutrient samples were collected by the Microinorganics, Inc. staff on multiple days, over complete tidal cycles, at multiple depths and transects, and the samples were analyzed by the MERL facility at URI/GSO, this data has not been utilized by RIDEM in their current evaluation.
- Beginning in April 2004, NBC conducted a pilot study of Hydroxyl Systems' IFAS (integrated fixed film activated sludge) nitrogen removal technology at NBC's FPWWTF to supplement NBC's facility planning.
- In October of 2004, NBC jointly funded work with the coastal physical oceanography lab led by Dr. Chris Kincaid of URI/GSO to further develop circulation and hydrodynamic modeling of the Providence and Seekonk Rivers and Upper Bay. A circulation model is needed for a successful nutrient TMDL. Earlier in 2004, RIDEM had reported that their TMDL modeling efforts had failed and that a TMDL for nutrients was not going to be delivered.
- In December 2004, NBC asked the director of the MERL facility to comment on the feasibility of repeating the MERL study of 1981–84, which is cited by RIDEM as the principal justification for the proposed nutrient limits. The 1981–84 study, while of significant value, is not an appropriate substitute for a TMDL as the experiments did not sufficiently duplicate the nitrogen loading to the bay in a number of respects. See attachment #1 for a critique of the 1981–84 MERL study and attachment #2 for a draft budget proposal from the MERL associate director to conduct an improved study with the MERL tanks.

As demonstrated above, the NBC has been proactive in determining the relevant causal relationships between its discharges and water quality issues in the Bay, as well as reducing the impacts that normal WWTF operations have on the receiving waters. Because we do not consider the results of the 1981 – 84 MERL tank studies to be an acceptable substitute for a TMDL to establish nitrogen effluent limits, NBC requests that RIDEM complete the federally required TMDL. Until a TMDL is complete, NBC is opposed to the proposed nitrogen permit modifications for the following reasons:

- Without a TMDL, the current phased approach lacks (a) clear, scientific justification, (b) a definite schedule or endpoint, and (c) a clear assessment plan to determine the need for future tighter restrictions.

- Nitrogen loading to Narragansett Bay is a regional, inter-state issue that needs a comprehensive plan, as was implemented in Long Island Sound. Such a plan cannot be developed without a working TMDL.
- Researchers at URI/GSO, including the late Dr. Dana Kester, were able to predict the hypoxic events that lead to the August 2003 fish-kill, based on water column stratification from warm temperatures and periods of minimal tidal amplitude, among other factors. New research is currently underway to investigate the role of nitrogen in these hypoxic events more fully. A joint project between the Narragansett Bay Estuary Program and GSO, sponsored by Sea Grant, is investigating the physical, biological, and chemical processes that lead to seasonal hypoxia in upper Narragansett Bay. The investigators include Dr. Mary-Lynn Dickson, Dr. David Ullman, Dr. David Hebert, and Dr. Chris Deacutis. The results of this research effort are needed to clarify the role of nutrients in these events along with a TMDL that can replicate the physical and chemical conditions observed in the Bay.
- Dr. Scott Nixon of URI/GSO has analyzed historical data and made recent measurements in 2003-04, determining that total nitrogen loading to the Bay has been essentially level in the past three decades (see Attachment #3). These findings emphasize the need for a TMDL to determine the appropriate relationship and relative importance of nutrient loading and climatic conditions to producing hypoxic conditions.
- As was mentioned by a number of presenters at the Sea Grant sponsored Nutrient Symposium in November 2004, NBC is concerned about the unanticipated effects of a dramatic nitrogen reduction on the Upper Bay. It will certainly reduce and change primary production, yet it may also have a detrimental effect on fisheries and shellfishing. Decreased primary productivity as a result of nutrient loading reductions has been linked to decreased secondary productivity in Tampa Bay, despite increases in water clarity, eelgrass coverage, and overall habitat quality (Workshop Proceedings, Galveston, TX).
- With multiple plant upgrades under construction, the total nitrogen loading to the Upper Bay will decrease by 20 – 35%, depending on the use of Dr. Nixon's or DEM's figures. This reduction is significant and should be monitored and assessed as part of completing a TMDL.
- Any attempt to nitrify and denitrify wastewater will result in extremely high operating costs to acquire additional, non-renewable resources such as chemicals (for alkalinity and carbon sources) and electricity. For the new Bucklin Point Facility upgrades, the additional electrical use alone is expected to cost our ratepayers $1,000,000/year more. Passing the higher operating and capital costs off to our ratepayers without benefit of scientific basis would be irresponsible.

"Nutrients are valuable resources with wide ranging potential impacts, some desirable, some not. Basic ecology and common sense dictate that we recognize this complexity." (Nixon, 2002). The NBC is in a prime position to make an impact on nutrient loadings to the Bay as one of the major point sources. However, we are reluctant to burden our ratepayers with additional increases without firm justification and investigation of the best solutions for this regional issue. For the reasons listed above, without a completed TMDL, NBC opposes the permit modifications. The development of a comprehensive plan to address this issue will only improve the widespread acceptance and effectiveness of its implementation. We are committed to reaching our mutual goal of improving water quality through scientifically based, logical solutions.

Thank you in advance for considering the concerns of the Narragansett Bay Commission in your evaluation of the proposed permit modifications. If I may provide any additional information pertaining to this issue, please do not hesitate to contact me at 461-8848.

Sincerely,

Paul Pinault, P.E.
Executive Director
Narragansett Bay Commission

Enclosure

Cc: Raymond Marshall, P.E.
Thomas Uva
Paul Nordstrom, P.E.
Thomas Brueckner, P.E.
Taylor Ellis
Jennifer Cragan
Catherine Walker
John Motta

References:

Christensen, V and C. Walters, Using Ecopath modeling for analysis and management of estuarine food webs, Workshop Proceedings, Galveston, TX, November 2004

Nixon, S.W. and B. Buckley. 2002. "A Strikingly Rich Zone" – Nutrient enrichment and secondary production in coastal marine ecosystems. *Estuaries* 25:782 – 786

Attachments:

1) NBC's Comments on RIDEM's "Evaluation of Nitrogen Targets and WWTF Load Reduction for the Providence and Seekonk Rivers"
2) Draft Budget Proposal from MERL Associate Director Candace Oviatt to Conduct a Revised MERL Tank Experiment
3) *Draft Report:* Anthropogenic Nutrient Inputs to Narragansett Bay: A Twenty-Five Year Perspective.

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# Attachment 1: NBC Comments on RIDEM's "Evaluation of Nitrogen Targets and WWTF Load Reduction for the Providence and Seekonk Rivers"

## Evaluation Report

RIDEM's efforts to establish a Total Maximum Daily Load (TMDL) for the Providence and Seekonk Rivers by means of a computerized model were unsuccessful because the mass transport portion of the model could not be successfully calibrated. The model was to be used to determine nitrogen loadings in the Providence and Seekonk Rivers necessary to achieve water quality standards for dissolved oxygen.

Instead of the TMDL, RIDEM prepared an analysis entitled "Evaluation of Nitrogen Targets and WWTF Load Reductions for the Providence and Seekonk Rivers" as the basis for the establishment of nitrogen loadings for the WWTFs. It is NBC's understanding that no further water quality modeling work is planned by RIDEM and that this report will serve as the basis of future decisions to be made by RIDEM with regard to allowable nitrogen limits from WWTFs. Therefore, NBC has conducted its review of this report as though it were the TMDL development document. with additional comments based on information provided by CH2M Hill and Associates', Dr. Jamie Maughan.

With this in mind, NBC has, as you suggested, closely reviewed the information and conclusions contained in the draft report, as well as the additional information provided by DEM in response to NBC's August 11, 2004 letter. Below, please find our comments and questions.

## Comments on the Proposed Permits

1. Basis for Limits

**We request the proposed limit for both the Field's Point and Bucklin Point WWTFs be changed to either a TN monthly load limit only or, if a concentration limit is also to be included, that it be 5 mg/l Total Biodegradable Nitrogen (i.e. TN minus refractory N).**

The Attachment A table of the draft RIDEM nutrient permit modifications includes a requirement to meet a monthly load limit of 1293 lbs/day (Bucklin Pont) and 2711 lbs/day (Fields Point) as well as a concurrent concentration limit of 5 mg/l TN. We believe that a monthly load limit without a concentration limit would be a more reasonable approach given the variability in flow and influent strength (particularly associated with wet weather) at both facilities.

In establishing the 5 mg/l TN permit limit, RIDEM has assumed that 1.95mg/l is refractory N. RIDEM also claimed in its 12/23/2004 letter that the average value for effluent organic nitrogen is 1.4 mg/L, while the data for 1995 and 1996 are 2.3 ± 3.8 ppm organic nitrogen for Bucklin Point and 2.1 ± 1.8 ppm for Field's Point (calculated as TKN minus ammonia). Due to improvements in the analytical methods used as well as operational improvements, both Field's Point and Bucklin Point effluent organic nitrogen data for 2004, which are thought to be more reliable, show an organic nitrogen component of 3.6 and 3.2 ppm for Field's Point and Bucklin Point respectively, with significant variability. RIDEM's loading estimations assume a 1.95 mg/l organic nitrogen component for WWTFs where data was not available to make this calculation. This value does not accurate represent WWTF effluent for a facility with secondary treatment, and does not support the calculations that DEM has made. DEM's DIN loading calculations are perhaps 20% greater than what is actually observed, and the literature value used is inappropriate to secondary treatment WWTFs. We reiterate our request for a TN monthly load limit only or, if a concentration limit is also to be included that it be 5 mg/l Total Biodegradable Nitrogen.

For the BPWWTF, we are now constructing an upgrade to this facility for BNR that is expected to go on-line no later than September 2006. The facility was designed to attain 5 mg/l DIN April – December. It will likely not meet the proposed 5 mg/l TN limit. If the proposed permit limit is not changed, NBC will be unable to comply with the new limit and will have to make further improvements to its Biological Nitrogen Reduction (BNR) facilities and changes to its operating budget. Since RIDEM is implementing a "phased approach to BNR", we propose that the facility be operated for one year to determine its performance and impact on receiving waters. The need for a lower nitrogen limit can then be discussed with RIDEM after these data have been evaluated. In the interim, we reiterate our request for a TN monthly load limit only or, if a concentration limit is also to be included that it be 5 mg/l Total Biodegradable Nitrogen.

2. Wet Weather Limits

**The NBC is requesting that consideration be given to providing a higher concentration limit during wet weather events.**

Maximizing wet weather flow treatment and simultaneously minimizing effluent nitrogen loads can be competing goals and provisions should be made in the permit to acknowledge different limits during wet weather events. US EPA Region I (New England) has acknowledged this issue and issued "two tiered" permit limits to account for wet weather events in many locations including, New Haven, CT, Bangor ME, and Boston MA. New York City, in Region II, has similar accommodations for wet weather in their permits, as does Ohio, in Region V.

3. Application of MERL Data

It has not been clearly established that surface area nutrient loading is the causative factor, and not concentration, for low dissolved $O_2$ in the Upper Bay. The RIDEM nitrogen evaluation is based on MERL nutrient addition experiments, which have merit but also potentially significant limitations. Specifically, our greatest concern is primary reliance on nitrogen loading rates based on surface area rather than volume (i.e. $kg/m^2/day$ rather than concentration in receiving water). As acknowledged in the document, (on page 12 and other locations) there is significantly greater flushing rate, and therefore dilution, in the Providence and Seekonk Rivers than in the MERL tanks, thus the nitrogen concentration in the rivers is significantly lower than in the MERL tanks given the same loading rate.

The algae, which produce the immediate response to nitrogen, are responsive to nitrogen concentrations, not loading rates, thus concentration is the critical factor. RIDEM acknowledges the importance of concentration on page 1 with the following statement:

> "Our inability to adequately validate the mass transport model also prevents us from …… setting load allocations that uses ambient total nitrogen concentration as the indicator, …. "

The document continues and addresses effluent limits based on MERL experiments surface area loading rates. Yet the MERL experiments do give ambient total nitrogen concentrations for all treatments. Thus, as originally envisioned by the TMDL modeling effort, the nitrogen concentration, and not the loading rate should be the primary parameter of concern. Since the document makes a strong case that conditions between the MERL 2X and 4X treatments are acceptable, the nitrogen concentrations in these treatments should be an integral part of establishing effluent limits. As shown in the attached Figure 1, current nitrogen concentration conditions in the Providence River are only slightly above concentrations measured within the range of the 2X and 4X treatments. This is also confirmed in Table 3 of RIDEM's document which shows DIN concentrations in the Providence River at or below 0.4 mg/l DIN, which is comparable to the 4X treatment in the MERL experiments (Figure 11 of RIDEM's document).

The report should clearly note that, as illustrated in Figures 1 and 2, DO values in the 1X and 2X treatments do not differ noticeably from control treatments. DO in the 4X treatment differs from controls only in August, and then by generally less than 1 mg/l. Similarly, the regression analysis (Figure 4) shows a poor relationship with DIN loading in the 1X, 2X, and 4X treatments (e.g. 1X shows a lower predicted DO then 2X or 4X). However at loading rates above the 4X treatment the relationship is strong and DO condition in treatments higher than 4X clearly present a problem. The chlorophyll, Figures 7 and 8, show a similar pattern, except the 4X treatment support noticeably higher chlorophyll concentrations than controls. Figure 12 is extremely misleading and should not be presented without qualification. As noted on Page 12, the flow through and resulting retention times in the Providence and Seekonk rivers is an order of magnitude different from the MERL tanks. Thus a comparison based on surface area loading rates is incorrect. As noted above, the comparison should be made based on DIN concentrations, and the Providence River concentrations are similar to the 2X to 4X treatments. The statement at the bottom of page 12 addressing using MERL data to establish limits, ("We feel, however, that the other relationships make the connection adequate") is incorrect for surface area loading, but as discussed above may be correct for DIN concentrations.

On Pace 25, the statement "Experimental data indicated the 2X and 4X conditions (loading rates given on a per $m^2$ basis) are the likely goal from the perspective of consistency with the State's water quality standards", should be changed to reference nitrogen concentrations rather than loading rates on a per $m^2$ for the reasons given above.

Thus, RIDEM's evaluation should clearly state that the appropriate comparison to the MERL experiments is the concentration of nitrogen and not the loading rate per surface area. Thus the target for establishing effluent limits should be on the nitrogen concentration and not loading rate. The conclusion that loading rates based on surface area are appropriate is challenged by NBC. Nutrient concentrations can be met in a phased approach, but surface area loading rates can never be met and should be significantly qualified in the final version of the Nitrogen Evaluation.

## 4. Forms of Nitrogen

The report is unclear and poorly documented in the treatment of the forms of nitrogen. All of the MERL data, which as indicated above is the basis for establishing limits, is presented as dissolved inorganic nitrogen (DIN). Yet the conclusions of RIDEM's evaluation are in total nitrogen (TN). There is general reference to approximately 2 mg/l of TN as refractory and presumably dissolved organic nitrogen. However this generalization may not apply to NBC's effluent and/or may vary significantly at various times. During facilities planning there should be an opportunity to evaluate the forms of the effluent nitrogen and make scientifically justified modifications to the form(s) of nitrogen specified in the permit. DEM's statement that the average value of TN – DIN of 2 mg/l is equivalent, or slightly higher, than what is observed for the Bucklin Point and Field's Point facilities is inaccurate. A review of our relevant plant data from 1995 – 1996, when compared with data and calculations DEM supplied in response to NBC's request, shows that average organic nitrogen is higher than 1.95 mg/l, with a large standard deviation. A review of 2004 effluent data from both facilities, as mentioned previously, indicate an organic nitrogen component that is approximately twice the value DEM has used in its calculations.

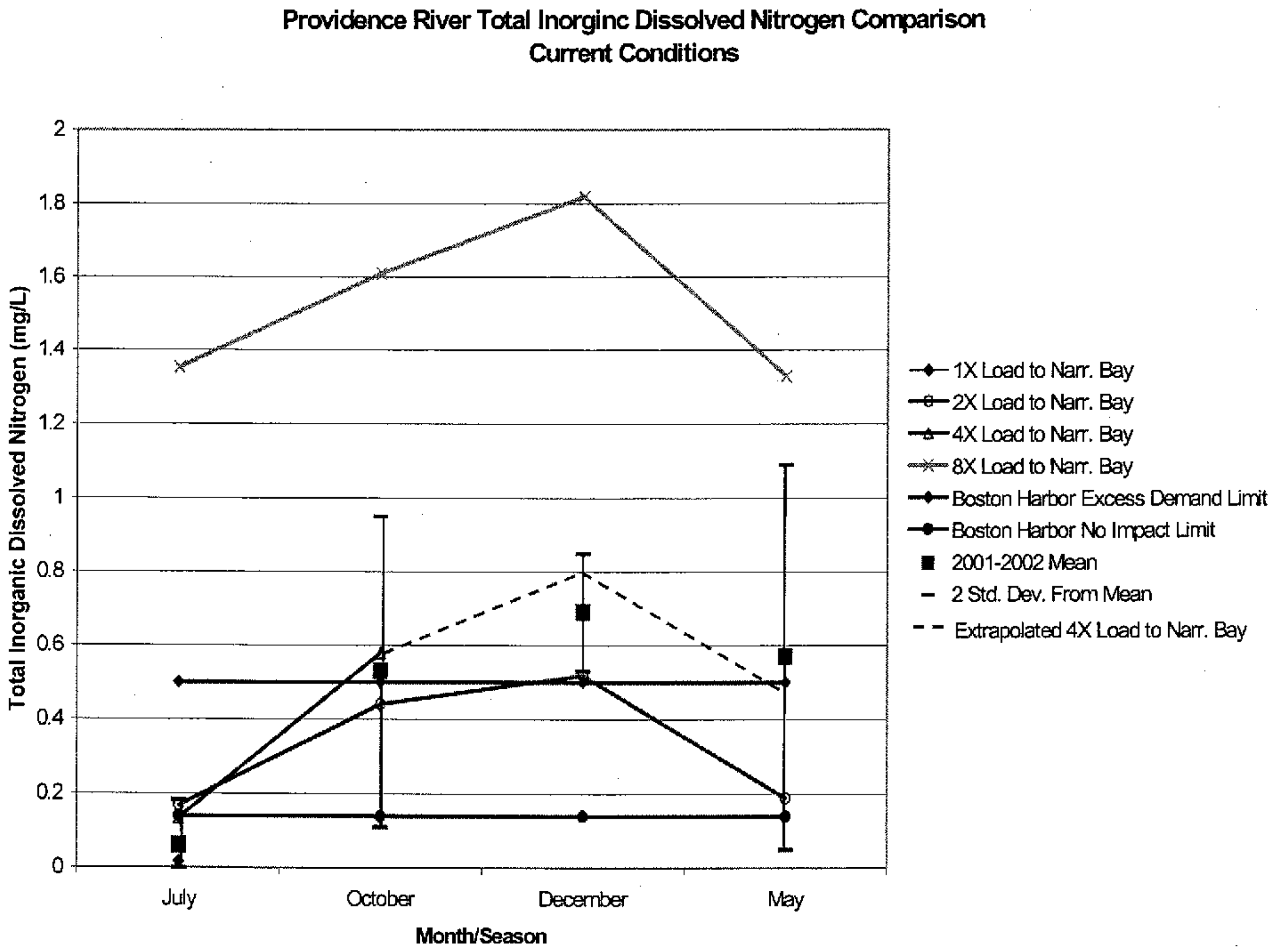
## 5. Estimated Costs

The cost table accompanying RIDEM's communication indicates a capital cost of $13.9 MM to reach a seasonal limit of 5 mg/l nitrogen. However, the cost of meeting a seasonal 5 mg/l total nitrogen effluent limit from the Fields Point WWTF is estimated to be $20 MM capital cost. This capital cost estimate includes a necessary methanol building within the concept plan. Operating costs must be considered as well.

## 6. General Permit Conditions

As part of the Phased Implementation approach, the permit should include provisions for technically justified modification during the Facilities Planning process as long as the overall objectives are maintained. With so much uncertainty associated with establishing limits (as discussed above) and the variables of winter limits, wet weather conditions, and combined effects of Bucklin and Fields Points plants there should be opportunities to achieve maximum water quality value for every dollar spent. This could be achieved during the facilities planning process.

Figure 1


Providence River Total Inorginc Dissolved Nitrogen Comparison
Current Conditions
Total Inorganic Dissolved Nitrogen (mg/L)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
July
October
December
May
Month/Season
1X Load to Narr. Bay
2X Load to Narr. Bay
4X Load to Narr. Bay
8X Load to Narr. Bay
Boston Harbor Excess Demand Limit
Boston Harbor No Impact Limit
2001-2002 Mean
2 Std. Dev. From Mean
Extrapolated 4X Load to Narr. Bay

In summary, NBC takes this matter very seriously and has expended a lot of time and money evaluating the information that you submitted to us, undertaking facilities planning and conducting a pilot study of the fluidized bed system for the FPWWTF, and designing and constructing the BPWWTF to provide nitrogen removal before this was a permit requirement.

We are ready to do our part to reduce nutrient loads to the Providence and Seekonk Rivers as long as we have a sound scientific basis to do so, in order to spend the ratepayer's funds wisely. We look forward to meeting with you to resolve these issues so we can expedite this matter and move forward with our mutual goal of improving water quality in Narragansett Bay.

# Attachment 2: Draft Budget Proposal from MERL Associate Director Candace Oviatt to Conduct a Revised MERL Tank Experiment

Summer MERL experiment - 4 months

| | FY1 | |
|---|---|---|
| Personnel | | |
| Operations Coordinator | 70,000 | |
| Operations Technician | 35,000 | |
| MRS Phyto | 50,000 | |
| MRS Zoopl | 50,000 | |
| MRS Modeling | 50,000 | |
| GRS Benthos | 24,000 | |
| GRS Nutrients | 24,000 | |
| GRS Plankton | 24,000 | |
| UGS operations | 12,000 | |
| Data management | 30,000 | |
| fringe | 28000 | |
| | 14000 | |
| | 20000 | |
| | 20000 | |
| | 12000 | |
| | 20000 | |
| Health&fica | 2400 | |
| | 2400 | |
| | 2400 | |
| | 850 | |
| | | 491,050 |
| Equipment | | |
| hoist & electrical track | 15,000 | |
| mixing motors | 6100 | |
| spare pump | 9000 | |
| System Controls | 60,000 | |
| monitoring instru. | 150,000 | |
| Autoanalyzer | 75,000 | |
| | | 315,100 |
| Repairs | | |
| Temperature control | 17,000 | |
| Plumbing | 12,000 | |
| Electrical | 2,000 | |
| Painting, carpentry | 20,000 | |
| | | 51,000 |
| Supplies | | |
| Facility | 50,000 | |
| Laboratory | 25,000 | |
| Travel | 11,000 | |
| Sediment Recovery | 12,000 | |
| | | 98,000 |
| Tuition | 42,600 | 42,600 |
| Indirect costs @ 25% | | 160013 |
| Total | | 1,157,763 |

# Attachment 3: *Draft Report:* Anthropogenic Nutrient Inputs to Narragansett Bay: A Twenty-five Year Perspective

A Report to
The Narragansett Bay Commission
and
Rhode Island Sea Grant

February 2005

Scott Nixon, Betty Buckley, Stephen Granger, Lora Harris, Autumn Oczkowski, Luke Cole, and Robinson Fulweiler

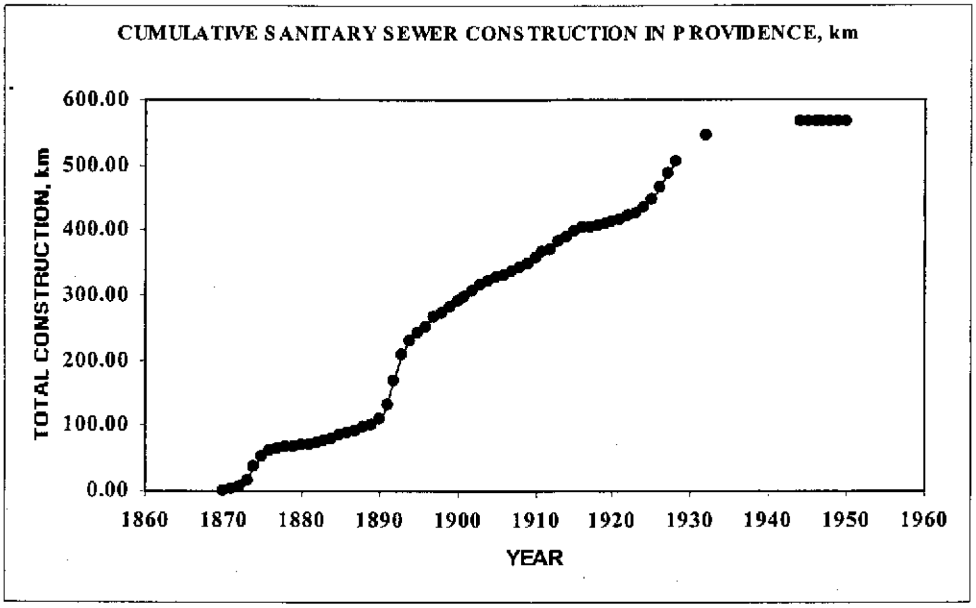
Graduate School of Oceanography
University of Rhode Island
Narragansett, RI 02882

# INTRODUCTION

Increasing amounts of nitrogen, phosphorus, and other anthropogenic materials began to enter Narragansett Bay as an unintended consequence of the introduction of a public water supply to the city of Providence in 1871. While the availability of clean running water was a great contribution to public health and fire safety, it brought with it the rapid spread of flush toilets and the "water carriage" system of waste disposal for human sewage (Tarr 1996). Nixon (1995) has described the development of the Providence sewer system, especially with respect to the history of metal pollution in Narragansett Bay, and the story is similar in many ways for the history of nutrient inputs to the bay. The sewer system first used numerous small outlets in the Seekonk and upper Providence River estuaries, but it was expanded and integrated during the 1870's and 1880's. By late in 1892, interceptor sewers began carrying sewage from the city to Fields Point on the Providence River estuary for discharge, and the system expanded rapidly during the next decade. The sewage effluent was treated for the first time using simple precipitation in 1901. Treatment produced large volumes of sludge which were first dewatered and used as fill on the site. By 1908, this option had been exhausted and the sludge was dumped in Narragansett Bay in deep water below Prudence Island. This practice continued until 1949 when the city began to incinerate the sludge (Nixon 1995). Virtually all of the sewage from the city of Providence was being captured by the sewer system by the 1930's and the numbers of people served has remained relatively stable since that time (Fig. 1).

The development of water and sewer systems in Providence was soon mirrored in the other dense urban areas around the Seekonk and Providence River estuaries and in the city of Fall River on Mt. Hope Bay. The number of people served by sewer systems in the urban shoreline cities and towns that discharge directly to Narragansett Bay rose steadily from 1870 until about 1950, and has remained relatively constant since then (Fig. 2). The now large urban areas on the Pawtuxet River only began sewer construction around the middle of the last century, but the numbers of people served by those systems (Cranston, Warwick, West Warwick) have increased only modestly since the 1970's (Fig. 2).

While regular measurements of different forms of nitrogen were made in raw and treated sewage effluents during the early decades of the Fields Pt. treatment plant, the reporting of the measurements in the Annual Reports of the City Engineer ceased during the 1930's. Even during the period when measurements were reported, there is some uncertainty in the values given for organic nitrogen (and thus total nitrogen) because of analytical difficulties (Hamlin 1990) and phosphorus was not normally measured. As far as we are aware, the first systematic monitoring using modern chemical methods of all of the forms of nitrogen and phosphorus released by the largest three treatment plants that discharge directly to Narragansett Bay was carried out approximately monthly over an annual cycle by our laboratory beginning in December, 1975. Bi weekly sampling over an annual cycle of the final effluent from Fields Pt., Bucklin Pt., and the East Providence treatment plants was repeated in 1983 and 1992. By 2002-03, regular monitoring by the treatment plants themselves of all


CUMULATIVE SANITARY SEWER CONSTRUCTION IN PROVIDENCE, km
TOTAL CONSTRUCTION, km
600.00
500.00
400.00
300.00
200.00
100.00
0.00
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
YEAR

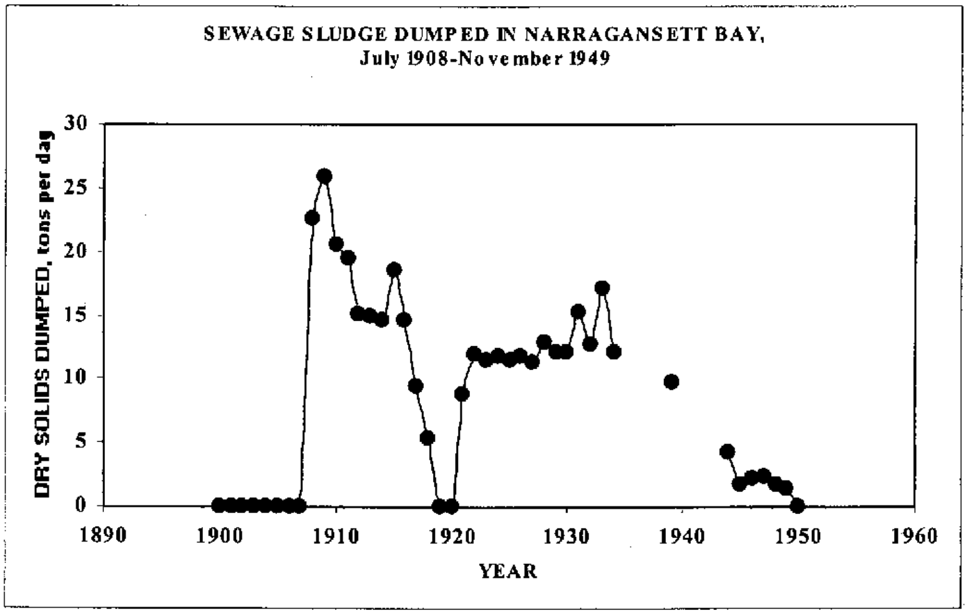

SEWAGE SLUDGE DUMPED IN NARRAGANSETT BAY,
July 1908-November 1949
DRY SOLIDS DUMPED, tons per day
30
25
20
15
10
5
0
1890
1900
1910
1920
1930
1940
1950
1960
YEAR

Figure 1.

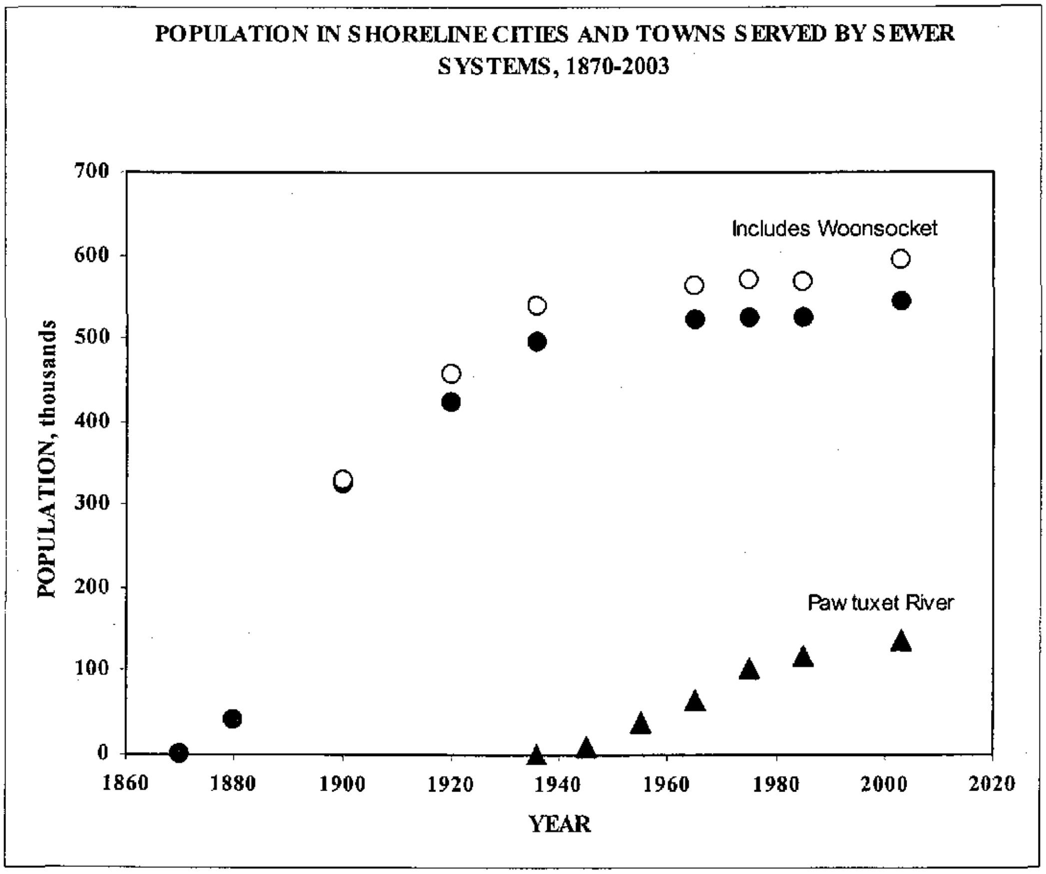

POPULATION IN SHORELINE CITIES AND TOWNS SERVED BY SEWER SYSTEMS, 1870-2003
POPULATION, thousands
700
600
500
400
300
200
100
0
1860
1880
1900
1920
1940
1960
1980
2000
2020
YEAR
Includes Woonsocket
Pawtuxet River

Figure 2.

forms of nitrogen and of total phosphorus had been implemented at the three larger plants as well as at the Fall River treatment plant and at many of the smaller treatment plants that discharge directly to the bay and in the bay watershed.

Our effluent analyses during 1975, 1983, and 1992 were supported by the Rhode Island Sea Grant Program. The Fall River treatment plant and the smaller treatment plants discharging directly to the bay (East Greenwich, Quonset, Warren, Bristol, Newport, and Jamestown) were sampled seasonally for total nitrogen and total phosphorus as part of the Narragansett Bay project in 1985-86 (Pilson and Hunt 1989), so that there is at least some basis for comparing their current operation with earlier nutrient release estimates (Nixon et al. 1995).

While the population served by sewage treatment plants that discharge directly to the bay has remained relatively stable during the past thirty years, the total population in the Narragansett Bay watershed has been increasing almost linearly since the mid 1800's (Fig. 3). Assessing the input of nutrients to the bay from the sewered and unsewered population in the watershed is more difficult. The most practical approach is to measure the amount of nitrogen and phosphorus in the larger rivers just before they enter the bay. Such measurements capture not only the nutrients released by the human population but also the nutrients put into the bay from all other sources in the watershed, including fertilizer, animal waste, and atmospheric deposition. Equally important, measurements at or close to the point of entry into the bay also reflect the processes in the watershed that attenuate the nutrients between their point of release in the watershed and their point of entry into the bay. For example, phosphorus adheres strongly to soils and nitrogen may be sequestered in soils or biomass or removed through denitrification in wetlands and in stream or river beds. It is not uncommon for these processes to account for half or more of the total nutrient input to a watershed (Howarth et al. 1996, Boyer et al. 2002, Seitzinger et al. 2002, Fulweiler 2003).

Our laboratory measured the concentrations of all forms of dissolved and particulate nitrogen and phosphorus in the Blackstone and Pawtuxet Rivers just before they discharge to Narragansett Bay between December 1975 and November 1976. We repeated these measurements again in 1983 and added the Woonasquatucket and Moshassuck Rivers. With the assistance of volunteer water sampling by employees of Citizens Bank and partial support from the Citizens Charitable Foundation, we analyzed concentrations in all four rivers over an annual cycle again in 1991 and 1992 (Kerr 1992). Our most recent survey was carried out between March 2003 and March 2004 and included the Ten Mile River. All of the river sampling and analyses were supported by the Rhode Island Sea Grant Program and the last was jointly supported by The Narragansett Bay Commission. Details of the sampling locations are given in Fig.4, and the analytical methods are summarized in Table 1. Of course, the concentration measurements alone will not give the flux of nutrients into the bay. For that calculation we relied on measurements of water discharge obtained by the U.S. Geological Survey (USGS). Since the USGS measurements are made somewhat upstream from our sampling points, we increased the reported water discharge by the ratio of total watershed area to gauged area (Pilson 1985, Ries 1990). In the case of the Ten Mile River, no water discharge measurements were available during our sampling period. However, we were able to

**Table 1: Analytical methods used in this study.**

| Parameter | Method Reference | Detection Limit |
|---|---|---|
| Ammonium | USEPA Method 365.3<br>Grasshoff (1976) | 0.07 µM |
| Nitrite + Nitrate | USEPA Method 353.2<br>Grasshoff (1976) | 0.02 µM |
| Total Nitrogen | Valderrama (1981) | 0.02 µM |
| Particulate Nitrogen | Hauck (1982)<br>Kirsten (1983) | < 0.03 µM |
| Orthophospate | USEPA Method 365.5<br>Grasshoff (1976) | 0.01 µM |
| Total Phosphorus | Valderrama (1981) | 0.01 µM |
| Particulate Phosphorus | Solaranzo and Sharp (1980) | 0.10 µM |

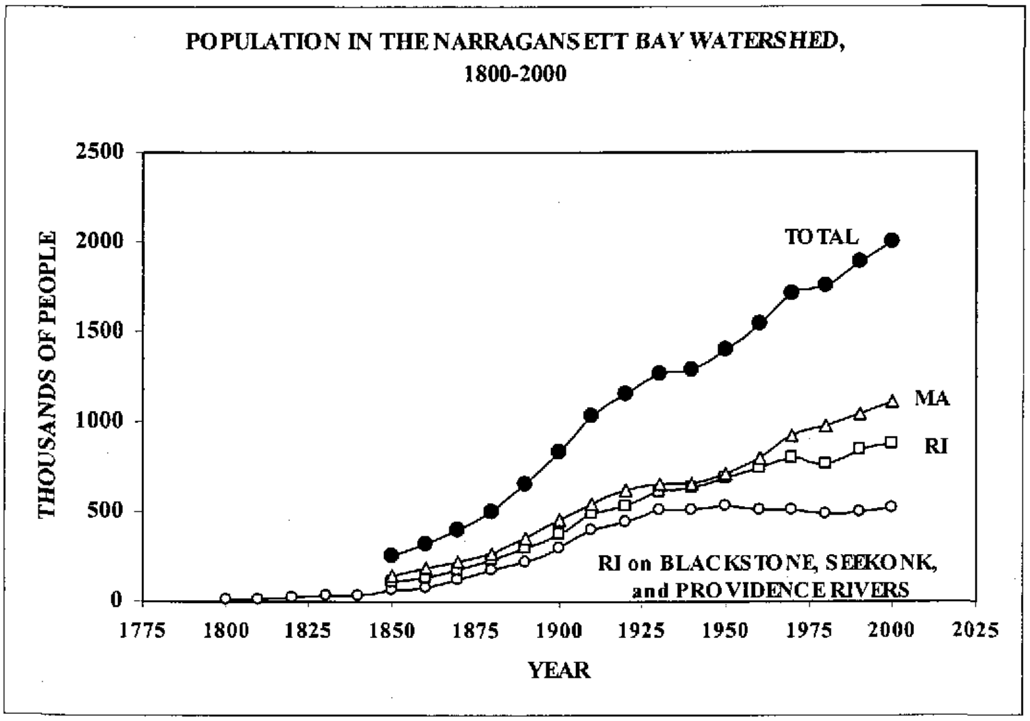

POPULATION IN THE NARRAGANSETT BAY WATERSHED, 1800-2000
THOUSANDS OF PEOPLE
2500
2000
1500
1000
500
0
1775
1800
1825
1850
1875
1900
1925
1950
1975
2000
2025
YEAR
TOTAL
MA
RI
RI on BLACKSTONE, SEEKONK, and PROVIDENCE RIVERS

Figure 3.

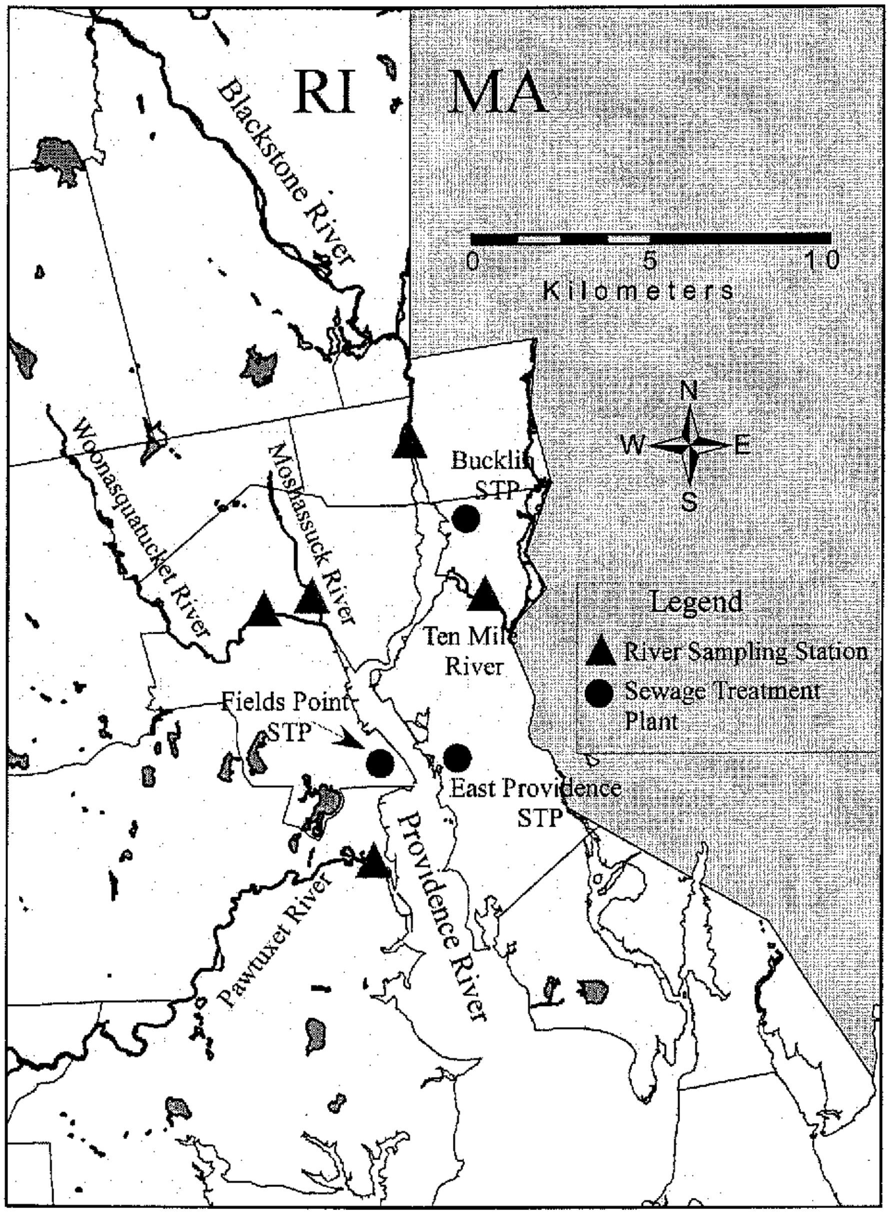


Figure 4. The Providence and Seekonk River estuaries, Narragansett Bay, Rhode Island showing river and sewage treatment plant sampling locations. Blackstone River samples were collected in Pawtucket, RI approximately 50 meters upstream of the Slater Mill Dam. Pawtuxet River samples were collected approximately 100 meters upstream of Pawtuxet Cove. Moshassuck River samples were collected from a small wooden foot bridge behind Moshassuck Square Apartments, 73B Charles St, Providence. Woonasquatucket River water samples were collected from the Acorn Street bridge (Bridge # 705) located between Promenade and Acorn Street, Providence. Ten Mile River samples were collected from a traffic bridge on Roger Williams Avenue, East Providence, RI., approximately 250 meters east of Omega Pond. Sewage Treatment samples were collected from the plants effluent stream just before chlorination and discharge.

correlate the discharge of the Ten Mile when it was measured from 1983 through 2003 with the measured discharge of the Blackstone River during that period (log Ten Mile discharge, $m^3 d^{-1}$ = 0.83 log *Blackstone discharge + 0.23 , $R^2 = 0.87$ ). We used this regression to estimate discharge from the Ten Mile during the recent study based on measurements reported by USGS for the Blackstone River. The daily nutrient flux calculations were used to estimate annual fluxes in each river using Beale's unbiased estimator (Beale 1962, Dolan et al. 1981).This estimator provides a flow-weighted annual flux from a set of instantaneous flux measurements that are skewed and/or not normally distributed (Richards 1999), two features that are characteristic of discrete river sample data sets. The times of water sampling along the annual hydrograph of each river during the 2003-2004 study are shown in Fig.5 and document the wide range of flow conditions that were sampled.

The purpose of this report is to provide a comparison of the nitrogen and phosphorus inputs to Narragansett Bay from direct sewage treatment plant discharges in the mid 1970's, the mid 1980's, and in 2002/2003, and to report the results of the most recent river nutrient flux measurements. We also provide a summary of nutrient fluxes from our earlier river studies and a statistical comparison of river fluxes of total nitrogen and phosphorus from the Blackstone, Pawtuxet, Woonasquatucket, and Moshassuck Rivers to Narragansett Bay over the period of record. A more extensive compilation of the 2002/03 river data will follow as a technical report. The data from the mid 1980's have been published previously as part of comprehensive nutrient budgets for the bay (Nixon et al. 1995). Nutrient concentrations in the Taunton River, which enters Narragansett Bay through Mt. Hope Bay, were measured in 1988-89 by Boucher (1991). We calculated annual fluxes from her data. In the 1980's, the flux of total nitrogen in the Taunton was about 90% of what we calculated for the Blackstone and the flux of total phosphorus was the same in both rivers (Nixon et al. 1995). A nutrient monitoring program in the Taunton has recently been initiated (Brian Howes, University of Massachusetts, Dartmouth, personal communication).

The three sewage treatment plants for which we have the longest record account for over 80% of the sewage discharged directly to Narragansett Bay. The Blackstone and Pawtuxet Rivers (for which we have the longest record) together account for about 36% of the long-term mean surface fresh water inflow to the bay, with the Woonasquatucket and Moshassuck adding another 4% and the Ten Mile accounting for just over 3% (Ries 1990). Taken together, various small streams and coastal drainage add a significant amount of fresh water to the bay, but they may be relatively less important as sources of nitrogen and phosphorus since none receives sewage treatment plant discharges. Direct flow of ground water to Narragansett Bay is not thought to be large, though it may be conspicuous in some coves (e.g. Urish and Gomez 2004). A simple comparison of the annual volume of rainfall on the area of the entire Narragansett Bay watershed between 1964 and 2000 compared with the gauged surface flow corrected for ungauged area during the same period suggests that only about 46 to 55 cm of the rainfall is unaccounted for each year, an amount in general agreement with the rates of evapotranspiration in this part of the U.S. (Michael Pilson, University of Rhode Island, personal communication).

While we cannot claim to have a complete inventory of nitrogen and phosphorus inputs to Narragansett Bay at any time, we believe that the data presented herein

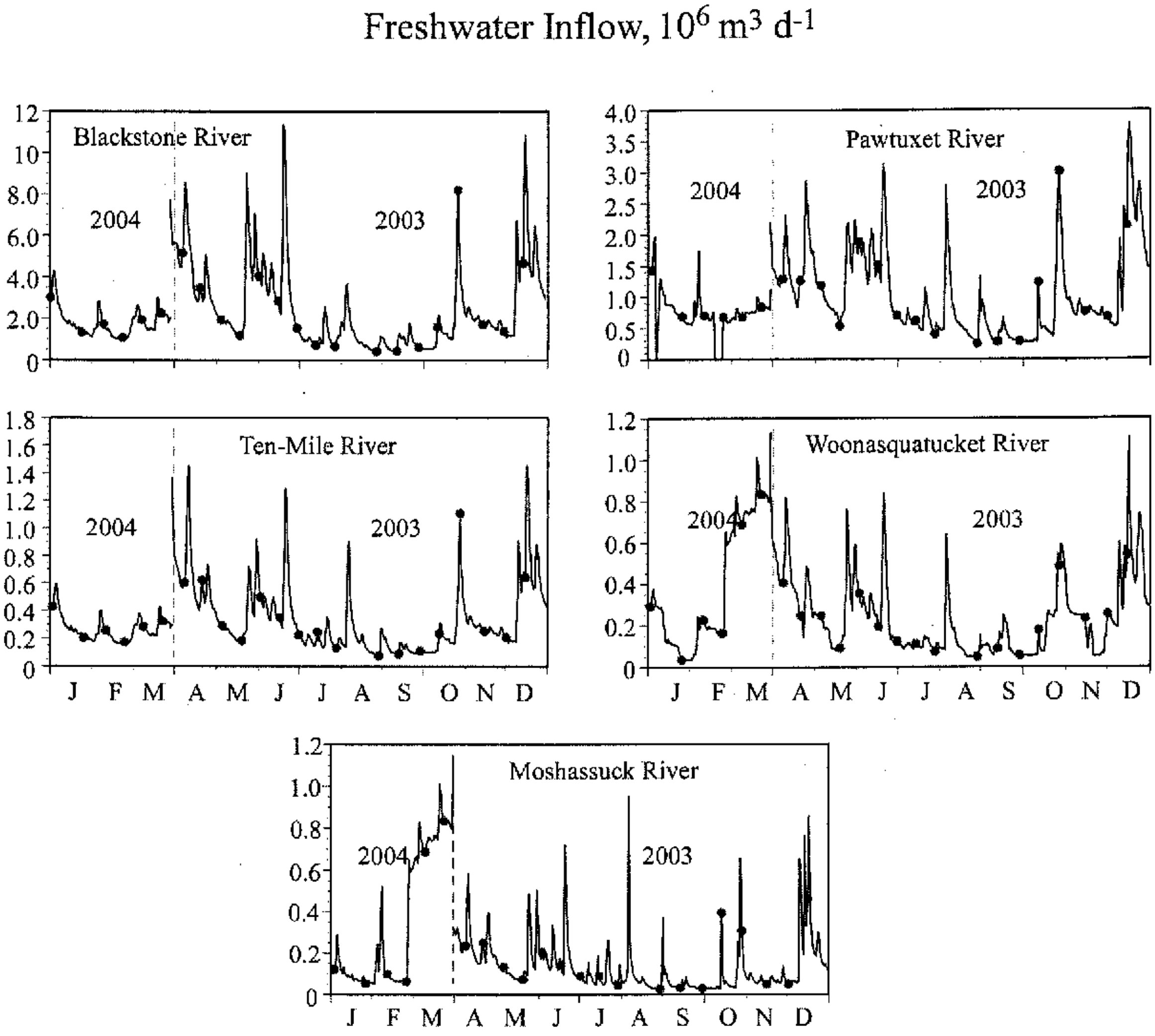


Figure 5. Hydrographs for various rivers sampled during 2003 and 2004, with freshwater flow expressed in millions of cubic meters per day. Sample days are indicated as solid circles and are superimposed over the flow history for each river. Note the highly variable river flow and range of flow conditions sampled during the surveys.

capture the major pathways by which nitrogen and phosphorus enter the bay and that they provide useful evidence for evaluating the approximate magnitude of those inputs at various points during recent decades.

## RESULTS

### Sewage Treatment Plants

#### *Nitrogen*

Comparison of the effluent analyses from the three largest treatment plants discharging to upper Narragansett Bay made in 1976-77 with those reported for 2002-03 shows little, if any, change in the aggregate amount of total nitrogen being released from these sources over the past quarter century (Table 2). The apparent increase in the volume of effluent and total nitrogen discharge from the Bucklin Point and the East Providence plants between 1976-77 and the remaining study years may be an artifact of the small sample size (N=9-10 days per year in the first study) or reflect decreased bypassing of effluent with improving plant operations. Comparing the more robust 1983 data set with the 2003 data suggests that declines in total nitrogen discharged from the Fields Pt. plant have approximately balanced increases in total nitrogen discharged from the Bucklin Pt. plant during the past twenty years. Total nitrogen discharge from the East Providence plant appears virtually unchanged. The evidence from the remaining sewage treatment plants that discharge directly to the bay, as well as from the Fall River plant, also suggests that there has been no significant increase in total nitrogen discharged from these sources since the mid 1980's (Table 3).

The more detailed analyses of the nitrogen being released from the three larger upper bay plants document significant changes in the form of nitrogen in the effluents that may have been important in terms of their ecological impact in Narragansett Bay. While about 60% of the nitrogen was in organic form in the mid 1970's, this fraction accounted for only 13% and 24% of the total nitrogen in 2002 and 2003, respectively (Table 4). We do not believe that this difference is due to differences in analytical technique because an intercalibration between our laboratory and the Narragansett Bay Commission laboratory carried out in September and November 2004 showed excellent agreement on all forms of nitrogen in final effluents from both the Field's Pt. and Bucklin Pt. facilities. It is also important to emphasize that our own analyses showed that the change had taken place by the early 1980's (Table 4), so whatever the ecological impact may have been, it has been manifest in the bay for at least twenty years. While the shift from organic to inorganic nitrogen obviously involved compounds that were biologically accessible, we do not know their rate of mineralization under field conditions or where in the bay the nitrogen they contained would have been made available to support the growth of phytoplankton and macroalgae. It would be a great irony if the improvement of secondary treatment in the plants contributed to increased discharges of readily available inorganic nitrogen that shifted algal blooms to the upper bay where vertical mixing of the water column is less vigorous. If so, it would not be the first time that management interventions undertaken with the goal of improving water quality have produced unanticipated and undesired

## Table 2

**Nitrogen and phosphorus inputs to Narragansett Bay in the 1970's and 1980's, and in 2002 and 2003 from the three largest sewage treatment plants that discharge directly into the bay.* Units are millions of moles per year.**

### Narragansett Bay Commission, Field's Point

| | 1976-77[a] | 1983[b] | 2002[c] | 2003[c] |
|---|---|---|---|---|
| Discharge, $10^3\ m^3 d^{-1}$ | 151 | 195 | 158 | 168 |
| Total Nitrogen | 70 | 83 | 61 | 71 |
| Ammonia | 22 | 60 | 44 | 39 |
| Nitrite + Nitrate | 3 | 3 | 10 | 11 |
| Organic Nitrogen | 45 | 20 | 7 | 21 |
| Total Phosphorus | 3.3 | 3.3 | 1.7 | 1.6 |

### Narragansett Bay Commission, Bucklin Point

| | 1976-77[a] | 1983[b] | 2002[c] | 2003[c] |
|---|---|---|---|---|
| Discharge, $10^3 m^3 d^{-1}$ | 50 | 78 | 79 | 95 |
| Total Nitrogen | 20 | 26 | 37 | 35 |
| Ammonia | 8.8 | 20 | 31 | 30 |
| Nitrite + Nitrate | 0.1 | 0.3 | 0.6 | 0.3 |
| Organic Nitrogen | 11 | 5.4 | 6 | 5.4 |
| Total Phosphorus | 1.7 | 2.9 | 1.2 | 1.7 |

### Riverside, East Providence

| | 1976-77[a] | 1983[b] | 2002[c] | 2003[c] |
|---|---|---|---|---|
| Discharge, $10^3 m^3 d^{-1}$ | 9.7 | 22 | 22 | 28 |
| Total Nitrogen | 6.1 | 12 | 9.2 | 11.5 |
| Ammonia | 4.0 | 10 | 1.0 | 2.2 |
| Nitrite + Nitrate | 0.1 | 0.8 | 7.0 | 7.8 |
| Organic Nitrogen | 2.1 | 1.6 | 1.2 | 1.5 |
| Total Phosphorus | 0.4 | 0.8 | 0.9 | 0.6 |
| **TOTAL PHOSPHORUS** | **5.4** | **7.0** | **3.8** | **3.9** |
| **TOTAL NITROGEN** | **96** | **121** | **108** | **118** |

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*In 1983 these sources accounted for 66% of the N and 50% of the P from direct sewage discharges to the bay.

[a] Mean discharge on 9-10 days when samples were collected over an annual cycle.

[b] From Nixon et al. (1995).

[c] Data from the Narragansett Bay Commission and East Providence treatment plant.

## Table 3

**Nitrogen and phosphorus inputs to Narragansett Bay in the 1980's and in the early 2000's from smaller sewage treatment plants that discharge directly into the bay below Conimicut Point and from the Fall River treatment plant. Units are millions of moles per year. Discharges during 2001-03 are based on concentrations measured by treatment plant self-monitoring programs.**

| | **Total N** | | **Total P** | |
|---|---|---|---|---|
| | 1985-86* | 2001-03 | 1986-86* | 2001-03 |
| Jamestown | 0.2 | 0.3 | 0.06 | 0.09[a] |
| Quonset | 1.0 | 0.9 | 0.09 | |
| East Greenwich | 2.1 | 1.0 | 0.52 | 0.54[b] |
| Warren | 2.4 | 2.4 | 0.16 | 0.05[a] |
| Bristol | 5.3 | 6.5 | 0.33 | 0.18 |
| Newport | 20 | 13[c] | 1.12 | 0.5[c] |
| **Sub Total** | **31** | **24** | **2.3** | **1.4** |
| Fall River | 31 | 32 | 4.53 | 1.19[d] |
| **TOTAL** | **62** | **56** | **6.8** | **2.6** |

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[*] From Nixon et. al. (1995) based on the measurements of Pilson and Hunt (1989)
[a] 1996, [b] 2000. [c] Newport does not monitor nutrients in their effluent. These values are estimates based on daily per capita N and P release rates from other plants during 2001-03. [d] Calculated from a daily per capita P release rate of 38 mmol.

## Table 4

**Composition of the nitrogen in the effluent being discharged to Narragansett Bay by the Fields Pt., Bucklin Pt., and East Providence treatment plants. Units are millions of moles per year (see Table 2).**

| | 1976-77 | 1983 | 2002 | 2003 |
|---|---|---|---|---|
| **Organic Nitrogen** | 58 | 27 | 14 | 28 |
| **Ammonia** | 35 | 90 | 76 | 71 |
| **Nitrite +Nitrate** | 3 | 4 | 18 | 19 |
| | 96 | 121 | 108 | 118 |

consequences. At the same time, of course, the reduction in organic load from the plants must have had a positive impact on oxygen conditions in the Seekonk and Providence River estuaries. Unfortunately, there were no monitoring programs in place that allow us to evaluate the ecological impacts, if any, of a large change in the form of nitrogen input to the bay. The smaller but interesting increase in nitrite and nitrate in the effluent is due approximately equally to the Fields Pt. and East Providence facilities. The increasing concentrations of nitrate may have supported some ancillary denitrification and thus reduced the total nitrogen that might otherwise have entered the bay.

### *Phosphorus*

It is clear that the input of total phosphorus to Narragansett Bay from sewage treatment plants has decreased in recent decades, especially with respect to the sampling done in 1983 (Tables 2 and 3). Since the supply of phosphorus is not thought to be important in regulating primary production in the bay (Kremer and Nixon 1978, Oviatt et al. 1995), it is less frequently monitored. In compiling total nitrogen and phosphorus discharge data from sewage treatment plants in the Narragansett Bay watershed, it also became apparent that the amount of phosphorus released per capita served by the plants varied more widely for phosphorus than for nitrogen (the highest N release was 2.8 times the lowest, while the highest P release was almost 14 times the lowest; Table 5). This probably reflects the varying importance of industrial sources of phosphorus relative to nitrogen and the relative ease with which it can be removed using advanced wastewater treatment. Much of the decline in phosphorus discharges may be due to treatment plant operations, though declines in the levels of phosphorus used in detergents may also have contributed (Booman et al. 1987).

## Rivers

### *Nitrogen*

The total amount of nitrogen entering Narragansett Bay through rivers varies from year to year, largely in response to water flow (Nixon et al. 1995). While particulate nitrogen was not measured in the 1975-76 study or in the 1990's, the measurements from 1983 and 2003-04 show that this form accounts for only about 5% of the total nitrogen carried by the rivers (Table 6). The contribution of the various forms of dissolved nitrogen to the total flux also varies somewhat each year. In general, ammonia accounts for about 20%, nitrite plus nitrate for 30-60%, and dissolved organic nitrogen provides the remainder. During 2003-04, the five rivers entering the Seekonk and Providence River estuaries delivered about 1.5 times more nitrogen to the estuaries than the combined discharges of the Fields Pt., Bucklin Pt., and East Providence sewage treatment plants (Table 7). The rivers provided about 1.45 times more dissolved inorganic nitrogen and about 1.9 times more dissolved organic nitrogen than the treatment plants did.

Because the annual flux of nitrogen from the rivers varies with water flow, it is not easy to recognize longer term trends (or the lack of them) by a simple inspection of the annual flux estimates. For this reason, we carried out a detailed statistical examination of the river flow and concentration data for all of the sampling periods. Since our concentration sampling usually extended several months on each side of a calendar year,

## Table 5

**Recent (~2001-2003) per capita daily nitrogen and phosphorus discharge rates from different sized sewage treatment plants in the Narragansett Bay watershed. All plants are in Rhode Island unless noted. Nutrient data are from treatment plant monitoring files and estimates of the population served from US EPA. Units are moles per person per day for N and mmoles per person per day for P.**

| | Population Served | N | P |
|---|---|---|---|
| **Fields Point** | 208,745 | 0.93 | 21 |
| **Bucklin Point** | 119,660 | 0.80 | 39 |
| **Brockton, MA** | 109,510 | 0.91 | 19 |
| **Fall River, MA** | 93,615 | 0.95 | ---- |
| **Cranston** | 81,000 | 0.61 | 44 |
| **Woonsocket** | 51,370 | 0.93 | 116 |
| **East Providence** | 47,835 | 0.66 | 34 |
| **West Warwick** | 29,075 | 0.77 | 130 |
| **Warwick** | 28,000 | 0.46 | 54 |
| **Attleboro, MA** | 18,200 | 0.68 | 31 |
| **Bristol** | 16,900 | 1.07 | 29 |
| **North Attleboro, MA** | 15,160 | 1.28 | 33 |
| **Somerset, MA** | 14, 310 | 0.81 | 31 |
| **Warren** | 8,000 | 0.81 | 16 |
| **Burrillville** | 7,685 | 0.48 | 9.4 |
| **East Greenwich** | 2,500 | 0.99 | ---- |
| **Jamestown** | 1,720 | 0.46 | 59 |

**Table 6**

**Annual estimate of nitrogen fluxes into Narragansett Bay from rivers at various times between 1975 and the present. Nitrogen in millions of moles per year.**

| | 1975-1976 | 1983 | 1991 | 1992 | 2003-2004 |
|---|---|---|---|---|---|
| Blackstone River | | | | | |
| Mean Daily Flow, $10^6$ $m^3$ $d^{-1}$ | 2.47 | 3.17 | 2.24 | 1.99 | 2.57 |
| Dissolved | | | | | |
| Inorganic | 63.72 | 98.70 | 59.14 | 63.71 | 68.88 |
| Organic | 31.08 | 28.06 | 38.36 | 50.94 | 23.25 |
| Particulate | | 5.04 | | | 6.50 |
| **Total** | | 131.80 | | | 98.63 |
| Pawtuxet River | | | | | |
| Mean Daily Flow, $10^6$ $m^3$ $d^{-1}$ | 1.06 | 1.57 | 1.06 | 1.10 | 1.00 |
| Dissolved | | | | | |
| Inorganic | 31.27 | 46.17 | 47.70 | 43.63 | 44.61 |
| Organic | 12.08 | 17.99 | 30.04 | 37.20 | 11.61 |
| Particulate | | 3.41 | | | 3.07 |
| **Total** | | 67.57 | | | 59.29 |
| Woonasquatucket River | | | | | |
| Mean Daily Flow, $10^6$ $m^3$ $d^{-1}$ | | 0.31 | 0.17 | 0.18 | 0.28 |
| Dissolved | | | | | |
| Inorganic | | 4.73 | 2.87 | 3.80 | 6.62 |
| Organic | | 2.39 | 3.44 | 3.83 | 1.67 |
| Particulate | | 0.44 | | | 0.30 |
| **Total** | | 7.56 | | | 8.59 |
| Moshassuck River | | | | | |
| Mean Daily Flow, $10^6$ $m^3$ $d^{-1}$ | | 0.19 | 0.11 | 0.12 | 0.19 |
| Dissolved | | | | | |
| Inorganic | | 4.16 | 1.74 | 1.82 | 3.50 |
| Organic | | 1.40 | 1.96 | 1.56 | 1.01 |
| Particulate | | 0.35 | | | 0.26 |
| **Total** | | 5.91 | | | 4.77 |
| Ten Mile River | | | | | |
| Mean Daily Flow, $10^6$ $m^3$ $d^{-1}$ | | | | | 0.35 |
| Dissolved | | | | | |
| Inorganic | | | | | 9.86 |
| Organic | | | | | 3.30 |
| Particulate | | | | | 0.91 |
| **Total** | | | | | 14.07 |

Table 7

**Contribution of dissolved inorganic (DIN), dissolved organic (DON), and total nitrogen (TN) to the Seekonk and Providence River estuaries during 2003-04 from the five rivers that discharge above Conimicut Point (Table 6) compared with the combined nitrogen discharges from the Fields Pt., Bucklin Pt., and East Providence sewage treatment facilities (see Table 2). Units are millions of moles per year.**

| | DIN | DON | TN |
|---|---|---|---|
| **Rivers*** | 133 | 40 | 173 |
| **Sewage Treatment Plants** | 92 | 21 | 113 |

* Blackstone, Pawtuxet, Ten Mile, Woonasquatucket, Moshassuck

we refer throughout this discussion to the sampling by decades (e.g. 1970's, 1980's, etc.) rather than by the specific calendar years used in the annual flux calculations, but the time periods are essentially comparable. We first inspected 1/x and log log transformations of the nitrogen concentration and water discharge data to satisfy conditions of linearity and normality. We found that log transformations did a better job at increasing linearity, while also reducing skewness and kurtosis and producing means and medians that were more comparable. We then tested the fit of a multivariate regression as part of an analysis of covariance using the model:

$$Logconc=\beta_0 + \beta_1 log\,flow + \beta_{70's} + \beta_{80's} + \beta_{90's} + \beta_{00's} + \epsilon$$

We used a SAS program to carry out this analysis with year variables converted into a binary classification of 1 or 0 for four columns representing the 70's, 80's, 90's, and 00's; the regression was fit to determine if a single line could appropriately describe all the years of data with one slope. When this was the case, an analysis of covariance was completed by fitting this regression to remove the trend and then testing to see if the adjusted means (i.e. intercepts) were significantly different from one another for each of the time groups. Results report both the transformed and un-transformed values for adjusted means. The comparison was completed using Tukey's multiple comparisons test to determine which years were different from one another. Significant ($p < 0.01$) regressions were found for dissolved inorganic nitrogen, dissolved organic nitrogen, and total dissolved nitrogen in the Blackstone and Pawtuxet Rivers and for dissolved inorganic and total dissolved nitrogen in the Woonasquatucket and Moshassuck Rivers. When the concentration and flow regressions were not significant (dissolved organic nitrogen in the two smaller rivers), we tested the mean concentrations for differences from one another during each sampling period using analysis of variance. Since the Woonasquatucket and Moshassuck Rivers were not sampled in the 1970's, we had a shorter window of time in which to look for changes. No time analysis was done on the Ten Mile River concentration data because we lacked comparable earlier measurements.

Results of the analyses described above showed that there was no consistent trend in nitrogen concentration in any of the rivers tested. Total dissolved nitrogen was significantly lower in the Blackstone River during the 2003-04 sampling than in the 1990's, dissolved inorganic nitrogen was significantly lower than it was in the 1980's, and dissolved organic nitrogen was significantly lower than it had been in the 1970's and 1990's (Table 8). Total dissolved nitrogen was also significantly lower in the Pawtuxet and Moshassuck Rivers in 2003-04 than it was in the 1990's (Table 8). Overall, dissolved nitrogen (accounting for about 95% of the total nitrogen in the rivers) has not significantly increased in any of the four rivers studied since the 1980's, nor has it increased significantly in the Blackstone or Pawtuxet Rivers since the 1970's (Table 8). In fact, total dissolved nitrogen concentrations in the two larger rivers, the Blackstone and the Pawtuxet, were significantly lower in 2003-04 than they had been a decade earlier. These reductions were substantial and amounted to about 20% in the Blackstone and 25% in the Pawtuxet. The causes of the reductions in spite of continued population growth in the watershed are not known. Atmospheric nitrogen deposition in the watershed may be declining as it has been in coastal Connecticut (Luo et al. 2002) and perhaps on Cape Cod (Bowen and Valiela 2000). Alternatively, there may have been reductions in other sources such as fertilizer use or improved application practices or improvements in human wastewater treatment.

## Table 8.

**Results of statistical analysis testing differences between decades of nitrogen concentration in the Blackstone, Pawtuxet, Woonasquatucket, and Moshassuck Rivers. ANCOVA/Tukey's Probability Tables (unless noted as ANOVA) with p<.01 in bold[a].**

### Blackstone River

| Year | LOG**TDN** LSMEAN | **TDN** LSMEAN | 70s | 80s | 90s | 00s |
|---|---|---|---|---|---|---|
| 70s | 2.14 | 138.49 | | .9927 | .9696 | .0336 |
| 80s | 2.15 | 141.68 | .9927 | | .9997 | .0261 |
| 90s | 2.15 | 142.67 | .9696 | .9997 | | **.0020** |
| 00s | 2.05 | 112.19 | .0336 | .0261 | **.0020** | |

| Year | LOG**DIN** LSMEAN | **DIN** LSMEAN | 70s | 80s | 90s | 00s |
|---|---|---|---|---|---|---|
| 70s | 1.97 | 93.83 | | .0101 | .4249 | .9567 |
| 80s | 2.12 | 130.79 | .0101 | | **<.0001** | **.0043** |
| 90s | 1.91 | 80.96 | .4249 | **<.0001** | | .8351 |
| 00s | 1.95 | 88.48 | .9567 | **.0043** | .8351 | |

| Year | LOG**DON** LSMEAN | **DON** LSMEAN | 70s | 80s | 90s | 00s |
|---|---|---|---|---|---|---|
| 70s | 1.66 | 45.23 | | .0230 | .4890 | **.0004** |
| 80s | 1.44 | 27.24 | .0230 | | **<.0001** | .8047 |
| 90s | 1.74 | 55.14 | .4890 | **<.0001** | | **<.0001** |
| 00s | 1.37 | 23.33 | **.0004** | .8047 | **<.0001** | |

### Pawtuxet River

| Year | LOG**TDN** LSMEAN | **TDN** LSMEAN | 70s | 80s | 90s | 00s |
|---|---|---|---|---|---|---|
| 70s | 2.1625 | 145.38 | | .4378 | **.0001** | .1589 |
| 80s | 2.2097 | 162.06 | .4378 | | **.0001** | .9604 |
| 90s | 2.3536 | 225.72 | **.0001** | **.0001** | | **.0001** |
| 00s | 2.2249 | 167.83 | .1589 | .9604 | **.0001** | |

| Year | LOG**DIN** LSMEAN | **DIN** LSMEAN | 70s | 80s | 90s | 00s |
|---|---|---|---|---|---|---|
| 70s | 2.0389 | 109.38 | | .4573 | *.0215* | .0736 |
| 80s | 2.0863 | 121.99 | .4573 | | .4628 | .6506 |
| 90s | 2.1288 | 134.51 | *.0215* | .4628 | | .9999 |
| 00s | 2.1264 | 133.79 | .0736 | .6506 | .9999 | |

| Year | LOG**DON** LSMEAN | **DON** LSMEAN | 70s | 80s | 90s | 00s |
|---|---|---|---|---|---|---|
| 70s | 1.5811 | 38.11 | | .9507 | **.0016** | .5601 |
| 80s | 1.5311 | 33.97 | .9507 | | **.0002** | .8869 |
| 90s | 1.8809 | 76.02 | **.0016** | **.0002** | | **<.0001** |
| 00s | 1.4649 | 29.17 | .5601 | .8869 | **<.0001** | |

## Table 8 continued.

**Results of statistical analysis testing differences between decades of nitrogen concentrations in the Blackstone, Pawtuxet, Woonasquatucket, and Moshassuck Rivers. ANCOVA/Tukey's Probability Tables (unless noted as ANOVA) with p<.01 in bold[a].**

### Woonasquatucket River

| Year | **TDN** CONC LSMEAN | 80s | 90s | 00s |
|---|---|---|---|---|
| 80s | 83.67 | | .0829 | .7258 |
| 90s | 102.56 | .0829 | | .3567 |
| 00s | 91.16 | .7258 | .3567 | |

| Year | **DIN** CONC LSMEAN | 80s | 90s | 00s |
|---|---|---|---|---|
| 80s | 78.693 | | **.0005** | .6458 |
| 90s | 50.853 | **.0005** | | *.0371* |
| 00s | 71.002 | .6458 | *.0371* | |

| Year | **DON** CONC LSMEAN – *ANOVA only* | 80s | 90s | 00s |
|---|---|---|---|---|
| 80s | 19.85 | | **<.0001** | .9822 |
| 90s | 55.43 | **<.0001** | | **<.0001** |
| 00s | 20.71 | .9822 | **<.0001** | |

### Moshassuck River

| Year | 1/y **TDN** CONC LSMEAN | **TDN** CONC LSMEAN | 80s | 90s | 00s |
|---|---|---|---|---|---|
| 80s | .0121 | 82.35 | | .9936 | .0158 |
| 90s | .0123 | 81.63 | .9936 | | **.0051** |
| 00s | .0152 | 65.62 | .0158 | **.0051** | |

| Year | log **DIN** LSMEAN | **DIN** CONC LSMEAN | 80s | 90s | 00s |
|---|---|---|---|---|---|
| 80s | 1.867 | 73.66 | | **<.0001** | **.0005** |
| 90s | 1.672 | 47.01 | **<.0001** | | .4152 |
| 00s | 1.718 | 52.24 | **.0005** | .4152 | |

| Year | **DON** CONC LSMEAN – *ANOVA only* | 80s | 90s | 00s |
|---|---|---|---|---|
| 80s | 19.85 | | .0152 | .9139 |
| 90s | 55.97 | .0152 | | **.0018** |
| 00s | 14.16 | .9139 | **.0018** | |

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[a] Nitrogen concentration units μM/L

**Table 9**

**Annual estimate of phosphorus fluxes into Narragansett Bay from rivers at various times between 1975 and the present. Phosphorus in millions of moles per year.**

| | 1975-1976 | 1983 | 1991 | 1992 | 2003-2004 |
|---|---|---|---|---|---|
| | | Blackstone River | | | |
| Mean Daily Flow, $10^6\ m^3\ d^{-1}$ | 2.47 | 3.17 | 2.24 | 1.99 | 2.57 |
| Dissolved | | | | | |
| Inorganic | 2.62 | 2.72 | 2.42 | 1.05 | 1.69 |
| Organic | 1.89 | 1.11 | 1.64 | 2.04 | 0.35 |
| Particulate | | 1.83 | 2.34 | 0.65 | 1.83 |
| **Total** | | 5.66 | 6.40 | 3.74 | 3.87 |
| | | Pawtuxet River | | | |
| Mean Daily Flow, $10^6\ m^3\ d^{-1}$ | 1.06 | 1.57 | 1.06 | 1.10 | 1.00 |
| Dissolved | | | | | |
| Inorganic | 2.61 | 4.45 | 1.63 | 1.00 | 1.96 |
| Organic | 0.60 | 0.93 | 0.98 | 1.66 | 0.32 |
| Particulate | | 0.79 | 1.18 | 1.11 | 1.33 |
| **Total** | | 6.17 | 3.79 | 3.77 | 3.61 |
| | | Woonasquatucket River | | | |
| Mean Daily Flow, $10^6\ m^3\ d^{-1}$ | | 0.31 | 0.17 | 0.18 | 0.28 |
| Dissolved | | | | | |
| Inorganic | | 0.12 | 0.06 | 0.07 | 0.16 |
| Organic | | 0.06 | 0.10 | 0.11 | 0.04 |
| Particulate | | 0.10 | 0.11 | 0.13 | 0.12 |
| **Total** | | 0.28 | 0.27 | 0.31 | 0.32 |
| | | Moshassuck River | | | |
| Mean Daily Flow, $10^6\ m^3\ d^{-1}$ | | 0.19 | 0.11 | 0.12 | 0.19 |
| Dissolved | | | | | |
| Inorganic | | 0.07 | 0.05 | 0.12 | 0.07 |
| Organic | | 0.04 | 0.02 | 0.04 | 0.01 |
| Particulate | | 0.07 | 0.05 | 0.06 | 0.05 |
| **Total** | | 0.18 | 0.12 | 0.22 | 0.13 |
| | | Ten Mile River | | | |
| Mean Daily Flow, $10^6\ m^3\ d^{-1}$ | | | | | 0.35 |
| Dissolved | | | | | |
| Inorganic | | | | | 0.24 |
| Organic | | | | | 0.22 |
| Particulate | | | | | 0.35 |
| **Total** | | | | | 0.81 |

### *Phosphorus*

The total amount of phosphorus brought into the Seekonk and Providence River estuaries by rivers varied by less than a factor of two during the years of measurement. In contrast to nitrogen, particulate phosphorus is a significant (30-50%) part of the total flux (Table 9). Particulate phosphorus was included in all of the sampling except for the first survey in 1975-76. The dissolved phosphorus was dominated by inorganic phosphate. During the 2003-04 study, the rivers brought 2.7 times more phosphorus into the Seekonk and Providence River estuaries than the combined effluents from the Fields Pt., Bucklin Pt., and East Providence sewage treatment facilities (Table 10).

As with nitrogen, we carried out statistical analyses comparing the phosphorus fluxes from each river (except the Ten Mile) over time. Statistically significant regressions of dissolved inorganic phosphate with water discharge were found for all the rivers except the Moshassuck. Phosphate concentrations in the Blackstone decreased markedly (over 50%) in the 1990's and in the most recent survey compared with conditions in the 1970's and 1980's (Table 11). Phosphate in the Pawtuxet River in 2003-04 was high and not statistically different from concentrations found earlier. Phosphate in the Woonasquatucket had approximately doubled compared with the 1990's and 1980's. Analysis of variance on phosphate in the Moshassuck showed statistically significant declines (by about two thirds) in the 1990's and in 2003-04 compared with conditions in the 1980's (Table 11). A statistically significant regression between dissolved organic phosphorus concentration and discharge was only found for the Pawtuxet River, where concentrations in 2003-04 were much lower than they had been in any of the earlier decades back to the 1970's (Table 11). Analyses of variance for the other rivers showed large and statistically significant declines in dissolved organic phosphorus in the Blackstone and in the Woonasquatucket in 2003-04 compared with the 1990's (Table 11). No statistically significant changes were found for dissolved organic phosphorus in the Moshassuck River. The relatively large amounts of particulate phosphorus are almost certainly tied to suspended sediment discharge, and the availability of this phosphorus to play a significant role in biological processes in the bay is not known.

## SUMMARY

A review of past and present data on nitrogen and phosphorus in direct sewage treatment plant discharges to Narragansett Bay show that the amount of total nitrogen entering the bay from these sources has changed little, if at all, since the mid 1980's. For the Narragansett Bay Commission facilities at Bucklin Pt. and Fields Pt., as well as the East Providence treatment plant, this conclusion appears to hold for the past twenty five years or more. Direct phosphorous discharges to the bay in sewage effluent have declined markedly in recent decades.

Recent sampling of the flux of all forms of nitrogen and phosphorus in the five major rivers entering the Seekonk and Providence River estuaries at the head of Narragansett Bay shows that the rivers contribute about 1.5 times more nitrogen and about 2.7 times more phosphorus to the bay than the combined discharges of the Fields Pt., Bucklin Pt., and East Providence sewage treatment facilities. Among the rivers, the Blackstone contributed 53% of the nitrogen and 45% of the phosphorus and the Pawtuxet contributed

32% and 43%, respectively. The Ten Mile River provided about 7.5% of the total riverine nitrogen and phosphorus. The Woonasquatucket and Moshassuck rivers make only small additions, with the contribution of the former about twice that of the latter. Dissolved inorganic nitrogen makes up about 50 to 80% of the river nitrogen with dissolved organic nitrogen accounting for most of the rest.

A statistical assessment of the nutrient concentrations in the rivers shows that there has been no consistent trend in the four rivers for which data extend back to the 1980's (Woonasquatucket and Moshassuck) or the 1970's (Blackstone and Pawtuxet). Total dissolved nitrogen was significantly lower in the Blackstone, Pawtuxet, and Moshassuck rivers during 2003-04 than it was during the 1990's. The decrease amounted to about 20% in the Blackstone and 25% in the Pawtuxet. Overall, dissolved nitrogen (accounting for 95% of the total nitrogen in the rivers) has not increased significantly in any of the four rivers studied since the 1980's. Nitrogen has not increased significantly in the Blackstone and Pawtuxet rivers since the mid 1970's or before. Phosphate concentrations in the Blackstone decreased markedly (by over 50%) in the 1990's and in the current survey compared with the 1980's and 1970's. Phosphate in the Pawtuxet remains high and not significantly changed from conditions during the 1990's, 1980's, and 1970's. Phosphate in the small Woonsocket River approximately doubled compared with the 1990's and 1980's while those in the still smaller Moshassuck declined markedly in the 1990's and in the current sampling compared with the 1980's.

Taken as a whole, the evidence available does not indicate that nitrogen inputs to Narragansett Bay from sewage treatment plants or the rivers we examined have increased in recent decades. Phosphorus inputs have declined.

**Table 10**

Contribution of dissolved inorganic (DIP), dissolved organic (DOP), particulate (PP) and total phosphorus (TP) to the Seekonk and Providence River estuaries during 2003-04 from the five rivers that discharge above Conimicut Point (Table 9) compared with the combined phosphorus discharges from the Fields Pt., Bucklin Pt., and East Providence sewage treatment facilities (see Table 2). Units are millions of moles per year.

| | DIP | DOP | PP | TP |
|---|---|---|---|---|
| **Rivers*** | 4.1 | 0.9 | 3.7 | 10.7 |
| **Sewage Treatment Plants** | | | | 3.9 |

*Blackstone, Pawtuxet, Ten Mile, Woonasquatucket, Moshassuck

## Table 11

**Results of statistical analysis testing differences between decades of phosphorus concentrations in the Blackstone, Pawtuxet, Woonasquatucket, and Moshassuck Rivers. ANCOVA/Tukey's Probability Tables (unless noted as ANOVA) with p<.01 in bold[a].**

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### Blackstone River

| Year | LOG**DIP** LSMEAN | **DIP** LSMEAN | 70s | 80s | 90s | 00s |
|---|---|---|---|---|---|---|
| 70s | .601 | 3.99 | | .9437 | **<.0001** | **<.0001** |
| 80s | .561 | 3.64 | .9437 | | **<.0001** | **.0002** |
| 90s | .265 | 1.84 | **<.0001** | **<.0001** | | .9649 |
| 00s | .231 | 1.7 | **<.0001** | **.0002** | .9649 | |

| Year | **DOP-** *ANOVA* LSMEAN | 70s | 80s | 90s | 00s |
|---|---|---|---|---|---|
| 70s | 2.41 | | **.0014** | .9997 | **<.0001** |
| 80s | 1.08 | **.0014** | | **.0003** | .3333 |
| 90s | 2.44 | .9997 | **.0003** | | **<.0001** |
| 00s | 0.44 | **<.0001** | .3333 | **<.0001** | |

### Pawtuxet River

| Year | LOG**DIP** LSMEAN | **DIP** LSMEAN | 70s | 80s | 90s | 00s |
|---|---|---|---|---|---|---|
| 70s | .897 | 7.9 | | .8139 | **.0001** | .1073 |
| 80s | .964 | 9.2 | | | **<.0001** | .0103 |
| 90s | .581 | 3.81 | **.0001** | **<.0001** | | .3682 |
| 00s | .707 | 5.09 | .1073 | .0103 | .3682 | |

| Year | LOG**DOP** LSMEAN | **DOP** LSMEAN | 70s | 80s | 90s | 00s |
|---|---|---|---|---|---|---|
| 70s | .245 | 1.76 | | .5727 | .1603 | **<.0001** |
| 80s | .125 | 1.33 | .5727 | | **.0017** | **.0010** |
| 90s | .436 | 2.73 | .1603 | **.0017** | | **<.0001** |
| 00s | -.247 | 0.57 | **<.0001** | **.0010** | **<.0001** | |

### Woonasquatucket River

| Year | LOG**DIP** LSMEAN | **DIP** LSMEAN | 80s | 90s | 00s |
|---|---|---|---|---|---|
| 80s | -0.112 | 0.77 | | .8273 | **.0008** |
| 90s | -0.153 | 0.70 | .8273 | | **<.0001** |
| 00s | 0.207 | 1.61 | **.0008** | **<.0001** | |

| Year | **DOP** CONC LSMEAN – *ANOVA only* | 80s | 90s | 00s |
|---|---|---|---|---|
| 80s | .667 | | **<.0001** | .3610 |
| 90s | 1.570 | **<.0001** | | **<.0001** |
| 00s | .422 | .3610 | **<.0001** | |

## Table 11 continued.

**Results of statistical analysis testing differences between decades of phosphorus concentrations in the Blackstone, Pawtuxet, Woonasquatucket, and Moshassuck Rivers. ANCOVA/Tukey's Probability Tables (unless noted as ANOVA) with p<.01 in bold[a].**

### Moshassuck River

| Year | **DIP** CONC LSMEAN – *ANOVA only* | 80s | 90s | 00s |
|---|---|---|---|---|
| 80s | .937 | | **<.0001** | **<.0001** |
| 90s | .214 | **<.0001** | | .6366 |
| 00s | .307 | **<.0001** | .6366 | |

Moshassuck DOP – No significant differences between means.

[a] Phosphorus concentration units µM/L

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