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.

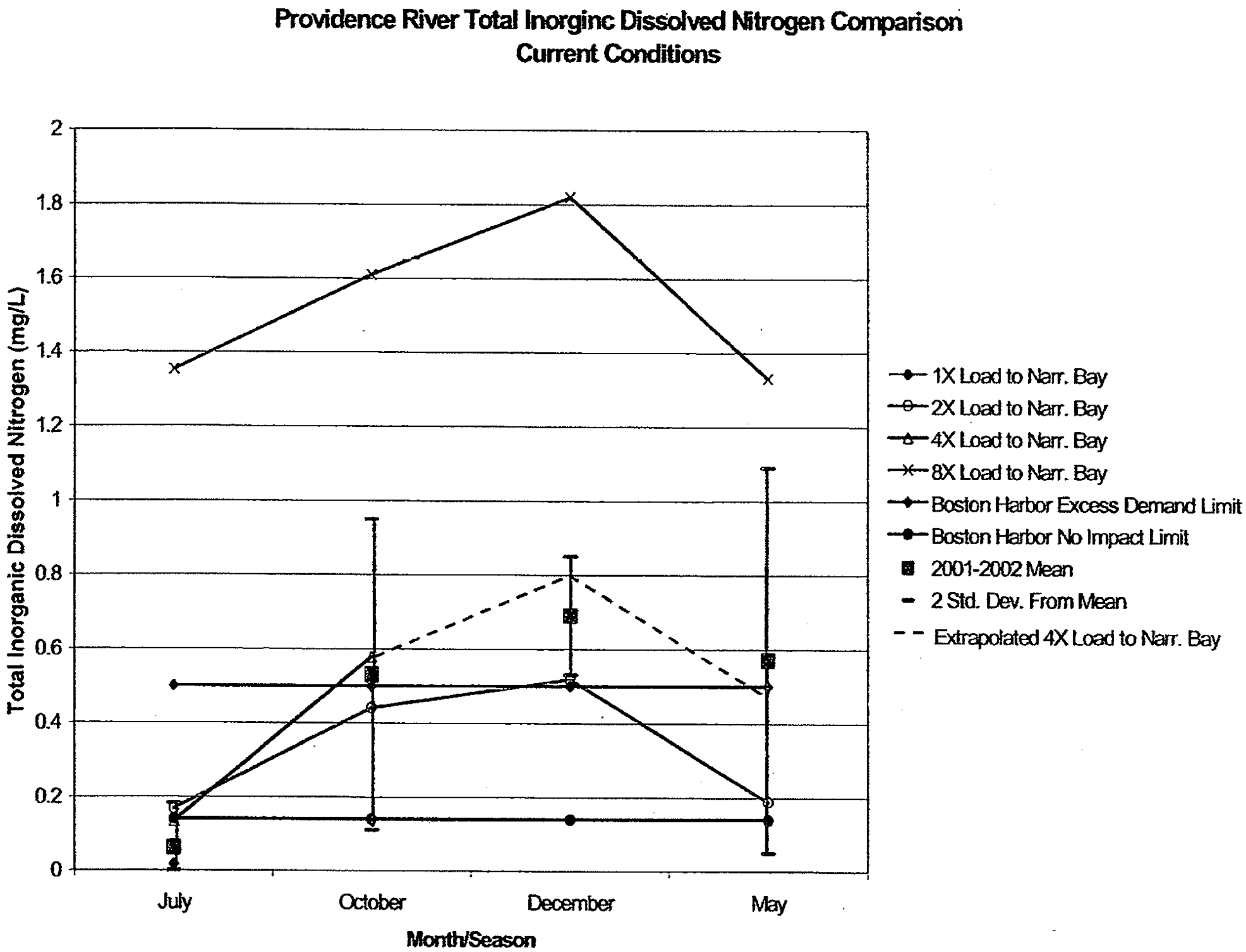
5. Estimated Costs

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 A7

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Control of Nutrient Concentrations in the Seekonk-Providence River Region of Narragansett Bay, Rhode Island

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ABSTRACT: Six synoptic samplings of nutrient concentrations of the water column and point-source inputs (rivers, sewage treatment plants) were conducted in the Seekonk-Providence River region of Narragansett Bay. Concentrations of nutrients (NH_4^+, NO_2^- + NO_3^-, PO_4^{-3}, dissolved silicon, particulate N, particulate C) were predicted using a conservative, two-layer box model in order to assess the relative influence of external inputs and internal processes on observed concentrations. Although most nutrients were clearly affected by processes internal to the system, external input and mixing explained most of the variability in and absolute magnitude of observed concentrations, especially for dissolved constituents. In the bay as a whole, two functionally distinct regions can now be identified: the Seekonk-Providence River, where dissolved nutrient concentrations are externally controlled and lower Narragansett Bay where internal processes regulate the behavior of nutrients. A preliminary nitrogen budget suggests that the Seekonk-Providence River exports some 95% of the nitrogen entering the system via point sources and bottom water from upper Narragansett Bay.

Introduction

Owing to the present position of sea-level, most rivers empty into estuaries or marginal seas rather than directly into the coastal ocean (Thurman 1985). Furthermore, major urban centers are often located on estuaries. As a result, estuaries receive some of the highest inputs of nutrients (N and P) on an areal basis of any class of ecosystems (Nixon et al. 1986). Understanding the behavior of nutrients in estuaries has important implications for global nutrient budgets (Wollast 1983; Kaul and Froelich 1984) and for controlling eutrophication of these systems (e.g., Tippie 1984).

Perhaps one of the most pivotal questions concerning nutrients in estuaries is the degree to which estuaries behave as traps, retaining and recycling nutrients within the system (e.g., Smullen et al. 1982; Nixon 1987a). Related to this issue are the relative contributions of external nutrient supply and internal nutrient recycling to observed concentrations within the estuary (D'Elia et al. 1983; Oviatt et al. 1984; Pilson 1985a).

In this paper we report results of six synoptic surveys of nutrient concentrations, salinity, and nutrient inputs in the Seekonk-Providence River region of Narragansett Bay. Tidally averaged nutrient concentrations are estimated using a two-layer, conservative box model reliant upon external input and mixing in the water column (Officer 1980). Predicted nutrient concentrations are compared to those measured in the field by functional regression (Ricker 1973). The slope of this regression is employed to calculate the proportion of observed concentration which may be attributable to external input and mixing. By inference, the remainder is due to internal processes. Finally preliminary estimates of net nitrogen flux through this portion of Narragansett Bay are presented.

Study Area

The Seekonk and Providence rivers lie at the head of Narragansett Bay, Rhode Island. Together they comprise about 7% of the total area of the bay and at mean low tide, hold some 3.3% of its water (Chinman and Nixon 1985). The mean depth of the Seekonk River is 1.29 m while that of the Providence River is 3.99 m (Chinman and Nixon 1985). However, a relatively deep (13–14 m) shipping channel runs the length of the Providence River. A marginally navigable, much shallower (3–4 m) channel also exists in the Seekonk.

The bay in general has been characterized as "well mixed" (Kremer and Nixon 1978) or "weakly stratified" (Weisberg and Sturges 1976), with

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near surface and bottom salinities differing by about 2‰ (Pilson 1985b). By contrast, the Seekonk-Providence River region exhibits considerably stronger stratification (Nixon 1987b; Spaulding 1987). The long-term average freshwater input to Narragansett Bay is estimated to be 105 $m^3 s^{-1}$ with about 50% of the gauged input to the bay emptying into the Seekonk-Providence River (Pilson 1985b). The average residence time of freshwater in the bay is 26 d (range 10 to 40 d) and depends on freshwater input (Pilson 1985b). Best estimates for the Seekonk-Providence River range from 3 d to 10 d (Spaulding 1987).

Because it is surrounded by the greater Providence Metropolitan area, the Seekonk-Providence River receives considerable amounts of nutrients, trace metals, and hydrocarbons, mostly from rivers and sewage treatment plants (Oviatt et al. 1984). Comparison of bay-wide estimates of dissolved inorganic nitrogen loading (Nixon and Lee 1979) with those for the Seekonk-Providence River (Oviatt 1981) suggest that nearly 60% of the total loading to the bay enters in the Seekonk-Providence River. Perhaps due to a combination of relatively small volume and relatively high pollutant loading, the Seekonk-Providence River is arguably the most degraded region of Narragansett Bay (Oviatt et al. 1984). These factors no doubt also contribute to the horizontal concentration gradients observed for many substances both in the water column and sediments of Narragansett Bay. Such gradients show a consistent pattern: high concentrations in the Seekonk-Providence River, decreasing sharply toward the mouth of the bay (see Oviatt et al. 1984).

Methods

Sampling

Six cruises were conducted at intervals of about two months (1986: October 11, December 15; 1987: March 11, April 22, June 27, August 12). Cruises were timed to occur during "dry weather": no major rainfall (> 0.25 inches) within 4 d or 5 d of initial point-source sampling. The purpose of this constraint was to minimize the effects of non-point-sources upon the system. During each cruise 10 stations (Fig. 1) in the Seekonk (3) and Providence rivers (7) were occupied at both high and low tide. In general, stations were sampled within ±1.5 h of slack tide. Discrete water samples were pumped (bellow or hand) from within 1.0 m of the surface and 1.0 m of the bottom through acid-rinsed (1% HCl) Teflon tubing. Vertical hydrographic profiles of temperature and salinity were obtained either with an Applied Microsystems, Inc. STD-12 (Providence River) or a Beckman Instruments Inductive Salinometer (Seekonk River). The resolution of depth was about 0.5 m.

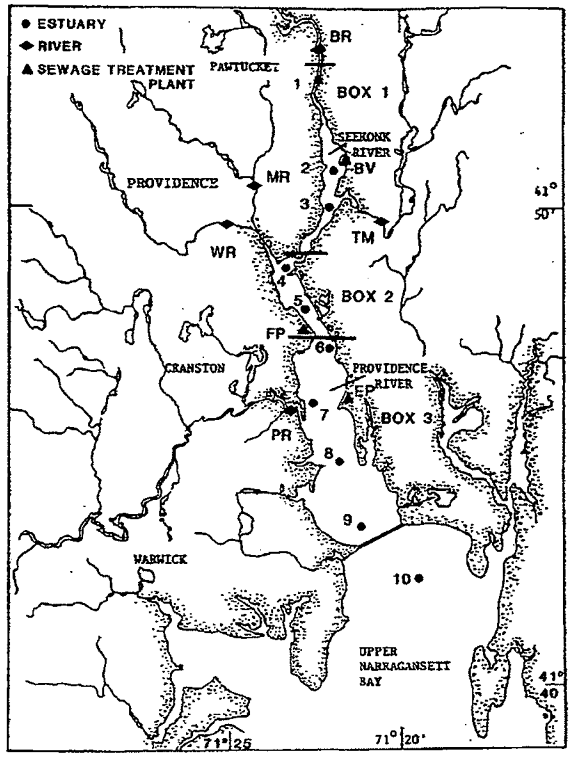

Fig. 1. Station locations. Solid lines delimit boxes used in modelling effort. BR = Blackstone River, BV = Blackstone Valley Sewage Treatment Plant (STP), TM = Ten Mile River, MR = Moshassuck River, WR = Woonasquatucket River, FP = Field's Point STP, EP = East Providence STP, PR = Pawtuxet River.

Coincidentally with each cruise, five rivers and three sewage treatment plants (Fig. 1) were sampled on the 3 d preceding each cruise. Rivers were sampled at low tide to minimize saltwater intrusion. Sampling was usually conducted from a bridge or other structure which allowed access to mid-stream. Samples were taken with a plastic bucket suspended from a rope. An inverted funnel prevented contamination of the sample by drippings from the rope.

Composite (24 h) samples of effluent were collected from the three sewage treatment plants by plant operators. These were refrigerated until returned to the laboratory. In general, samples were brought to the laboratory within 24 h of collection.

Processing and Analysis

Samples for dissolved inorganic nutrients (NH_4^+, $NO_2^- + NO_3^-$, PO_4^{-3}, dissolved silicon) were manually (60-ml plastic syringe) passed through 47 mm diameter, 0.4 μm pore size membrane filters (Nu-

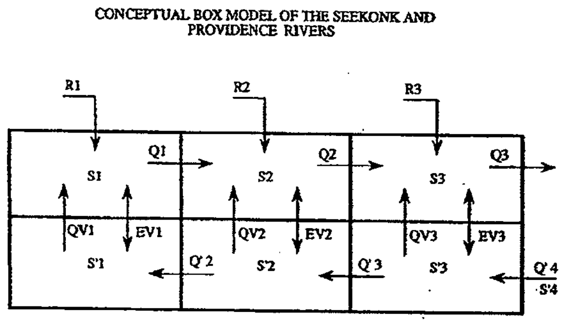

Fig. 2. Diagram of box model used to predict nutrient concentrations. S = salinity, R = freshwater input, Q's = coefficient of advective transport, E's = coefficient of nonadvective transport, V = vertical, number = box number. Superscripts: ' = lower layer.

clepore) into 60-ml polypropylene jars. These were stored on ice until returned to the laboratory where they were frozen until analysis on a Technicon Autoanalyzer (Lambert and Oviatt 1986). Duplicate samples from station 1 were refrigerated for silicate analysis to avoid problems caused by freezing low salinity samples (Macdonald et al. 1986).

Particulate carbon and nitrogen samples were passed manually (60-ml plastic syringe) through 13 mm diameter Whatman GF/F glass-fiber filters (nominal pore size 0.7 μm) which had been combusted at 425°C. Duplicate filters were stored on ice until returned to the laboratory where they were dried (40°C) and stored until analysis. The filtrate was collected and its weight determined in the laboratory. Carbon and nitrogen retained on the filters were determined by elemental analysis on a Carlo Erba Model 1106 Elemental (CHN) Analyzer. The mean coefficient of variation for 218 analyses of replicate filters ($n = 2$) was 12% for carbon and 14.5% for nitrogen.

Discrete salinity samples were stored in 60-ml plastic bottles. Duplicate samples were analyzed on an Autosal Model 8400 Inductive Salinometer. The mean coefficient of variation of 222 analyses of replicate ($n = 2$) samples was 0.84%.

TABLE 1. Calculation of advective (Q's) and nonadvective (E's) transport coefficients in the first two boxes of the model. The solutions for remaining box follow those for Box 2. For definition of terms see Fig. 2. Superscript ' denotes lower layer. Subscripts refer to box number.

For Box 1:

$$Q_1 = R_1 \cdot [S'_2/(S'_2 - S_1)]$$
$$Q'_2 = R_1 \cdot [S_1/(S'_2 - S_1)]$$
$$Q_{V1} = Q'_2$$
$$E_{V1} = (Q_1S_1 - Q_{V1}S'_1)/(S'_1 - S_1)$$

For Box 2:

$$Q_2 = [S'_3/(S'_3 - S_2)] \cdot (Q_1 - Q'_2 + R_2)$$
$$Q'_3 = [S_2/(S'_3 - S_2)] \cdot (Q_1 - Q'_2 + R_2)$$
$$Q_{V2} = Q'_3 - Q'_2$$
$$E_{V2} = (Q_2S_2 - Q_1S_1 - Q_{V2}S'_2)/(S'_2 - S_2)$$

TABLE 2. Equations used to predict the concentration of a given substance in the upper and lower layers of a given box. Subscript m refers to box number, and r to river, superscript ' denotes lower layer, C = concentration. Other terms as in Fig. 2.

Upper layer:

$$\text{Predicted } C_m = [Q_{m-1}C_{m-1} + R_mC_{rm} + C'_m(Q_{vm} + E_{vm})]/(Q_m + E_{vm})$$

Lower layer:

$$\text{Predicted } C'_m = (Q'_{m+1}C'_{m+1} + E_{vm}C_m)/(Q'_m + Q_{vm} + E_{vm})$$

Box Model

A two-layer conservative box model (Pritchard 1969; Officer 1980) was employed to 1) predict nutrient concentrations as a function of point source inputs and mixing, and 2) estimate net flux of nutrients through the system to upper Narragansett Bay (Fig. 2). The model, based on that given by Officer (1980), assumes steady-state conditions, that net circulation effects rather than tidal exchange dominate, and instantaneous mixing within each layer of each box. The model captures the gross features of net circulation in a stratified estuary: landward flow of saltwater in the lower layer and seaward flow of fresher water in the surface layer, with vertical exchange (advective and nonadvective) between layers. Vertical salinity profiles in Narragansett Bay are consistent with this classic, two-layer estuarine circulation (Pilson 1985b).

The equations used to calculate advective and nonadvective transport coefficients are given in Table 1. These solutions assume that volume and salt (see Aston 1978) are conserved. Once transports have been calculated, the steady-state concentration of a given substance can be calculated from flux (transport × concentration) considerations: what goes into a layer must equal that which leaves. Solutions are given in Table 2.

The net flux of nutrients through the system to upper Narragansett Bay is calculated from the difference between inputs (point source + bottom water) and outputs (down estuary flux in the surface layer). Bottom water input and surface layer output can be calculated from observed concentrations and longitudinal water transport across the boundary between the Providence River and upper Narragansett Bay.

Application of the Model

The Seekonk and Providence rivers were divided into three boxes (Fig. 1, Table 3) following