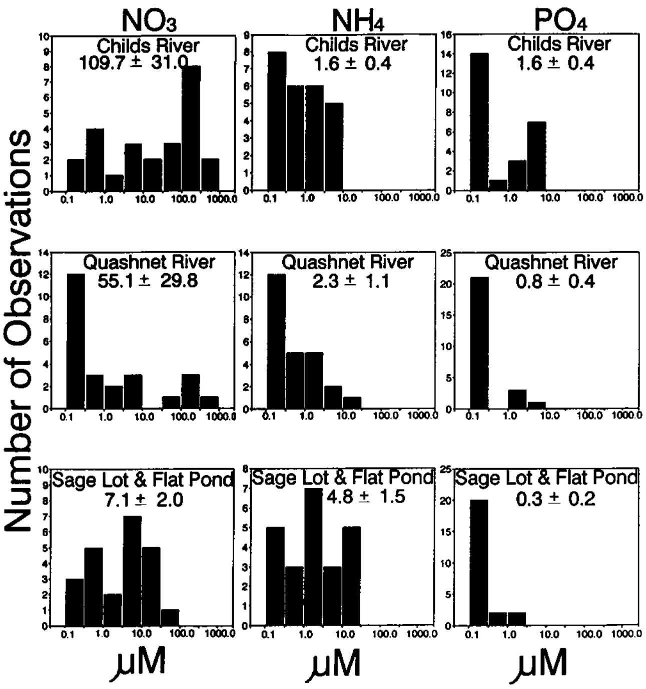

Figure 1. *Frequency distributions of inorganic nutrient concentrations in three estuaries of Waquoit Bay. All graphs show mean concentrations ± standard error. [Note: distributions do not include suspected anoxic samples (sulfurous or tinted samples).]*

Childs River and Quashnet River, combined with the absence of such spikes at Sage Lot and Flat Ponds, suggests input by plumes from septic tanks.

Mean NH_4^+ concentration in groundwater varied over a relatively small range across the three sites (Fig. 1, middle panels). NH_4^+ contributed less than 5% of the mean dissolved inorganic nitrogen (DIN) at Childs and Quashnet Rivers. Most of the inorganic nitrogen, therefore, enters these two estuaries in the form of NO_3^-. Nitrogen from septic tanks and soils enters the aquifer in reduced forms, such as NH_4^+ [untreated septic water contains up to 8000 μM NH_4^+ (J. McClelland, unpub. data)], which are oxidized to NO_3^- in the aquifer before reaching the estuary.

Mean PO_4^{3+} concentrations were relatively low and similar in the three estuaries (Fig. 1, right panels). One would not expect PO_4^{3+} to vary across the sites, despite a gradient in residential area, because PO_4^{3+} is readily adsorbed by soils.

Groundwater data from Waquoit Bay suggest that differences in land use can have a major effect on the concentrations of nitrogen entering a shallow estuary. To estimate the loading from groundwater to receiving estuaries and to estuarine systems, such as Waquoit Bay, concentration data such as those reported in this paper must be converted to flux by estimating actual water and nutrient transport. Calculated values of total system loading will be useful in deciding how to manage coastal estuaries threatened by eutrophication.

This work was supported by Waquoit Bay Land Margin Ecosystems Research and a Research Experience for Undergraduates grant. Special thanks to Lori Soucy for operating the autoanalyzer.

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From Watershed to Estuary: Assessment of Nutrient Loading, Retention, and Export from the Ipswich River Basin

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High concentrations of dissolved nitrogen and phosphorus (80–150 μM N and 20–70 μM P) have been observed in small streams draining predominantly urban and agricultural watersheds within the Ipswich River drainage basin; at the same time, low nutrient concentrations in water are exported from the lower end of the river (< 20 μM N and 2 μM P) (Hopkinson, pers. obs.). To investigate this seeming paradox, transects were run along the entire 40-km length of the river to determine where nutrients were being removed, and a mass balance budget of nutrients was constructed for the entire drainage basin.

Concentrations of inorganic N and P were low along the entire length of the river, averaging 14 μM NO_3^--N, 1 μM NH_4^+-N, and 0.6 μM PO_4^{3-}-P. Concentrations were elevated at only 1 to 3 of the 20 stations investigated, and these were sites immediately adjacent to streams draining heavily populated residential areas or agricultural areas with livestock. Thus it appeared that high concentrations of nutrients entering the river were removed within 1–2 km downstream.

A nutrient mass balance budget for a 3-month growing season was constructed, including estimates of nutrient loading, uptake by wetland vegetation, and export from the watershed. Loading was estimated by combining information on land use for the 11 watersheds within the Ipswich River drainage basin with literature values for nutrient runoff from various types of land use and known point sources (1, 2, 3). Land use information was obtained using data from the Massachusetts Geographic Information System for 1985. In 1985, approximately 50% of the Ipswich watershed was classified as forest, 22% urban, 13% agri-

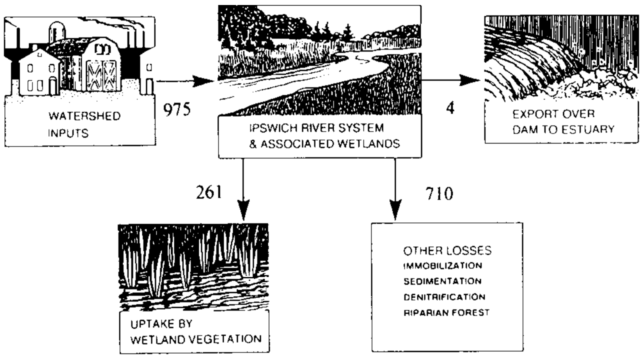

Figure 1. *Annual budget of nitrogen loading, uptake, and export for the Ipswich River drainage basin. Units are in metric tonnes for a 3-month growing season during summer. (Drawn by Bob Golder.)*

culture, and 12% wetland. Estimates of 3-month loading for individual watersheds draining into the Ipswich River ranged from < 10 to 250 metric tonnes N and < 10 to 130 metric tonnes P.

Nutrient uptake by wetland vegetation along the Ipswich River was calculated from information on wetland area along the 11 reaches identified for the Ipswich River, observed species composition, and literature values for plant productivity and N and P content (4). Estimates of nutrient uptake for each reach ranged from 1 to 50 metric tonnes N and < 1 to 15 metric tonnes P. Variation between reaches was due solely to variations in wetland area.

The nutrient mass balance for the Ipswich River drainage basin indicated a large discrepancy between calculated nutrient loading and wetland plant uptake and measured export (Fig. 1). The total mass balance was constructed by summing values for each of the 11 watersheds. Of the 975 tonnes of nitrogen calculated to be entering the river, only 4 tonnes were measured leaving the river over the dam in Ipswich. Wetland vegetation was calculated to remove approximately 261 tonnes of N. This leaves 710 metric tonnes that could not be accounted for with this analysis. Additional removal mechanisms that are probably important include microbial immobilization, sedimentation, denitrification, and uptake by vegetation in the extensive riparian zone along the river.

These observations and calculations reveal the important role of river-basin processes in the removal of nutrients originating in agricultural and urban areas. In addition, the study indicates how increases in urbanization and decreases in wetland buffer communities can affect the chemical composition of riverine and estuarine systems.

This research was supported by supplemental funding to NSF grant (OCE-92-14461) from the NSF Research Experiences for Undergraduates program.

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Reference: *Biol. Bull.* **187:** 278–279. (October, 1994)

Dissolved Organic Nitrogen in Groundwater Bordering Estuaries of Waquoit Bay, Massachusetts: Relations with Watershed Landscape Mosaics

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Anthropogenic activity generally increases inorganic nutrient content of groundwater (1), but factors influencing dissolved organic nitrogen (DON) are less well known. In this study we examine the effect of human activity as well as natural landscape configuration on concentrations of DON in groundwater.

In unconsolidated sandy soils like those that underlie the Waquoit Bay watershed, virtually all fresh water flows via groundwater transport (1). To assess the DON that potentially reaches three estuaries of Waquoit Bay, we collected fresh groundwater samples (salinity < 0.5 ppt) from the periphery of each estuary. Particulate matter was excluded from our samples with a 0.45 μm pore-size filter. We analyzed groundwater samples for total nitrogen by the method of D'Elia *et al.* (2), and nitrate (NO_3^-) by Lachat autoanalyzer.

To assess the impact of urbanized areas on concentrations of DON in groundwater, we selected three watersheds that supported differing percent residential area (27% in Childs River, 7% in Quashnet River, and 3% in Sage Lot Pond) (3). Mean concentration of DON in groundwater samples was higher in watersheds with lower percentage of residential area (Fig. 1, left column). This pattern contrasts with the large increase in dissolved inorganic nitrogen (DIN) observed in Childs compared to Sage Lot Pond groundwater (4). In our most urbanized site, DON:DIN in groundwater was approximately 1:2. In our least urbanized site, the ratio of DON:DIN was 7:1.

DON concentration seems not to be related directly to urbanization, but rather to the mosaic of vegetation covering the surface of the land. For example, mean concentration of DON