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Ipswich River Nutrient Dynamics: Preliminary Assessment of a Simple Nitrogen-Processing Model

Katherine M. Pease[1], *L. Claessens, C. Hopkinson, E. Rastetter, J. Vallino, and N. Kilham*
(Marine Biological Laboratory, Woods Hole, Massachusetts)

The Ipswich River is a low-gradient, coastal river in northeastern Massachusetts. It is about 55 km long and drains an area of 401 km^2. Previous observations and studies indicate high levels of dissolved inorganic nitrogen (DIN) in the headwaters of the river due to urban and residential land use (1). However, concentrations drop quickly with distance downstream, presumably due to biological processing of the nitrogen. A mass balance budget of nitrogen indicates a large unknown nitrogen sink in the Ipswich River (1). To further investigate the dynamics of N cycling in the Ipswich River, nutrient concentrations were measured along transects running the length of the river, and a simple nitrogen-processing model was constructed and analyzed.

Water samples were collected on 1 and 2 July 1998 and analyzed for NH_4^+, NO_3^- (collectively dissolved inorganic N-DIN), PO_4^{3-}, total dissolved N (TDN), and total dissolved P (TDP). The samples were collected in the main channel between river kilometers 6 and 50 at intervals of 1 to 5 km (river mouth = km 0). Samples were also collected from three headwater sites (between river km 60 to 63) and analyzed for nutrients. A simple nitrogen-cycling model was developed that included compartments for

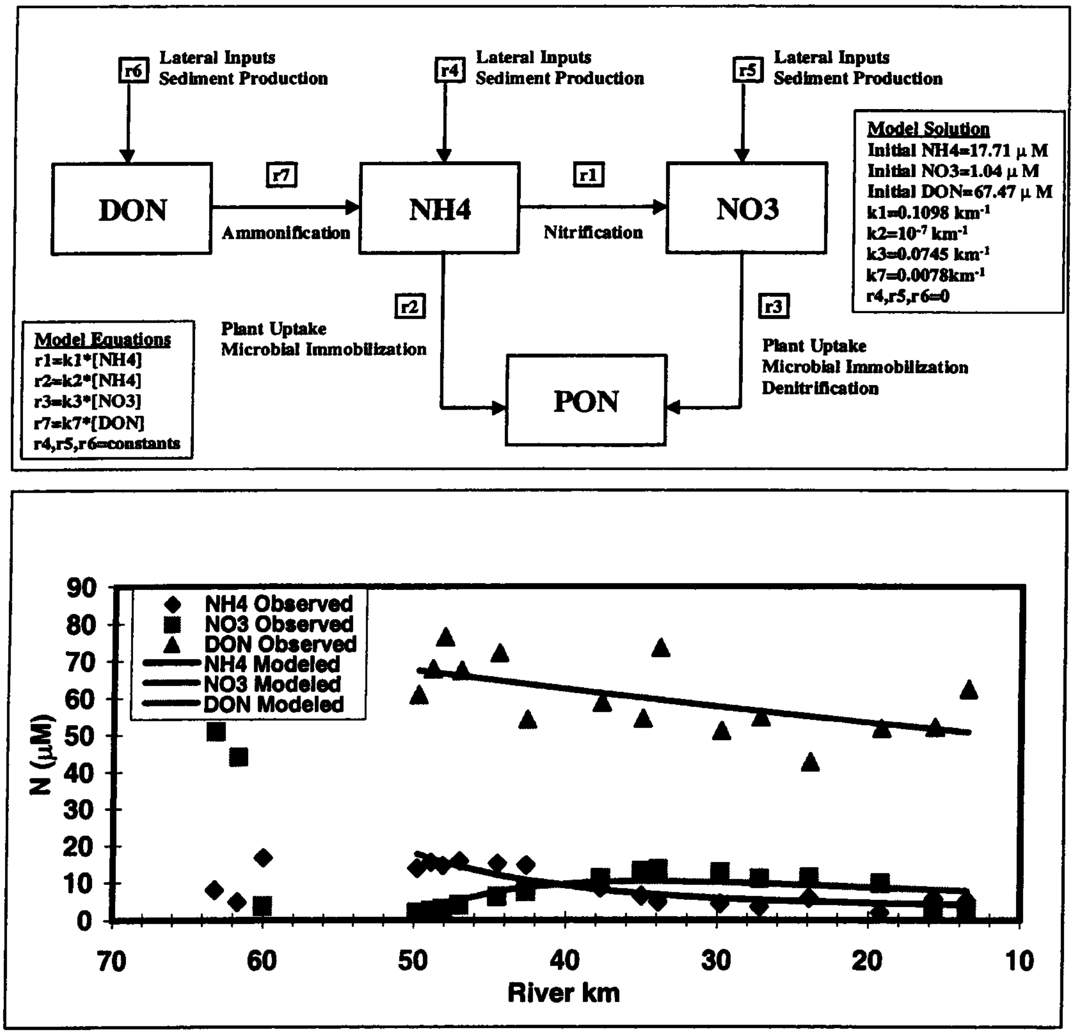

Figure 1. *(Top): A simple N-processing model showing compartments, equations, and calculated rate coefficients. (Bottom): Observed (symbols) and predicted (lines) concentrations of* NH_4^+, NO_3^-, *and dissolved organic nitrogen (DON) for the Ipswich River in July 1998.*

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[1] Barnard College, New York.

NH_4^+, NO_3^-, dissolved organic N (DON), and particulate organic N (PON) and considered the processes of ammonification, nitrification, and immobilization (Fig. 1, top). First-order kinetics were assumed for all processes except for lateral inputs. Concentrations were modeled as functions of distance. The least squares approach was used to fit the model to the main channel concentration data. The concentration data from the headwater sites were not used in the model. Constraints were placed on the model so that the initial concentrations, rate coefficients (k), and uptake rates (r) were greater than zero. Uptake lengths (1/k) were calculated from the rate coefficients; an uptake length is an estimate of the average distance traveled by an element before it is removed from the water column.

Phosphate concentrations were very low at the headwater sites, averaging only 0.3 μM P (data not shown). Further downstream in the main stem of the river, PO_4^{3-} was roughly the same as upstream (0.6 μM). TDP concentrations showed no apparent downstream pattern and were only slightly higher than PO_4^{3-}, indicating very low DOP concentrations (0–1.5 μM). DIN concentrations at the headwater sites were high, approaching 60 μM N (Fig. 1, bottom). Further downstream in the main stem of the river, DIN concentrations were markedly lower (averaging 17 μM). TDN concentrations were much higher than DIN but, as with TDP, showed no apparent spatial pattern. Of the DIN fractions, NO_3^- exhibited a large drop in concentration with distance down the headwater stream. Although NO_3^- dropped, NH_4^+ increased slightly, suggesting denitrification of the NO_3^- and ammonification without subsequent nitrification. In contrast, in the main channel, NH_4^+ and NO_3^- concentrations were mirror images of each other but with NH_4 dropping and NO_3 increasing. This pattern suggests nitrification.

Our simple N model tracked observed data well (Fig. 1, bottom). Plots of predicted *versus* observed concentrations of NH_4^+, NO_3^-, and DON illustrated close agreement for all fractions. Slopes of regression lines were between 0.96 and 1.2 for the three components. Not only was there close agreement in a general sense, but the spatial patterns were also close to observed patterns for all components.

Rate coefficients determined with the model differed greatly between the various N fractions, ranging from 0.0078 km^{-1} for ammonification to 10^7 km^{-1} for plant uptake and microbial immobilization (Fig. 1, top). For all fractions, uptake, or transformation, lengths calculated from the rate coefficients were much longer than those usually reported for more pristine stream systems (2). The uptake lengths for NH_4^+ and NO_3^- were 9 km and 13 km, respectively. The uptake length for NO_3^- was dominated by nitrification, as the rate of nitrification was 10^6 times that of plant uptake. The uptake length for DON exceeded the length of the river. NH_4^+ uptake lengths reported in the literature for low-nitrogen, pristine stream systems are often between 30 and 400 m (2). Reported NO_3^- uptake lengths for similar systems typically range from 40 to 690 m (2). The long Ipswich River uptake lengths are probably due to the relatively high concentrations of inorganic and organic N in the Ipswich River. For a given rate of processing, calculated uptake rate coefficients vary inversely with concentration. The observed uptake lengths may also represent slow overall rates of N cycling in this system, which as evidenced by extremely high inorganic N:P ratios, is probably P limited.

Patterns of nutrient concentration and the results of the N model suggest that an important location for N retention or loss is in the headwater streams of the Ipswich River. Inorganic N concentrations decrease markedly in this region. The N-cycling model indicates very long uptake lengths in the mid and lower stretches of the river. It is possible that nutrient processing is greater in the headwaters because of greater relative contact with the riverbed. There may also be more active exchange between surface and hyporheic waters in the headwater streams. We would expect high rates of denitrification in anoxic hyporheic waters. Additional studies, such as tracer-nutrient releases and ^{15}N additions could be profitably conducted in the upper reaches. Study of nutrient processing in the Ipswich River is increasingly important because N loading is rising in this rapidly urbanizing watershed. It is unclear how long the Ipswich River will be able to continue to process the high loads of inorganic N before the uptake capacity is reached.

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Increased Lability of Estuarine Dissolved Organic Nitrogen From Urbanized Watersheds

Felisa L. Wolfe[1], Kevin D. Kroeger, and Ivan Valiela (Boston University Marine Program, Marine Biological Laboratory, Woods Hole, Massachusetts 02543)

Inputs of nitrogen from land can lead to eutrophication of estuaries (1–5, 6). Terrestrial N is transported as NO_3^-, NH_4^+, PON (particulate organic nitrogen), and DON (dissolved organic nitrogen), but most estimates of N loading are based on DIN (NO_3^- + NH_4^+). DON had been thought to be mostly refractory to organisms, but recent studies show that some portion of the DON may be labile (6, 7). Land-derived DON may thus be mineralized within estuaries, and the NH_4^+ released may be available to organisms (4). Most calculations of N inputs to estuaries

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[1] Oberlin College, Oberlin, Ohio.