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Modeling the Effects of Land-Use Change on Nitrogen Biogeochemistry in the Ipswich Watershed, Massachusetts

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The Ipswich River Basin, which is located in northern Massachusetts and drains into the Plum Island Sound Estuary, covers a 400-km^2 area composed of forest, wetlands, open and agricultural land, and a gradient of low- to high-density residential and commercial land (1). Over the last century, population growth and land-use changes in the basin have altered the land cover of the watershed. The United States Geological Survey (USGS) has recently modeled the hydrology of the Ipswich River Basin using a precipitation-runoff model called Hydrological Simulation Program-Fortran (HSPF) (2). Their intent was to develop a better understanding of the effects of water withdrawal on the water budget of the river basin (1). In addition to the hydrological data that has been collected by the USGS, we have monitored nutrient loading to build a better picture of the effects of land-use change on nutrient biogeochemistry in the Ipswich river basin. To further investigate nutrient processing in the watershed, the USGS HSPF model (1) was modified to include simulation of nutrient processing on land and in the Ipswich River and tributaries. Considering the projections that have been made for urban development in the Ipswich watershed, the ability to accurately model the resulting changes in nutrient processing may be an important tool in understanding the health of the Ipswich ecosystem. It could also become an important aid in planning future development that minimizes harmful effects to the watershed.

HSPF, in addition to simulating hydrology, is capable of simulating nutrient processing, sediment transport, pH and gasses, phytoplankton, and algae dynamics in a watershed. Nitrate-processing components for stream reaches and land areas were added to the HSPF model. Initial values required by the model were obtained from a database (3) which contains parameter values used in similar HSPF projects in the northeastern United States. Nitrate processing and output from different land types was further calibrated using an empirical relationship between fractional cover of agricultural and forested land in small catchments *versus* nitrate concentration in the streams into which they drain (Fig. 1A, B). In this calibration, the only nitrate input was atmospheric deposition; so the differences in nitrate output between the two land types (Fig. 1B) represent the different values chosen for constants in equations governing the simulation of nutrients in the two land-use types. A more rigorous calibration of the model, which is in progress, will include comparing simulated data on nitrate concentration in the Ipswich River with data we are collecting. All simulations run on the model were driven by meteorological input for the years 1989 to 1993, but future work on the model will include adding more recent meteorological data. The base simulation was run using 1991 land-use data for the watershed; other land-use change scenarios were run by modifying the areas of different land types in certain parts of the river basin.

Calibration of the model resulted in simulated nitrate output from forest and from open plus agricultural land (Fig. 1B) that coincided with the empirical relationship for fractional cover *versus* nitrate concentration (Fig. 1A). The base concentration of nitrate in first-order streams draining only forested lands was approximately 10 μM, whereas the value for streams fed by agricultural and open pasture land was closer to 70 μM (Fig. 1B). Modeled nitrate transects along the main stem of the Ipswich River show a strong trend of decreasing concentration near the head of the river, followed by a slowly decreasing concentration toward the Ipswich dam (Fig. 1C). This same general trend is seen in data collected for the same month, although in a different year (Fig. 1C). Stream-flow data along the Ipswich River reveal the opposite trend: a quick increase in flow near the head of the river, followed by a slower increase moving towards the mouth of the Ipswich River (Fig. 1C). Seasonally, nitrate concentrations at the mouth of the Ipswich River reach a peak during winter and spring (Fig. 1D). Similarly, river flow at the mouth has its highest peak in the spring and another, smaller peak in the winter (Fig. 1D). Data we have collected show similar correlation between peak discharge and peak nitrate concentrations (4).

The opposite trends in stream flow and nitrate concentration along transects from the head to the mouth of the Ipswich River suggest that the decreasing nitrate concentration may be due, at least partially, to a dilution effect. The other factors contributing to diminishing nitrate concentration in the river are in-stream processes, such as denitrification and uptake by plants and algae, that can be examined using the model. One purpose of continuing to examine nutrient processing with this model is to help determine what processes are the most important contributors to the trends that have been observed and modeled.

The HSPF model can be used to examine different scenarios for land use by modifying the areas of different land types in the basin. A 12-km^2 residential development was modeled at different locations in the watershed. The results from those scenarios indicated that nitrate concentration would increase at the mouth of the river, and that the increase would be greater the closer the development is to the mouth of the river. The model predicts that urbanization in the watershed will have a smaller effect if it occurs farther upstream and on tributaries, as opposed to farther downstream and on the main stem of the river. One simulation of two different scenarios showed that a 12-km^2 residential area built in the lower watershed on the main stem would increase nitrate concentrations at the mouth of the river by approximately 5 μM, but an identical development on a tributary feeding into the main stem at the same location would produce roughly baseline conditions at the mouth. The model can be used to look more closely at the sources and sinks of nitrate in the river basin to better characterize the processing of nitrogen and other nutrients in the watershed.

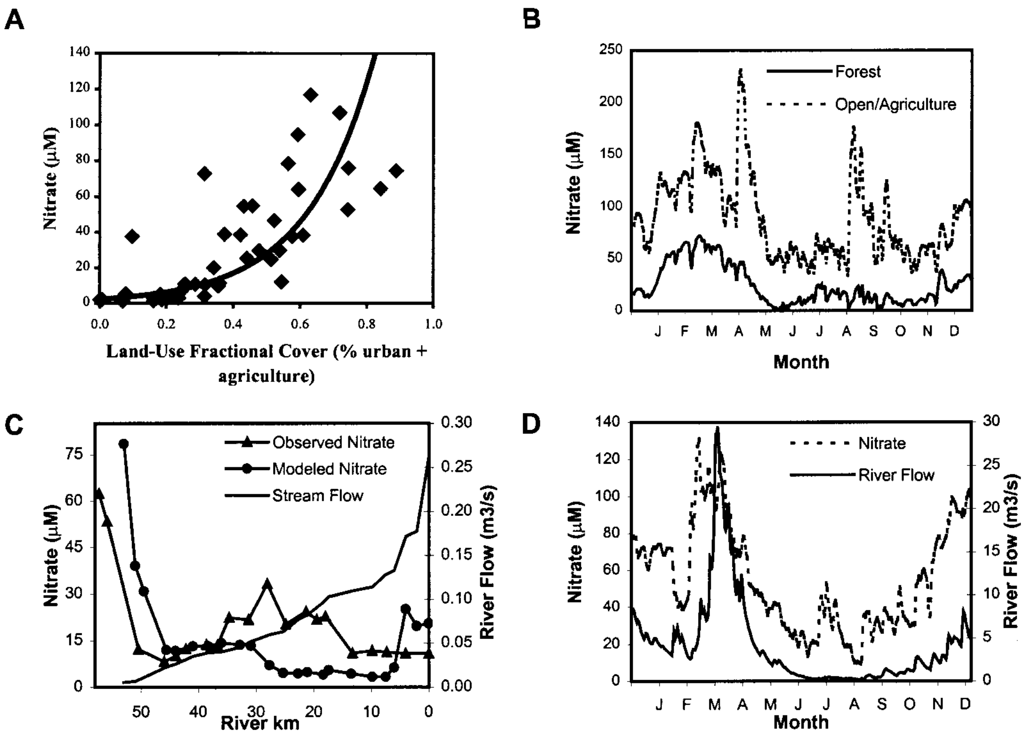

Figure 1. *(A) An empirical relationship between the forest cover in a catchment and the nitrate concentration in streams draining the catchment. (B) Modeled nitrate concentration timeseries in first-order streams with all forest and all open plus agriculture contributing land area. (C) Modeled nitrate concentration and stream flow transect along the main stem of the Ipswich River in July 1993, and observed nitrate data from July 1998. (D) Modeled nitrate concentration and river flow at the mouth of the Ipswich River over the course of 1993.*

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Solute Dynamics in Storm Flow of the Ipswich River Basin: Effects of Land Use

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The Ipswich River in northeastern Massachusetts has supplied surrounding suburban communities with water since the 1800s. With current projections of increased urbanization in the watershed (1), solute fluxes from developed areas may have an impact on the ecology of the Ipswich River. Solute fluxes from storm flow are particularly important since storms commonly flush solutes from storage reservoirs, thereby increasing the mass transfer of solutes to the aquatic system (2). The objectives of this study were to observe solute dynamics in storm flow in three first-order catchments of the Ipswich River basin to infer how increased development will affect the aquatic system.

The three catchments were selected to represent the end-members of different land-use areas commonly found in the Ipswich River basin. The catchments represent predominately urban (URB), agricultural (AG) and forested (FOR) areas. The baseline discharges were 100, 0.4 and 10 l/s at the URB, AG and FOR sites, respectively. Rain volume at each site was measured using manual rain gauges, and samples for chemical analyses were collected.