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Linkages of nitrate losses in watersheds to hydrological processes

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Nitrogen Saturation in Watersheds

A variety of factors can affect NO_3^- concentrations in surface waters, including atmospheric nitrogen (N) deposition, fertilizer N inputs, wastewater N contaminants, internal N cycling processes (e.g. plant uptake, mineralization, nitrification, denitrification) and hydrological flowpaths. Elevated levels of N inputs to ecosystems due to anthropogenic influences may have profound effects, including alterations of biotic diversity and N cycling (Vitousek *et al*., 1997). The dominant N solute in surface and ground waters for those systems experiencing 'N saturation' is often NO_3^-, with NH_4^+ and dissolved organic N (DON) generally being of lesser importance. In contrast, DON often predominates in systems with lower total N (TN) concentrations. 'Nitrogen saturation' can be defined as an increase in NO_3^- when N sources exceed the biotic demand for this element. Stages of 'N saturation' in catchments have been described as a continuum with increasing NO_3^- concentrations and changes in the seasonal patterns of NO_3^- in surface waters (Stoddard, 1994). Elevated NO_3^- can contribute to freshwater acidification and coastal eutrophication.

Relationships between hydrological flowpaths and nitrate

There are complex relationships among hydrology, chemical and biotic processes that affect N cycling. Hydrological flowpaths affect not only the sources of N, but also the relative influence of various biochemical processes on N transformations (Cirmo and McDonnell, 1997). In some catchments NO_3^- can be consumed in streams, riparian areas, groundwater (Groffman *et al*., 1996), hyporheic zones (Triska *et al*., 1993) and wetlands (mostly due to denitrification), whereas in other catchments some of these zones may be NO_3^- sources (Ohrui and Mitchell, 1998). The relative importance of these zones in affecting the temporal patterns and concentrations of NO_3^- is a function of not only the strength of various biotic transformations, but also the ways these zones are hydrologically connected.

Temporal patterns can have a major influence on NO_3^- export. For example, the importance of spring snowmelt episodes to NO_3^- loss in snow-dominated systems has been clearly demonstrated. Although some of the NO_3^- is derived directly from the snowpack

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itself, most of the NO_3^- is lost by the water draining through the soil. During the dormant season, N is not taken up by the vegetation, allowing more N to be available for microbial N mineralization and subsequent nitrification. Not only can snowmelt periods dominate annual NO_3^- export from small, upland catchments, these episodes can also lead to acidification of surface waters with low acid-neutralizing capacity. Such areas are found in some regions of North America and Europe. This 'episodic acidification' can be deleterious to water quality and the aquatic biota.

The influence of temporal patterns of hydrology on NO_3^- has also been shown for temperate forest catchments in Japan. In contrast to much of North America and Europe, NO_3^- exports and concentrations are highest during the summer on Honshu Island. During the summer, high temperatures and elevated precipitation in Japan contribute to high rates of nitrification and elevated NO_3^- concentrations in drainage waters. Within Japan this elevated NO_3^- does not result in acidification of surface waters since most drainage waters have high acid-neutralizing capacities (Ohte *et al.*, 2001).

Catchments with high landscape heterogeneity (e.g. uplands, wetlands, streams and lakes) show different spatial and temporal patterns in the relative importance of biotic and abiotic processes affecting N retention and NO_3^- loss (Inamdar *et al.*, 2000). The importance of hydrological pathways has been demonstrated in Ontario, Canada, by a modelling approach that linked hydrological and biogeochemical processes and showed how topographic features can be used to explain much of the variability in NO_3^- export among small watersheds (Creed and Band, 1998). Burns *et al.* (1998) have suggested for Catskill Mountain watersheds in New York, USA that deep groundwaters with high concentrations of NO_3^- may be an important source of N in surface waters during periods of baseflow when groundwater would be the major contributor. However, Lovett *et al.* (2000) have argued that the differences in the spatial patterns in surface water NO_3^- concentrations in the Catskill Mountains are mostly attributed to differences in forest species composition and forest history that affect N retention. Thus, there is some controversy on the relative importance of biotic versus hydrologic processes affecting NO_3^- concentrations in drainage waters.

Research needs

Concomitant evaluation of the interrelationships between hydrology and biotic processes is clearly needed. Recent advances using isotopic tracer techniques have advanced our ability to identify sources and sinks of N and follow water pathways (Kendall, 1998). Various groups are currently using these techniques (e.g. Hill *et al.*, 2000; Mitchell *et al.*, 2001). However, biogeochemical and hydrological relationships need to be better integrated and tested in models that predict NO_3^- concentrations in catchment surface waters. Some of the models place more emphasis on biotic processes (e.g. PnET–BGC; Gbondo-Tugbawa *et al.*, 2001), whereas other models emphasize hydrological components (e.g. TOPMODEL; Creed and Band, 1998). These models need to be developed and tested with actual field measurements that include both hydrologic and biogeochemical processes. Moreover, anthropogenic influences such as agriculture, suburbanization, urbanization and industrialization, which can dominate N inputs, should be included in these models, especially across broad regions with significant human influences. Measuring hydrological and biogeochemical parameters within and across a range of catchments with different hydrological regimes, vegetation types, disturbance histories, and anthropogenic influences will be very useful in developing model predictions of how changes in atmospheric inputs, climatic regimes and land use will affect retention and/or loss of N to surface waters.

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