The U.S. Geological Survey National Water-Quality Assessment Program: Advances in Understanding Sources, Transport, and the Biological Effects of Nutrients From Headwater Streams to Coastal Rivers

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Abstract:

The U.S. Geological Survey (USGS) implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to provide nationally consistent information on the status and long-term changes in the physical, chemical, and biological condition of streams and rivers. This information directly supports national, regional, state, and local information needs and decisions related to water-quality management and policy. The NAWQA Program uses a combination of monitoring-based observations and watershed models to assess nutrient and biological conditions in streams, nutrient transport from headwaters to coastal waters, and effects of human activities and natural processes on nutrient conditions. Agricultural and urban land uses are major sources of stream nutrients, with the highest nitrogen concentrations associated with agricultural streams and the highest phosphorus concentrations associated with agricultural and urban streams. NAWQA studies of nitrogen processing in small streams indicate that some nutrient-enriched agricultural streams are ineffective at removing nitrogen from the water column because of high nutrient inputs and reduced retention time, and therefore, export a large fraction of their nitrogen load to downstream waters. Although biological communities in streams are influenced by various natural and anthropogenic factors, nutrient enrichment has a strong influence on biological communities. For example, the condition of algal, macroinvertebrate, and fish communities decreased in streams nationwide as nutrient concentrations increased. Additionally, regional- and national-scale models were developed that provided information on the downstream fate of nutrients and the effect of hydrological and biogeochemical processes on delivery of nitrogen and phosphorus loads from inland watersheds to coastal estuaries. These assessments reveal that agricultural sources (cultivated crops, livestock manure) in the central and eastern Mississippi River Basin contribute most of the nitrogen and phosphorus to the northern Gulf of Mexico, where elevated nutrients have contributed to long-term seasonal hypoxia. New regional-scale models, based on updated geospatial and stream monitoring data, are currently under development for six major river basins of the conterminous United States. Results from these models will be used to identify the nutrient sources and watersheds that contribute elevated nutrient loads to estuaries and other receiving waters, including those in the South Atlantic and Gulf of Mexico, inland and coastal waters of the Northeast, the Upper Mississippi and Great Lakes, and Puget Sound.

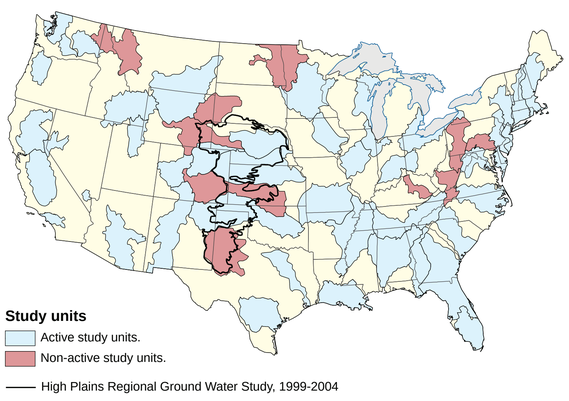


Figure 1. National Water-Quality Assessment Program study units.

Introduction:

The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to develop long-term consistent and comparable information on streams, rivers, and ground water in support of national, regional, state, and local information needs and decisions related to water-quality management and policy. The NAWQA program is designed to address: (1) what is the condition of our Nation's streams, rivers, and ground water, (2) how are these conditions changing over time, and (3) how do natural features and human activities affect these conditions, and where are those effects most pronounced? Nutrients are major components of the NAWQA Program and a wide variety of approaches are used to address nutrient-related issues. These include a combination of monitoring-based observations and watershed models to assess nutrient and biological conditions in streams, nutrient transport from headwaters to coastal waters, and effects of human activities and natural processes on nutrient conditions.

Nonpoint Nutrient Sources to Streams and Rivers

Variations in the occurrence and distribution of nutrients in streams partly reflect differences in land use and associated nutrient sources. Commercial fertilizers are a dominant non-point source of stream nutrients in agricultural and urban watersheds, with animal manure also an important source of nutrients in both land uses. In undeveloped areas (<10 percent agriculture), the dominant source of phosphorus is manure and the dominant source of nitrogen is manure (confined and unconfined livestock) and atmospheric deposition (fig. 2).

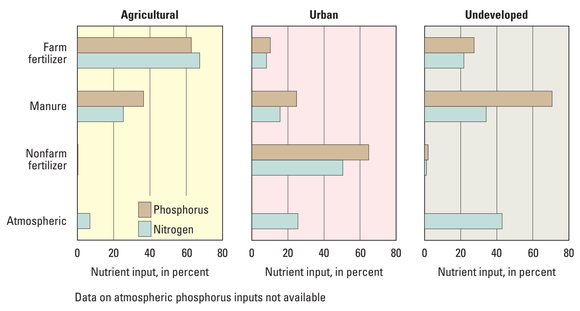


Figure 2. Relative inputs of nitrogen and phosphorus by land use.

Biological Communities Reflect Nutrient Conditions

Although biological communities in streams are influenced by various natural and anthropogenic factors, nutrient enrichment has a strong influence on biological communities. Biological condition (see figure 3 caption) for algal, macroinvertebrate, and fish communities decreased with increasing concentrations of nitrogen and phosphorus in streams (fig. 3). Of the three taxonomic groups, algae show the strongest response to increased nutrient concentrations. On average—based on categories of nutrient enrichment for total nitrogen and total phosphorus—biological condition for algal communities in high nutrient streams decreased 37 percent compared to communities in low nutrient streams. In comparison, biological condition in high nutrient streams decreased by 18 percent for fish communities and by 12 percent for macroinvertebrate communities compared to respective communities in low nutrient streams.

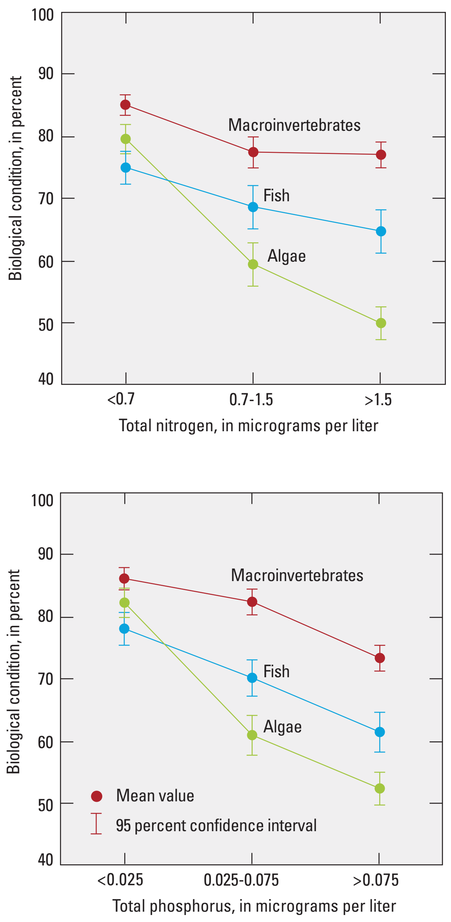
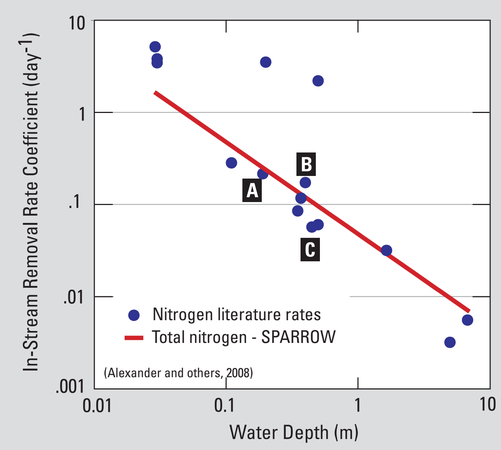


Figure 3. Biological condition for algae, macroinvertebrate, and fish communities in streams as a function of nutrient category. Biological condition scores for each community at about 1,400 stream sites across the Nation were calculated by determining the observed number of taxa and the expected number of taxa if the community was minimally disturbed by human activity. The observed value is derived from a sample collected at a site and the expected value is estimated with data from a set of environmentally similar reference sites. The ratio of observed to expected is expressed as a percentage. Data points represent mean values (280-480 sites per data point) with whiskers showing the 95 percent confidence intervals.

Headwater Streams as Nutrient Filtering Systems

Headwater streams play a critical role in reducing nutrients due to biological uptake and transformations, whereas larger rivers tend to transport nutrients to downstream receiving waters. Nitrogen removal from a stream is often expressed as an in-stream removal rate coefficient, which generally describes the fraction of the nitrogen concentration or load that is removed per day of water travel time in a stream. This rate coefficient is theoretically expected to decline with increases in water depth or stream size, a relation that has been observed in field- and model-based studies of denitrification and long-term storage processes in streams (fig. 4). Recent studies by Duff et al. (2008) of nitrogen removal rates in three agricultural streams found general agreement with the available literature for removal rates for nitrogen (fig. 4). However, the agricultural stream in Washington (fig. 4C) had a lower nitrogen removal rate due in large part to irrigation practices, which reduces retention time.



A: Nebraska–Broad and shallow, low organic matter, autotrophic, open canopy, moderate travel time.

B: Delaware–Narrow and deep, high organic matter, heterotrophic, closed canopy, slow travel rate.

C: Washington–Narrow and deep, high organic matter, autotrophic, open canopy, fast travel time.

Figure 4. Comparison of instream removal rates of nitrogen in three agricultural streams.

Sparrow Modeling - *Enhancing the Understanding of Nutrient Flux in Streams and Rivers across the Nation.*

The transport of excessive amounts of nitrogen in streams and rivers can result in eutrophication in downstream lakes, reservoirs, and estuaries, adversely affecting water quality for human use and aquatic ecosystems. To assist in efforts by Federal, State, and local water-resource managers to reduce nitrogen loading to these sensitive water bodies, the USGS has developed a predictive model of nitrogen transport in streams (SPAtially Referenced Regression On Watershed attributes, SPARROW) that can be used to help:

- predict mean annual nutrient loads in unmonitored stream reaches and in unmonitored reservoir and estuary inflow;
- estimate the proportion of nutrient load instream originating from different sources; and
- identify upstream areas estimated to contribute the largest nutrient load to reservoirs and estuaries.

A regional SPARROW model of nitrogen transport in southeastern United States streams (Hoos and McMahon, 2009) provides estimates of instream nutrient load and concentration for 8,000 stream reaches and delivered load to 170 reservoirs and 30 estuaries throughout the southeastern United States. Regional SPARROW models of in-stream nitrogen and phosphorus transport for the other major hydrologic regions of the United States are under development (fig. 5).

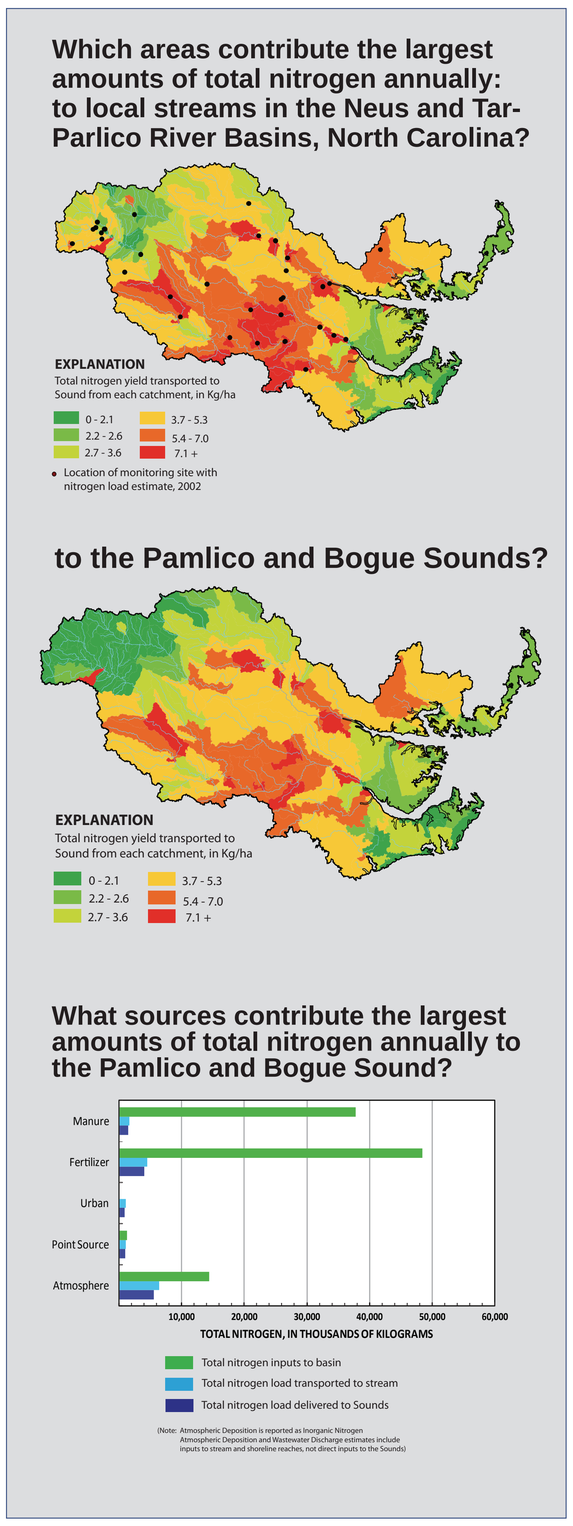


Figure 5. Total nitrogen to stream basins and coastal waters, North Carolina.

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Hoos, A.B., and others, 2008, Data to support statistical modeling of instream nutrient load based on watershed attributes, southeastern United States, 2002: U.S. Geological Survey Open-File Report 2008-1163, 50 p. Available online at http://pubs.usgs.gov/of/2008/1163/

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National Water-Quality Assessment (NAWQA) Program: ***http://water.usgs.gov/nawqa/***

National Nutrient Synthesis: ***http://water.usgs.gov/nawqa/nutrients/***

National Ecological Synthesis: ***http://water.usgs.gov/nawqa/ecology/***

Effects of Nutrients on Agricultural Stream Ecosystems: ***http://wa.water.usgs.gov/neet/***

SPARROW modeling: ***http://water.usgs.gov/nawqa/sparrow/***