Moving from Monitoring to Prediction: The Quality of the Nation's Streams

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Successful management of our Nation's water resources requires a commitment not only to monitoring but also to the development of predictive tools such as models. Such tools are needed to extrapolate measured water-quality conditions to unmonitored, comparable areas.

This ability to extrapolate or make predictions is critical for cost-effective assessment of our Nation's streams, which requires more information than can be measured directly in all places and at all times. The expense of monitoring limits the number of stream miles that can be measured. As noted in the most recent 305b reports, for example, States have assessed only about 20 percent of the more than 3.7 million stream miles in the Nation.

Models are powerful tools. They can be used to assess water quality over broad regions and the Nation. In addition, models can establish linkages between water-quality conditions and contaminant sources on land; track contaminants from their upstream origins to downstream destinations; and simulate changes in water quality resulting from management actions or trends in human activities. Such information provides estimates of conditions that often cannot be directly measured, such as the percentage of contamination in a stream that originates from different sources or the effects of specific pollution controls.

However, models are incomplete tools without monitoring—i.e., direct measurements or observations of water-quality conditions, contaminant sources, and factors that control the movement of contaminants on land and in water. Model predictions are only reliable and successful if they are developed and verified on the basis of credible, comparable, and comprehensive data from "on-the-ground" monitoring, assessment, and research.

SPARROW—A USGS model used to assess water quality

USGS scientists developed the SPARROW (SPAtially Referenced Regression On Watershed attributes) model to better understand the linkages between monitoring data collected at a large network of sampling stations and the watershed factors that determine water quality. The model correlates *contaminant loads* (or the mass of contaminants transported downstream past a point on a river) with

- *upstream sources,* such as fertilizer, manure application, wastewater discharges, and the atmosphere, and
- *watershed characteristics* affecting contaminant transport, including soil permeability, stream channel size, and streamflow.

Model predictions reflect repeated sampling of hydrologic and contaminant conditions over multiple years (reported as long-term annual average conditions).

Examples of SPARROW results presented in this briefing sheet include (1) in-stream concentrations of phosphorus that meet the recommended goal of the U.S. Environmental Protection Agency (USEPA); (2) sources of nitrogen pollution and their relative impacts on nitrogen concentrations in the Mississippi River basin and the Gulf of Mexico; and, (3) effects of changes in livestock production on concentrations of fecal coliform bacteria in streams and rivers.

Phosphorus concentrations related to the USEPA-recommended goal

SPARROW is used to predict concentrations of phosphorus in streams and rivers across the Nation that meet the USEPA recommended goal (0.1 milligrams per liter) to control excessive growth of algae

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Model estimates show that the percentage of stream miles meeting the USEPA recommended goal for phosphorus varies regionally (presented by water-resource regions). Note that the margin of error associated with model findings tends to be smaller for larger regions; for example, compare the margin of error for the entire U.S. (+/- 2.5 percentage points) to that for New England (+/- 7.5 percentage points) and in the Great Basin (+/- 12.3 percentage points) (Smith and others, 1997).

Water resource region	Percentage of stream miles meeting USEPA recommended goal (0.1 milligrams per liter)	Margin of error (+/- percentage)
U.S. (48 States)	39.4	2.5
New England	83.8	7.5
Mid-Atlantic	59.8	6.8
South Atlantic	58.0	5.0
Great Lakes	56.2	5.2
Ohio	51.1	6.3
Tennessee	70.9	10.9
Upper Mississippi	18.5	3.8
Lower Mississippi	47.1	8.0
Souris-Red-Rainy	21.7	7.0
Missouri	18.0	3.7
Arkansas-White-Red	18.9	5.0
Texas Gulf	21.2	5.1
Rio Grande	34.4	8.2
Upper Colorado	33.9	8.1
Lower Colorado	10.8	4.7
Great Basin	24.1	12.3
Pacific Northwest	67.3	3.9
California	45.3	5.7

and other nuisance plants. The phosphorus model was developed with USGS data on total phosphorus collected from 419 monitoring stations between 1975 and 1992.

Model results indicate that only about 40 percent of U.S. stream miles meet the recommended goal. Concentrations vary regionally; for example, about 20 percent of stream miles in the Upper Mississippi River basin meet the goal versus nearly 85 percent in New England. Such findings help to identify regions that are most vulnerable to elevated concentrations of phosphorus and contribute scientifically defensible information to the development of regional water-quality criteria for nutrients.

Nitrogen delivered to the Gulf of Mexico

SPARROW is used to quantify the relative contributions of sources of nitrogen to the Gulf of Mexico from the Mississippi River basin. Nitrogen in the Mississippi River that reaches the Gulf of Mexico has been cited as the leading cause of excessive algal growth and low dissolved oxygen in the Gulf.

Model results indicate that fertilizers contribute about 50 percent of the nitrogen; livestock, municipal wastewater, and the atmosphere each contribute from 10 to 20 percent.

Agricultural sources (i.e., fertilizers and livestock wastes) in the Midwest contribute some of the highest quantities of nitrogen. Municipal wastewater sources—some as far away as Pittsburgh—also can contribute large quantities.

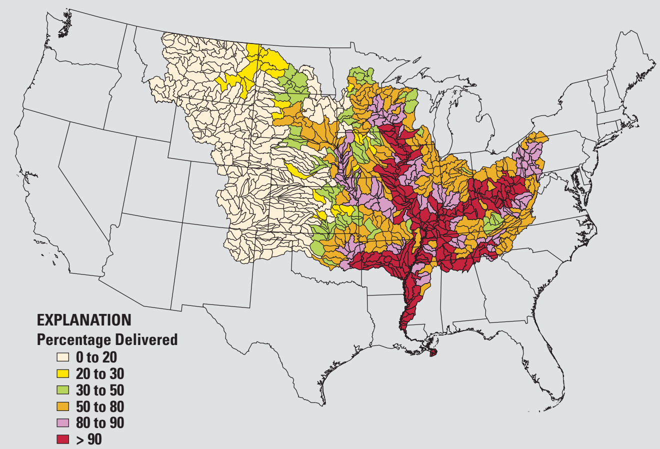
However, only about 15 percent of nitrogen released in the Mississippi River basin ultimately reaches the Gulf. The remaining nitrogen is taken up by crops or is stored or removed from soils and streams and rivers by a process called denitrification—the conversion of nitrogen to an innocuous gas by bacteria. Understanding where nitrogen loss occurs is, therefore, critical to quantifying sources and identifying watersheds that are primarily responsible for nitrogen delivery to the Gulf of Mexico.

Model results show that nitrogen loss in streams decreases rapidly as channel size increases. Therefore, despite long travel times, sources in watersheds close to large rivers—even those more than 1,500 miles from the Gulf—contribute a much larger percentage of nitrogen to the Gulf as compared to those watersheds located on smaller streams only a few hundred miles from the Gulf. The delivery of nitrogen to coastal waters from both point and nonpoint sources, therefore, is not simply a function of the distance of these sources from coastal waters.

These findings have important implications for nutrient management. The information can help States, Federal agencies, and other stakeholders target types of sources—such as from agricultural fields, livestock operations, urban runoff, and wastewater discharges—in the implementation of nutrient loss strategies.

In addition, model findings can be used to identify watersheds where it would be most cost effective to implement such strategies. For example, when the State of Kansas was developing its 2004 Nutrient Reduction Plan (as required by Section 204a of the Clean Water Act), USGS model results helped with identifying watersheds where nitrogen reductions would likely have the most beneficial effects on deliveries to the Gulf of Mexico (Kansas Department of Health and Environment, 2004).

Overall, the model suggests that it would be most efficient to control nitrogen in watersheds drained by large rivers with low rates of natural nitrogen loss (shown in red on the map). Removal of one pound of nitrogen in these larger rivers would cause a similar reduction in nitrogen delivered to the Gulf of Mexico. By contrast, removal of 2 to 3 pounds of nitrogen would be required in smaller watersheds with higher



Model findings show that the delivery of nitrogen to coastal waters from both point and nonpoint sources is not simply a function of the distance of these sources from coastal waters. In-stream nitrogen delivered to the Gulf of Mexico is greatest in those watersheds located along large rivers, as far as 1,500 miles away, as compared to those watersheds located on smaller streams only a few hundred miles from the Gulf (Alexander and others, 2000).

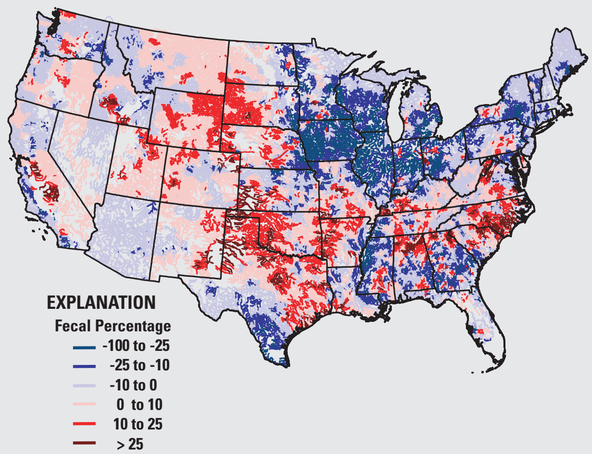
natural rates of nitrogen loss (shown in green on the map) to achieve a one-pound reduction in nitrogen delivery to the Gulf.

Agricultural sources in the Midwest contribute some of the highest quantities of nitrogen to the Gulf of Mexico from the Mississippi River Basin. Municipal wastewater sources—some as far away as Pittsburgh—also can contribute large quantities.

Fecal coliform concentrations related to livestock production

Models can be used to simulate water-quality conditions given a change in human activities, including those reflecting business or economic trends. For example, animal agriculture has undergone major structural changes in the United States over the past two decades. While the total number of animal units on farms has remained nearly unchanged (only about a 7 percent increase), the number of livestock producers has declined dramatically and the average size of the operations has increased substantially. This trend raises obvious questions about the effects of animal agriculture on water quality in regions where livestock production has become more intense.

SPARROW was used to predict the effects of changing the number and size of livestock operations, holding all other sources of fecal coliform constant. Model results showed that, nationally, fecal coliform contamination in U.S. streams and rivers from livestock waste remained relatively constant between the early 1980s and late 1990s. Annual average concentrations



Model simulations show that concentrations of fecal coliform bacteria increased in many areas of the Great Plains, Ozarks, and the Carolinas as a result of changes in confined and unconfined livestock production from 1982 to 1997 (Smith, Alexander, and Schwarz, 2004).

exceeded 1,000 colonies per 100 milliliters in about half of total U.S. stream miles throughout the period (a common State standard for recreational waters is 200 colonies per 100 milliliters).

The effects of changes in the livestock industry varied regionally, however; model simulations indicated that fecal coliform concentrations increased in many areas of the Great Plains, Ozarks, and the Carolinas, and decreased in most of the Upper Mississippi Basin and in parts of the Deep South and Northeast.

Model results also indicated that, on average across the Nation, a unit of animal waste from confined operations introduced only about 40 percent of the fecal coliform bacteria to streams that is introduced by the same amount of waste from unconfined operations. The difference may be, in part, because unconfined animals are free to wander close to, and even in, streams; and because the relatively large and concentrated amount of waste generated in confined operations is managed and stored through more tightly controlled systems, such as lagoons. These findings, although preliminary, may eventually help to lessen the effects of animal agriculture on water quality.

In summary

Models play an essential role in the assessment of water quality over broad regions and the Nation. They provide a cost-effective approach—particularly when the expense of monitoring limits the number of streams that can be measured during varying streamflow conditions—for prioritizing water resources for protection and restoration; targeting sources of pollution, and designing more efficient and integrated monitoring programs. As models are used to assess other pollutants, such as suspended sediment and pesticides, it is critical to remember that models are successful only if they are developed and verified on the basis of "on-the-ground" monitoring. The integration of monitoring and modeling is the key to our future understanding of the Nation's water quality.

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Details and publications on SPARROW can be accessed at http://water.usgs.gov/nawqa/sparrow