Monitoring in the 21st Century to Address our Nation's Water-Resource Questions

By Timothy L. Miller
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A time of increasing complexity

Water-quality monitoring has become a high priority across the Nation, in large part because the issues are more complex and money is tighter. The demand for high-quality water is increasing in order to support a complex web of human activities and fishery and wildlife needs. This increasing demand for water, along with population growth and point and nonpoint sources of pollution, threatens the quality *and* quantity—and therefore the availability—of all our water resources.

This is a challenge all across the country. Areas once thought of as "water rich"—mostly in terms of limitless availability—are now considered "water challenged," such as in southern Florida, where available water must support 6 million people along their coasts, extensive agriculture south of Lake Okeechobee, and ecosystems in the Everglades and the Florida Bay. No longer is only the arid western U.S. challenged to manage its water needs for drinking, irrigation, aquatic ecosystems, and recreation.

As was acknowledged more than 30 years ago when the Clean Water Act was implemented, monitoring is fundamental to successful management of water resources. However, the nature of monitoring must adapt to increasingly complex water demands and issues. Monitoring is no longer limited to "end of pipe" site-specific data on dissolved oxygen or suspended solids, collected for day-to-day evaluations of compliance or decisions about permitting. Three specific challenges force a shift in monitoring since the implementation of the Clean Water Act.

- Most water-quality problems are caused by diffuse "nonpoint" sources of pollution from agricultural land, urban development, forest harvesting, and the atmosphere. These sources are more difficult to monitor, evaluate, and control than point sources, such as discharges of sewage and industrial waste. The amount of pollution from nonpoint sources varies from hour-to-hour and season-to-season, making it difficult to monitor and quantify the sources over time.
- Water-quality issues themselves have become more complex. Forty years ago, concerns about water quality focused largely on the sanitary quality of rivers and streams—in bacteria counts, nutrients, dissolved oxygen for fish, and a few measures like temperature and salinity. While these factors are still important, new and more complex issues have emerged. Hundreds of synthetic organic compounds, like pesticides and volatile organic compounds (VOCs) in solvents and gasoline have been introduced into the environment. Over the last 10 years, improved laboratory techniques have led to the "discovery" in our waters of microbial and viral contaminants, pharmaceuticals, and hormones that weren't measured before.
- Evaluation and monitoring of pollution sources and of the condition of our water resources have been limited because available information is fragmented. Inconsistency in the types of data collected, the standards and analytical methods used, and the selection of monitoring sites makes it difficult to integrate the findings.

Different questions require different kinds of monitoring

It's important to understand that one monitoring design cannot solve all of our water-resource issues or questions. For example, depending on specific interests or responsibilities, one might ask:

- Is the water meeting beneficial uses; that is, is it acceptable for drinking or swimming or irrigation or for sustaining aquatic habitat?

- What percentage of streams is impaired within a State?
- Are regulatory requirements being met? Are concentrations or loads below those allowed in discharge permits?
- How does the water quality of one water body compare with those nearby or across the Nation?
- Is water quality getting better or worse? Does water quality change during certain times of the year?
- What are the sources of contaminants and causes of the problems?
- How do changes in land use or management practices affect water quality?

None of these questions is easy to answer, and each requires a different kind of monitoring—a specific set of data collected in certain places and at certain times. So, undoubtedly, monitoring designs end up being unique or different—varying in the timescales and spatial scales covered. The process, however, is always the same. The process begins with clearly defining the water-resource questions; outlining the decisions that will be made from the data; and then identifying the data (or monitoring) needed to make the decision.

Water-resource issues or questions determine monitoring objectives. And the objectives determine the monitoring design. No design, therefore, is "better" or "more successful" than another. Success is measured by whether the monitoring design addresses the specific objectives.

Different types of monitoring—such as "probabilistic" and "targeted" designs—answer different sets of questions. Although both of these designs can contribute to statewide, regional, or national assessments, and improve understanding of the general or "ambient" water resource, they provide different types of information. Both types of monitoring are important, and therefore, should not be viewed as competitive or duplicative, and both need support with adequate funding. In fact, these designs are so different that discussions should not focus on whether one design can substitute for another but on how to integrate the two in order to go beyond what each can provide individually, particularly in predicting conditions in unmonitored areas. This can be illustrated by addressing an overarching question driving many discussions "What is the quality of our Nation's waters?"

Monitoring the quality of our Nation's waters

What monitoring design best answers ***"What is the quality of our Nation's waters?"*** Again, it depends on specific objectives and questions.

To some, this may reflect an overall assessment of the resource as required in the Clean Water Act section 305(b): "What percentage of the Nation's waters is impaired? What percentage is in good condition? What percentage of streams is meeting their beneficial uses?"

Such questions require a broad-based probabilistic monitoring design, in which sites are chosen randomly and are distributed across a certain region. This type of monitoring provides a quantitative, statistically valid estimate of, for example, the number of impaired stream miles within a region or State.

Probabilistic monitoring and assessments help to document what is going well (how much of the resource is in good condition) and what is not (how much is in poor condition). The data collected help decision makers prioritize regions having the most degraded waters and assess which stressors—such as nutrients, sedimentation, and habitat disturbance—are of most importance in that region or State. Many probabilistic monitoring programs are currently implemented by States and within the U.S. Environmental Protection Agency, such as the Environmental Monitoring and Assessment Program (EMAP).

Probabilistic monitoring is a useful and cost-effective method for getting an unbiased, broad geographic snapshot of "whether there is a problem" and "how big the problem is."

To others, "assessing the Nation's waters" leads to other questions, including "Why are water-quality conditions happening and when? Do certain natural features, land uses, or human activities, and management actions affect the occurrence and movement of certain contaminants? Are water conditions changing over time? "

These are equally important questions, but require a “targeted” monitoring design that focuses on understanding the relations between water-quality conditions and the natural and human factors that cause those conditions. Monitoring sites are therefore not selected randomly within a grid, but because they represent certain human activities, environmental settings, or hydrologic conditions during different seasons or times of year. For example, sites may be selected to assess the effects of agriculture and urban development on pesticide and nutrient contamination in streams.

A “targeted” monitoring design requires data collection . . .

- **Over different seasons**. This is important because, for example, USGS assessments generally show low concentrations of contaminants, such as pesticides, in streams for most of the year—lower than most standards and guidelines established to protect aquatic life and human health. However, the assessments also show pulses of elevated concentrations—often 100 to 1,000 times greater in magnitude, exceeding standards and guidelines—during times of the year associated with rainfall and applications of chemicals. Such pulses could affect aquatic life at critical points in the life cycle and also could affect drinking water.

- **In different land uses**, including agricultural, urban, and more pristine land-use settings. USGS assessments show that water conditions are very different among the different settings; insecticides, for example, are more frequently detected at higher concentrations in urban streams than in agricultural streams. Water conditions also are different among different land-use practices; phosphorus, sediment, and selected pesticides, for example, are at higher concentrations in streams draining agricultural fields with furrow irrigation than in agricultural fields with sprinkler irrigation.

- **In different geologic settings**. The setting—whether it is sand and gravel or volcanic rock, for example—affects how readily water moves over the land and into the ground.

- **During different hydrologic conditions.** The amount of streamflow and the timing of high and low flows determine how contaminants are carried in streams, and the connections between streams and ground water determine how the ground water will be affected.

- **Over the long term**. Without comparable data collected over time, assessments cannot distinguish long-term trends from short-term fluctuations and natural fluctuations from effects of human activities. USGS assessments show that water quality continually changes. The changes can be relatively quick—within days, weeks, or months, such as in streams in the Midwest where types of herbicides used on corn and soybeans have changed, or relatively slow, such as in ground water beneath the Delmarva Peninsula where nitrate concentrations are beginning to decrease after 10 years of improved management of nitrogen fertilizers.

Targeted sampling brings an understanding of the causes of water-quality conditions. It establishes relations between water quality and the natural and human factors that affect water quality.

Targeted monitoring and assessments help decision makers to (1) identify streams, aquifers, and watersheds most vulnerable to contamination; (2) target management actions based on causes and sources of pollution; and (3) monitor and measure the effectiveness of those actions over time. Such monitoring would not be necessary if all streams and watersheds responded the same over time. But they *are* different. As shown by targeted assessments across the Nation, such as through the USGS National Water-Quality Assessment (NAWQA) Program, even among similar land uses, the differences in sources, land-use practices, hydrology and other natural factors make one watershed more vulnerable to contamination than another and result in different ways that management strategies can improve water quality.

Integrating the two designs

Neither probabilistic nor targeted monitoring designs answer all questions about the Nation's water resources. While the targeted design cannot provide a quantified estimate of, for example, percentage of streams impaired within a broad geographic region, a probabilistic design cannot account for sources, seasonal differences, varying streamflow and ground-water contributions, or processes that control the movement and quality of water.

Ideally, data collection and monitoring should be consistent and comparable so that the findings can be integrated. National investments and partnerships must commit to increasing the comparability and integration of monitoring in order to enhance our ability to answer critical questions about water resources and understand the quality of the Nation's waters.

Moving from monitoring to predicting

An equally important step in understanding and successfully managing our Nation's waters requires a recognition of and commitment to development and verification of predictive tools and models. Such tools and models are needed to extrapolate or forecast conditions to unmonitored, yet comparable areas—both in space and in time. This is a critical step for cost-effective protection of water resources, particularly in light of diminishing financial resources, which requires more information than can be measured directly in all places and at all times.

Development of predictive tools has come a long way, resulting in improved broad-based assessments of conditions (such as through probabilistic and targeted monitoring), as well as of key factors and processes that affect water quality—including land use, chemical sources of contamination, natural landscape features, and hydrologic transport.

Success will depend on the integration of monitoring and assessment with the predictive models. In other words, it is critical that credible, comparable, and comprehensive information continues to be generated—by means of "on-the-ground" monitoring, assessment, and research—that can be used to validate and verify the predictions. Such integration will lead to more cost-effective and grounded protection and restoration of water resources and more efficient monitoring designs in the future.

USGS contacts for more information:

Timothy L. Miller, Chief, Office of Water Quality
(703)-648-6868
tlmiller@usgs.gov

Donna N. Myers, Chief, NAWQA
(703) 648-5012
dnmyers@usgs.gov

Pixie A. Hamilton, Hydrologist
(804) 261-2602
pahamilt@usgs.gov

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