EDITORIAL

The Increasing Need for Science to Inform Policy—More than 30 Years after Passage of the Clean Water Act

The Clean Water Act (CWA) became law in 1972 in response to images of burning rivers and "dead lakes" and an increasing national consensus that pollution of our rivers and lakes was no longer acceptable. Control of point-source contamination, traced to specific "end-of-pipe" points of discharge or outfalls, such as from municipal dischargers, factories, or combined sewers, was the primary focus of the CWA. Significant progress towards cleaner water has resulted through engineering changes in manufacturing processes and wastewater treatment.

Water-quality issues facing the United States have changed, however, since implementation of the CWA and are now, in large part, focused on nonpoint sources of pollution, such as those associated with agricultural, urban, and suburban activities; forest harvesting; mineral extraction; and atmospheric deposition. We can no longer rely primarily on investments in water treatment technology. Instead, we need to align our monitoring and science with the way that human activities take place on the landscape, predominantly within the "nonpoint-source" context of issues.

The tall order for science and monitoring of water-quality conditions today is to sort out the myriad nonpoint-related sources and stresses that affect water resources and hinder attainment of CWA water-quality standards, whether these resources be for drinking, recreation, or sustaining aquatic life. It demands credible, objective interdisciplinary data on the physical, chemical, and biological conditions of a water body as well as data on the natural landscape and human activities that may contribute to those conditions. Possible explanations for degraded water resources are many, including changes in flow conditions, increases in water temperature and salinity, introduction of toxic chemicals, construction of physical barriers to fish passage, invasive species, disease, and harvesting. Specific factors include, for example,

- Large areas of impermeable surface in urban and suburban landscapes, which can increase the velocity and magnitude of storm flows and, in turn, affect streambed substrate, channel morphology, and essential habitat for fish and wildlife;
- Reduced base flows and/or increased stream temperature from groundwater pumping, which can result in habitats unsuitable for fish and other aquatic species;
- Disturbance in riparian land cover, which can result in bank erosion, removal of vegetation and tree cover, and increased water temperatures, all of which can degrade aquatic habitat;
- Nutrient enrichment, which can lead to algal blooms, light limitations, and large swings in pH levels and concentrations of dissolved oxygen and ammonia;
- Introduction of complex mixtures of organic compounds, such as pesticides, volatile organic compounds, pharmaceuticals, and hormones, which can, even at very low concentrations, adversely affect the health or reproductive success of aquatic organisms;
- Invasive species, which can replace important commercial species and/or result in significant changes in food webs and habitat alterations that are inhospitable to native species; and
- Construction of dams and other physical barriers to fish passage as well as increased harvest pressure by recreational or commercial fishermen, which can reduce species abundance, richness, and diversity.

An understanding of the consequences of human activities, as listed above, needs to be developed within a context of natural factors such as climate, physiography, geologic setting, and soils. Short-term climate swings, including excessively wet and dry periods, can overwhelm human influences. Monitoring the success of water-quality management strategies can best be thought of as a search for a rather modest "signal" from within a large amount of natural "noise" that comes from normal, year-to-year, and seasonal hydrologic fluctuations.

Without appropriately designed monitoring and thoughtful analysis of these fluctuations, the task of evaluating environmental-protection progress becomes quite difficult.

Successful future management of our waters also requires representation of physical, chemical, and biological processes and cause-and-effect factors in conceptual and (or) mathematical models. These models, developed on the basis of data collected at individual sites, help to extrapolate and forecast conditions in unmonitored, yet comparable areas, thereby enhancing the value of our existing data and our understanding of the hydrologic system and water conditions at several scales (including large- and medium-sized river basins, states, and even the country). In addition, models are important tools to help estimate conditions that often cannot be directly measured and predict how changes in our actions within a watershed, such as by adjusting nonpoint and point sources of contamination, converting land use, altering flow regimes, or implementing best-management practices, are likely to affect water conditions.

We should remain mindful that successful extrapolation and forecasting, however, require the ongoing collection of credible, comparable, and comprehensive data. Such data are needed to validate and verify model predictions and reduce the uncertainty of modeled estimates in unmonitored areas and for accurate forecasts. This may require a shift in monitoring designs because much of our current water-quality monitoring is designed for compliance purposes, thus is heavily focused on known problem areas rather than on the whole resource. In addition, we should invest nationally in expanding the collection of ancillary information on landscape features, human activities, and environmental settings. Specifically, we need to gather data on key factors affecting our waters, including our use and disposal of chemicals, land-use changes over time, water use, land-management practices, hydrologic setting, and point sources of contamination. Our understanding of the causes and solutions of water-quality problems will only advance if we have data on water quality and causative factors on the landscape. Our ability to design effective solutions will be greatly limited unless we invest in these relevant geospatial and time-series environmental data sets as part of our investments in water monitoring and science.

In conclusion, well-defined monitoring strategies and careful scientific analysis are needed to address nonpoint-source issues and serve as the key elements for making informed decisions and actions necessary to meet CWA water-quality standards. Because actions can be costly and time-consuming to multiple parties, including governmental agencies, industries, land owners, and the tax-paying public, data and scientific analysis, rather than speculation and conjecture, are even more critical to bring a water body back in the direction of desired uses and services. Complexities in hydrologic systems make the determination of our progress difficult. Therefore, we cannot approach water issues through single-science disciplines and compartmentalized training. Instead, we should promote collaboration and integration of our expertise to the extent possible to achieve a system-scale understanding of the myriad natural and anthropogenic factors affecting water resources and ecosystems. In addition, we need to continue monitoring hydrologic systems over the long term and remain patient and flexible in our analysis, adaptive monitoring and management, and understanding. Only by such investments in scientific efforts will we be able to separate natural from human influences; identify the physical, chemical, and biological processes leading to predictive modeling; create predictive tools with realistic and reliable outcomes; and lead the water community to protect and wisely use our available resources.

Robert M. Hirsch, Pixie A. Hamilton, and Timothy L. Miller
U.S. Geological Survey
National Water-Quality Assessment Program
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