Aquatic Processes and Systems in Perspective

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Introduction

This latest *Perspective on Aquatic Processes* focuses on a topic of great value but one that receives little attention—that of the need for water quality monitoring. Research often gets more attention from the public and from funding agencies, but it is monitoring—particularly long term programs—that provide the necessary data to determine trends in assessing ecosystem health. Monitoring programs have been receiving less and less support (and collecting fewer and fewer data), including those of the venerable U.S. Geological Survey (USGS), which has had water monitoring as central to its mission for 130 years. It is possible that there will not be sufficient data available to assess overall environmental quality trends in the near future. We cannot effectively manage or protect our environment without understanding its condition. Without the proper water monitoring data, we cannot develop models for management or forecasting. This Perspective is contributed by Dr Robert Hirsch and his colleagues at the USGS, and makes a strong case for the need for monitoring and discusses the erosion in support of these programs.

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U.S. Geological Survey perspective on water-quality monitoring and assessment†

Introduction

Protecting and enhancing the quality of rivers and streams has become a high priority across the United States (U.S.), generating substantial discussion and many reports on the current status and needs for monitoring in the future. Several studies, for example, by the Government Accountability Office (2002, 2004),[1,2] and The H. John Heinz III Center for Science, Economics, and the Environment (2002)[3] have documented the inadequacy of current water-quality monitoring efforts in the U.S. in recent years, and point to the lack of consistent and comprehensive, national-level data (Box 1). The studies report that lack of data has lead to (a) possible serious problems that go undetected; (b) a limited ability to develop cost-effective management and regulations; and (c) an inability to determine whether water quality is getting better or worse. (These reports can be accessed directly at http://water.usgs.gov/wicp/acwi/monitoring/network/links.html.) While the U.S. Geological Survey (USGS) acknowledges the issues, and actively participates in many of the ongoing discussions, we would like to address some of the critical scientific considerations that are fundamental to successful water-quality monitoring programs, regardless of, and transcending any organizational and political agendas, regulatory responsibilities, and jurisdictional boundaries.

† The opinions expressed in the following article are entirely those of the author and do not necessarily represent the views of either the Royal Society of Chemistry, the Editor or the Editorial Board of *JEM*.

Box 1: Current status of U.S. water-quality monitoring

Several studies by the Government Accountability Office (GAO, 2002; 2004),[1,2] The H. John Heinz III Center for Science, Economics, and the Environment (2002),[3] National Research Council of the National Academies (2004),[4] and other organizations have documented the inadequacy of water-quality monitoring and assessment efforts in the U.S. Overall findings point to a lack of consistent and comprehensive, national-level data; the possibility that serious problems may go undetected; data gaps that limit cost-effective management and regulation; and a lack of information on whether water quality is getting better or worse. The most recent GAO study was done in response to the 2002 Heinz Center "State of the Nation's Ecosystems" report that identified 100 key indicators needed for monitoring ecosystem health and measuring the efficacy of environmental protection, and reported that high-quality data existed for only half of the indicators. The GAO study noted continued slow financial erosion of U.S. water-quality data, reporting that 6 of 20 Federal programs—including the USGS National Water-Quality Assessment and National Stream Quality Accounting Network Programs—that had produced high-quality environmental indicator data used in the 2002 Heinz report may not be able to continue producing data of comparable quality, quantity, and scope for the planned 2007 Heinz report and more generally over the medium-term future (Government Accountability Office, 2004).[2] Specific findings cited in the GAO report and other reports on monitoring can be accessed at http://water.usgs.gov/wicp/acwi/monitoring/network/links.html.

Changing issues, changing questions

Before the U.S. Clean Water Act was implemented in 1972, many rivers flowing through urban centers were subjected to "point" discharges of sewage and industrial waste. Point source contamination can be traced to specific "end-of-pipe" points of discharge or outfalls, such as from wastewater treatment plants, factories, or combined sewers. Water-quality issues generally were acute in nature, including biologically dead rivers, fish kills, gross contamination, and massive algal blooms. Such issues culminated on June 23, 1969, when Cleveland's oily, contaminated Cuyahoga River caught fire, attributed to wastes dumped into the river by the waterfront industries. The Cuyahoga River became a poster child for the Federal clean water legislation that followed.

Although water-quality violations still occur, the legislation and investments in wastewater-treatment technology that it spawned have had a positive effect on water-quality conditions. Today, the overwhelming majority of water-quality problems are caused by a myriad of "nonpoint" sources of pollution from agricultural, urban, and suburban land; forest harvesting; energy and mineral extraction; and the atmosphere. The U.S. reauthorization of the Clean Water Act in 1987 added some provisions to begin addressing nonpoint sources and storm water, but legislation can carry actions only so far. Monitoring and science must be adapted to support decisions in this predominantly "nonpoint source" context.

The nature of water-quality issues facing the U.S. has substantially changed, both in geographic scale and over time. First, nonpoint-source issues are larger in scale than more localized, site-specific point-source issues, and include many diffuse and widespread origins within a watershed and even across regions and the nation. Sources and delivery systems are more difficult to pinpoint, evaluate, and control. Second, the amount of pollution delivered is highly variable—from hour to hour and season to season—making it difficult to quantify nonpoint-source contributions over time. Third, the number of nonpoint-source contaminants is significantly larger than those of 30 years ago, when concerns about water quality focused mostly on the sanitary quality of rivers and streams, including bacteria, turbidity, temperature, nutrients, and dissolved-oxygen concentrations. While these factors are still important, over the last 25 years new and more complex issues have emerged. For example, hundreds of synthetic organic compounds, including pesticides and volatile organic compounds (VOCs) in solvents and gasoline have been introduced into the environment. Fourth, nonpoint-source contamination is subject to, and largely influenced by, the natural and altered landscape and the type of human activities that take place on that landscape as water and associated contaminants move over the land and into the ground. Even given similar nonpoint sources within a watershed, differences in hydrologic processes and delivery mechanisms, land-management activities, and natural features, such as soils, geology, topography, and climate may result in one watershed being more vulnerable to contamination than another, and thus require different management strategies to protect or improve water quality.

Successful implementation of nonpoint controls and support in the political and legal systems depends on monitoring systems that help to identify and quantify possible nonpoint sources. Equally important, monitoring must clearly link water-quality conditions with the causes of those conditions, which are in turn related to the natural landscape, hydrologic processes, and human activities—building towards an understanding of how, when, where, and why water-quality conditions vary among watersheds across the nation. Sustainable, high-quality water and effective decision-making depend greatly on this scientific understanding.

Monitoring for scientific understanding of how and why watersheds work

What does monitoring for scientific understanding really entail? Primarily, it requires a design (referred to here as "targeted") in which sites are selected 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 land-use practices on pesticide and nutrient contamination in streams. A targeted monitoring design requires ancillary information on land use, chemical sources of contamination, natural landscape features, and hydrologic transport. Such a design also requires the collection of various data.

Data required for a targeted monitoring design

Over different seasons. 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—commonly 100 to 1000 times higher—during times of the year associated with rainfall and chemical applications than during other times of the year (Gilliom *et al.*, 2006).[5] Such pulses could affect aquatic life at critical points in the life cycle and also affect drinking-water supplies for short periods. These conditions cannot be described in a meaningful way unless repetitive, time- and flow-dependent, monitoring is conducted at given sampling locations, with a substantial part of that sampling focused at times that are prone to large water-quality changes. Multiple samples are less critical in ground water as changes occur more slowly and generally are less influenced by seasonal conditions or individual hydrologic events.

Among different land uses. Water-quality conditions differ substantially among different land-use settings, such as agricultural, urban and more pristine settings that are relatively undeveloped. USGS studies show, for example, that insecticides occur more frequently and generally at higher concentrations in urban streams than in agricultural streams (Gilliom *et al.*, 2006).[5] Water-quality conditions also vary considerably within land-use settings by crop type and land-use practices. For example, USGS assessments show that concentrations of phosphorus, sediment, and selected pesticides are higher in streams draining agricultural fields with furrow irrigation than in streams draining agricultural fields with sprinkler irrigation (Hamilton *et al.*, 2004).[6]

In different geologic or climatic settings. The setting—whether it is sand and gravel or igneous rock—affects how readily water and associated contaminants move over the land and into the ground. USGS studies show, for example, that ground water underlying intensive agriculture in parts of the Upper Midwest is minimally contaminated where it is protected by relatively impermeable soils and glacial till that cover much of the region, and yet subsurface agricultural tile drains and ditches provide quick pathways for contaminant delivery to streams in this same area (U.S. Geological Survey, 1999).[7] Similarly, climate can have profound effects on water quality. Water-quality conditions associated with a particular land-use practice in a hot, dry climate can differ substantially from those associated with a similar practice in a cold, wet climate.

During different hydrologic conditions. A large part of the variation in water quality at a given location on a stream is determined by stream flow. Amounts of contaminants measured at a sampling location or entering a receiving water body, such as a lake, reservoir, or estuary can increase substantially from year to year simply because of high flows during wet environmental conditions.

Including biological characteristics. Water quality and biological systems are closely interconnected. Aquatic organisms, such as algae, macroinvertebrates, and fish are susceptible to water-quality degradation. Meaningful water-quality assessments therefore depend on biological monitoring and determinations of how the biological response varies among diverse hydrologic settings.

Over the long term. Water quality continually changes. The changes can be relatively quick—within days, weeks, or months, such as demonstrated in streams in the Midwest where the types of herbicides used on corn and soybeans have changed. Or, changes can be relatively slow, such as in aquifers where changes can take decades because of slow ground-water movement (Gilliom *et al.*, 2006).[5] Without comparable data collected over time, long-term trends cannot be distinguished from short-term fluctuations, and natural fluctuations cannot be distinguished from the effects of human activities. Consistent and systematic long-term monitoring also is critical to evaluating whether environmental and management strategies are working, and to choosing the most cost-effective resource-management strategies for the future.

Solving water-resource issues

Targeted monitoring and the resulting scientific understanding help to answer questions, such as "Why do water-quality conditions occur and when? Do certain natural features, land uses, human activities, and management actions affect the occurrence and movement of certain contaminants? Is water quality getting better or worse?" The information helps decision-makers to more cost-effectively: (1) identify and prioritize those streams, aquifers, and watersheds most vulnerable to contamination and in need of protection; (2) target management actions to specific sources and causes of pollution; and (3) evaluate the effectiveness of those actions over time.

The USGS recognizes that one monitoring design cannot solve all water-resource issues or questions (Box 2). For example, probabilistic monitoring, in which sites are selected randomly across a certain region, is a useful method for obtaining an unbiased, broad geographic snapshot of "whether there is a problem" and "how big the problem is." Many probabilistic monitoring programs currently being implemented by States and within the U.S. Environmental Protection Agency (EPA) are providing quantitative, statistically valid estimates of, for example, the number of impaired stream miles within a region or State. Targeted and probabilistic monitoring designs are both important for answering different types of questions and for providing different types of information that are critical for understanding the ambient resource. The two designs, therefore, should not be viewed as competitive or duplicative, and both need to be supported by adequate funding. In fact, these designs are so different that discussions should not focus on

Box 2: Collaboration and cooperation

The USGS adheres to rigorous scientific standards and national quality-assurance programs with uniform methods of sampling and analysis. This approach is crucial for successful comprehensive regional and national assessments that identify current conditions and trends in water-quality conditions. However, no single agency can advance these goals alone, and therefore, the USGS strongly supports the coordination in which the wider water-quality monitoring community is heading. Much of the coordination is spearheaded by the National Water-Quality Monitoring Council (NWQMC) of the Advisory Committee on Water Information (ACWI); information on specific efforts can be accessed at http://water.usgs.gov/wicp/acwi/monitoring/index.html. Primary goals of the NWQMC are to: increase collaboration and partnerships among agencies and non-governmental organizations; standardize sampling and analytical methodology and quality assurance and quality control protocols; promote metadata to allow exchange and integration of data from a variety of organizations; develop stable national monitoring networks; and, integrate data management and data accessibility.

whether one design can substitute for another, but rather on how to integrate the two in order to go beyond what each can provide individually. Ideally, data-collection and laboratory analytical methods should be consistent and comparable so that findings can be integrated.

Hydrologic tenets that underpin successful monitoring

Water monitoring has been central to the USGS mission for nearly 120 years (Box 3). The USGS experience has shown that water information that supports effective decision-making requires recognition of, and commitment to, several fundamental hydrologic tenets that underpin all monitoring.

First, hydrology is a cycle

Water-quality data must be evaluated in a "total resource" context, including all components of the hydrologic cycle. Surface water, ground water, and the atmosphere are all connected, and the interactions among them are crucial to determining water flow, fate and transport of contaminants, and chemical and biological quality. Water quality and watersheds are too often considered solely in terms of rivers and streams and the land draining to those surface-water bodies. Yet, ground water can be a major contributor to rivers, streams, and other surface-water bodies; contaminated aquifers that discharge to waterways can, therefore, become nonpoint-pollution sources. For example, USGS studies show that in the Chesapeake Bay, more than half of the water and the nutrients it carries first travels through the ground-water system, and then is delivered as baseflow to tributary streams or directly into the bay (Bachman *et al.*, 1998).[8]

Quantifying ground-water contribution to surface water is essential to developing total maximum daily loads (TMDLs), issuing permits, and meeting Clean Water Act goals. To ensure that water-quality standards can be attained, for example, Clean Water Act Section 303(d) requires states to identify water bodies impaired by pollution and to establish a TMDL of selected pollutants for each water body. Yet, the percentage of the total contaminant load that is contributed by ground-water inputs rarely is evaluated in estimating stream contaminant loads. Exclusion of ground-water monitoring may prevent a full accounting of all available sources and may limit the effectiveness that TMDLs could have in future stream protection and restoration efforts. Similarly, surface water can be a major contributor to ground water and, therefore, a major nonpoint-contamination source for aquifers, particularly where high-capacity, public-supply wells are located near rivers and streams.

Second, hydrology controls the quality of our waters

Water-quality data must be evaluated in concert with water quantity. Concentrations and types of contaminants and their potential effects on ecosystems and drinking-water supplies vary over time,

Box 3: Mission of the U.S. Geological Survey

The U.S. Geological Survey (USGS) has monitored and assessed the quantity and quality of U.S. streams and ground water since its inception in 1879. Today, the USGS provides information on issues such as availability and suitability of water for public supply and irrigation, aquatic ecosystem health, effects of agriculture and urbanization on water resources, and disposal of radioactive waste. Through its programs, the USGS continues its mission to provide timely and relevant water-resources data and information that is freely available to all levels of government, non-governmental organizations, industry, academia, and the general public. The information provides a scientific basis for decision-making related to resource management and restoration, and how we as individuals interact with our environment. The USGS has no regulatory responsibilities and focuses on monitoring and evaluating the ambient water resource, which is the source of the nation's drinking water and water used for industry, irrigation, and recreation. The USGS monitoring programs thereby complement much of the compliance and regulatory monitoring conducted at the state level. The USGS monitors and assesses a multitude of chemicals, including some that are regulated and some that are unregulated, which helps to address new and emerging water-quality issues. Consistent methodology is used across States, which allows regional and national assessments.

and depend largely on the amount of water flowing in streams and the amounts and directions of ground-water flow. Contaminant concentrations vary greatly between low and high flows, during different seasons of a year, and during different hydrologic regimes—such as periods when snowmelt or ground-water inflow dominates river flow. It is critical to monitor water quality under these different hydrologic conditions, and to evaluate the load of material that is transported in a stream and river and delivered to receiving bodies, such as lakes, reservoirs, estuaries, and bays (this is referred to as the "mass flux", which is the concentration of a compound multiplied by stream flow).

Only part of the water-quality story can be told from monitoring for concentrations of chemical constituents in water without the quantitative hydrologic context and calculation of fluxes. Using the Chesapeake Bay as an example, USGS monitoring from 1985 through 2003 showed that concentrations of nitrogen and phosphorus decreased at 55 and 75 percent, respectively, of the stream sites along the major rivers entering the bay (Langland *et al.*, 2004; Cohn *et al.*, 1989).[9,10] An important conclusion from the concentration data and analysis is that management actions in the bay watershed are having some positive effect in reducing nutrients. However, the "flux story" of the bay is somewhat different, in large part because of high stream flows during 2003. USGS findings indicated that in 2003, fluxes of nitrogen and phosphorus were the second highest since 1990 in some of the large rivers (such as the Potomac and Susquehanna) entering the bay. These fluxes were influenced by near-record river flows from elevated precipitation—2003 represented the third-highest amount of river flow to enter the bay since 1937 when USGS record-keeping began for these rivers. More than twice the amount of river flow entered the bay in 2003 than in 2002, which marked the end of a 3-year drought. As a result, about 3 times the amount of nitrogen, 5 times the amount of phosphorus, and 11 times the amount of sediment entered the bay in 2003 compared to drier times in 2002. High stream flow and resulting high fluxes in 2003 may help to explain why the bay experienced periods of low concentrations of dissolved oxygen (hypoxia) and loss of submerged aquatic vegetation (Langland *et al.*, 2004).[9]

Third, hydrology controls much of the timing of our water issues

We must be patient, persistent, and committed to monitoring over long time scales, remaining mindful of placing our monitoring data within a historical, hydrologic context. This is particularly true for changes in ground-water and sediment quality, which may not be evident for years or even decades. Continuing with the Chesapeake Bay as an example, USGS studies show that dissolved nitrogen associated with ground-water discharge to streams may have a transport time through the ground-water system of years to decades, with a median time of about 10 years. Nutrients associated with sediment can have even longer transport times (several decades) in the watershed because of their storage in soil and stream corridors, both of which are greatly influenced by yearly rainfall. This is in contrast to dissolved nitrogen associated with surface runoff that has a transport time of hours to months in the watershed (Phillips and Lindsey, 2003).[11]

A long-term, hydrologic context is important when evaluating effects of management practices. For example, the effects of management practices to reduce nutrient inputs to ground water, which have been implemented in many agricultural areas on the Delmarva Peninsula (in Delaware, Maryland, and Virginia) over the last 10 years, are not generally apparent in the deep parts of the aquifer used for domestic supply. Because ground water typically moves slowly, about 0.25–2 feet per day, decreases in nutrient concentrations deep within the aquifer may not be apparent for decades (Hamilton *et al.*, 2004).[6]

The long-term, hydrologic context is also important to sort out the effects of natural variability from the effects of man's activities. Natural events such as floods or drought often can mask shorter term, human actions as suggested above in the case of Chesapeake Bay where we noted a pattern of particularly wet or dry years. Only after understanding the patterns within the historic hydrologic record are we likely to recognize any underlying changes that are taking place due to man's activities.

Moving from monitoring to prediction

The development and verification of predictive tools and models is an essential step in understanding and successfully managing U.S. waters in the future. Such tools are needed to extrapolate or forecast conditions to unmonitored, yet comparable areas, both in space and in time. In light of increasingly diminishing resources, we simply cannot expect to monitor our water resources directly in all places and at all times. We therefore must get smarter, enhancing the value of data collected at individual sites, and applying our understanding of the hydrologic system and water-quality conditions to broader areas, including entire stream reaches and aquifers, large river basins, ecoregions, states, and even the nation. Moving from monitoring to modeling ultimately gives us state-wide, regional, and even national assessments of water quality.

The development of predictive tools helps to prioritize contaminant sources and to tease out the importance of factors affecting water quality, including landscape features and hydrologic transport. These predictive tools can help estimate conditions that often cannot be directly measured, such as the effects of specific management practices or the percentage of contamination in a stream that originates from different sources. For example, the Gulf of Mexico experiences low concentrations of dissolved oxygen each spring and summer largely as a result of large amounts of nitrogen delivered by the Mississippi River, which in turn promotes excessive growth of algae and other nuisance plants and potentially can harm the fisheries. The USGS model SPARROW (SPAtially Referenced Regression On Watershed attributes) shows that a considerable amount of the nitrogen delivered to the Gulf of Mexico originates in distant watersheds in the Mississippi River Basin, such as in Ohio and Tennessee (Alexander *et al.*, 2000).[12]

In addition, models can be used to estimate probabilities that concentrations of selected compounds will exceed a specific value, such as a drinking-water standard or an aquatic-life guideline, at a particular location. The SPARROW model has been applied, for example, to predict in-stream concentrations of phosphorus in streams across the U.S. that meet the EPA recommended goal of 0.1 milligrams per litre to control excessive growth of algae and other nuisance plants. The USGS WARP (Watershed Regressions for Pesticides) model (developed from measured pesticide concentrations in streams, together with information on pesticide use and land use, climate and soil characteristics, and other natural features) has been used to estimate concentrations of atrazine in streams and, specifically, to predict the likelihood that annual average atrazine concentrations in any particular stream in the U.S. would exceed the EPA drinking-water standard of 3 micrograms per litre (Larson *et al.*, 2004).[13] A USGS ground-water model has been used to predict the presence of atrazine in shallow ground water within agricultural areas across the nation; model results show the highest detection frequencies of atrazine in parts of the Midwest, Great Plains, Pacific Northwest, and Mid-Atlantic regions where atrazine is heavily used in hydrologic settings that favor the transport of pesticides to ground water (Stackelberg *et al.*, 2006).[14] Similarly, a USGS nitrate model used to assess the risk of nitrate contamination in shallow ground water across the U.S. shows that nitrate concentrations are expected to be lowest in shallow ground water underlying areas with low inputs of nitrogen and poorly drained soils, such as in parts of the southeastern Coastal Plain, and highest in areas with high nitrogen inputs and well-drained soils that overlie unconsolidated sand and gravel aquifers, such as in the High Plains of northeastern Nebraska and the western U.S. (Nolan *et al.*, 2002).[15] Although results from these models may not be used directly when making policy decisions, they provide critical insights into the locations of our more vulnerable water resources, and help to prioritize where and how we spend our future monitoring dollars.

Continued advancements in predicting and modeling water-quality conditions will depend on two important components. First, we must dedicate resources to gather ancillary data necessary to interpret water-quality data, including better information on the use of chemicals, land-use changes, water use, land-management practices, geomorphology and stream networks, geologic setting, and also point-source discharges. Unfortunately, many of these spatial data are lacking. For example, current chemical-use information is generally insufficient—and in urban areas essentially unavailable—for local and regional water-resource management and decision-making, and yet, information on chemical use is needed to definitely attribute specific pollutants to different sources in non-point runoff and support management actions. Unless we continue to improve relevant geospatial data sets, we will make little progress in understanding and managing water quality. Advances in remote sensing may provide cost-effective ways to enhance and spatially extend selected compilations of data associated with the landscape, human activities, and environmental settings.

Second, we must continue to integrate monitoring with predictive tools. The direction for future model development is towards better representation of the physical, chemical and biological processes in the models, coupled with powerful statistical techniques to estimate the importance of various factors used in the models. Credible, comparable, and comprehensive information must continue to be generated—by means of "on-the-ground" monitoring, assessment, and research—that can be used to validate and verify model predictions. Continued monitoring and data collection will reduce the overall uncertainty of model predictions and estimates. In turn, uncertainty analyses associated with each prediction will help to guide future monitoring and data-collection needs.

Advancing monitoring technology

Advances related to monitoring technology also are needed to successfully support future water-quality issues. These advancements include, for example, continued development and testing of water-quality probes, monitors, data recorders, and telemetry equipment that allow us to monitor water-quality properties on a real-time or near real-time basis. Real-time sensors of water quality can allow a high density of measurements over relatively short periods, which is critical because water-quality conditions can vary widely, such as before, during, and after storms. Sensors can be cost-effective because they minimize costly field visits by scientists and technicians. In addition, real-time measurements for temperature, conductance, and turbidity can be correlated with other important properties, such as bacteria, that are more costly and difficult to monitor and analyze. Development, testing, and deployment of a new generation of real-time sensors for water quality have the potential to greatly increase the level of information available at a given level funding.

In summary

Water-quality issues have increased in complexity as we have moved from point-source controls, focusing on "end of pipe" site-specific data, to investments in water-quality protection and enhancement, focusing on nonpoint-source pollution and a whole-watershed approach. Given the increased complexity, achieving sustainable high-quality water supplies across the nation requires recognition of certain hydrologic tenets that drive water-quality conditions, and firm commitments to: (1) understanding the relations between water-quality conditions and the natural landscape, hydrologic processes, and the human activities that take place on the landscape within watersheds; (2) assessing water quality in a "total resource" context; (3) evaluating water quality in concert with water quantity; (4) evaluating water quality in concert with biological systems; (5) monitoring over long time scales, remaining mindful of placing measurements in a historical, hydrologic context; (6) moving from monitoring to prediction and applying our understanding of the hydrologic system and water-quality conditions to unmonitored, yet comparable areas; (7) investing resources to gather ancillary information on landscape and human factors controlling water quality; and (8) advancing monitoring technology, such as that for measuring water quality in real time.

This commitment will provide the critical and improved scientific basis for decision-makers to effectively manage and protect water resources across the nation and in specific geographic areas, now and in the future. The science will provide the needed basis to prioritize the multitude of decisions involving the increasing number of competing demands for safe drinking water, irrigation, aquatic ecosystem health, wetland protection, native and endangered species preservation, and recreation.

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