COMMENTARY

USGS Perspectives on an Integrated Approach to Watershed and Coastal Management

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Considerable public attention to the recent issues in the Gulf of Mexico, including oil spill, excessive nutrients, and hypoxia, underscore the desire for coordinated, comprehensive monitoring networks and research strategies that connect watersheds to ocean science and technology, and couple water quantity and quality networks and observations over the long term to support critical decisions necessary to ensure sustainable and healthy coastal and oceanic ecosystems.

Today, more than ever, demands for water and requirements for water storage, flood control, and other uses are competing with the needs for healthy coastal waters and ecosystems. Across the nation, scientists representing governmental agencies, academia, trade associations, and other nongovernmental organizations have independently collected data on water quantity and quality—across the landscape and out to sea—yet we still cannot adequately track the hydrologic delivery and timing of water and chemicals that are essential for supporting healthy coastal waters and ecosystems. Data also are not sufficient to predict and forecast the impacts of hydrologic events or effects of climate change.

In addition, we cannot adequately assess and forecast major impacts of our land-based activities—including urban and suburban development and agriculture—on water quality and the relative contributions of land-based sources of sediment, nutrients, and other pollutants to receiving coastal waters. While we have achieved considerable progress in cleaning up our waters, the temporal and spatial nature of water quality issues facing the nation has changed substantially in the past 30 years. Nonpoint sources of pollution from agricultural and urban/suburban land, forest harvesting, energy and mineral extraction, and the atmosphere are now the leading causes of water quality problems in the United States—much larger in scale than more localized, site-specific point-source issues related to end-of-pipe discharges from wastewater treatment plants, factories, or combined sewers. Nonpoint sources are diffuse and widespread, and the number of non-point-source contaminants is large, including hundreds of synthetic organic compounds, nutrients, and emerging waste compounds. These contaminants enter our waterways every day and can, even at very low concentrations, adversely affect the health and reproductive success of aquatic life. Nonpoint runoff from our lands—our suburban streets and lawns, farmland, industry, and roads—are degrading our coastal systems, as evidenced by hypoxic zones the size of New Jersey, habitat alteration, sedimentation, beach closures, invasive species, fish kills, harmful algal blooms, and other toxic contamination of our living resources.

Steps Needed for an Integrated Approach to Watershed and Coastal Management

The need for comprehensive information for policy and management has never been greater and will only be achieved through coordination and integration across the federal government and local, state, tribal, and regional partners. Fortunately, much of the foundation to accomplish this is in place or rapidly developing (see text box). Underpinning the success of current partnerships and proposed plans and strategies are three critically important steps necessary to achieve our goal for improved integrated approaches to watershed and coastal protection and management. These steps include long-term commitments (1) to modernize our monitoring networks (which will help to improve their cost-effectiveness and capabilities for observing conditions in key environmental settings) and our mapping and remote imaging systems (to acquire high-resolution topographic and bathymetry and geospatial data); (2) to develop modeling, assessment, and research tools that help to track water delivery and to identify the sources and causes of water quality degradation and the contaminant loads to coastal waters; and (3) to create a common data and web services infrastructure that helps quality-assure, manage, and share information collected from the mountains to the sea and to make data more accessible to the public.

Monitoring and Mapping

The tall order for science and monitoring of water quality today is to collect credible, objective, interdisciplinary data on the physical, chemical, and biological conditions of waters as well as data on the natural landscape and human activities that contribute to those conditions. Fulfilling that order requires:

- a targeted and adequate network of sites that assesses hydrologic delivery and water quality in a "total resource" context and that evaluates water quality in concert with water quantity;
- data that represent contaminant sources, human activities, environmental settings, water use, and hydrologic conditions;
- monitoring over long time scales, remaining mindful of placing measurements in a historical, hydrologic, and climatic context; and
- advancing monitoring technology, such as for measuring water quantity and quality in real time and with remote sensing.

As we tackle this tall order, we will build an understanding of where, when, how, and why conditions on the land affect the estuaries and coastal waters of the nation.

Unfortunately, interdisciplinary, long-term monitoring is woefully lacking and continues to decline in an era of diminishing fiscal resources. Despite climate change, growing populations, and competing priorities for water that drive the urgent need for more information, data collection networks are shrinking. Currently, about 7500 United States Geological Survey (USGS) gages measure streamflow as well as selected water quality parameters such as specific conductance, temperature, pH, dissolved oxygen, and turbidity. Every year, the USGS loses gages—as many as 70 in a year—many of which have the extensive periods of record needed to track long-term changes in climate and effects of land-based and water use activities.

Even greater reductions are occurring with USGS networks for water quality monitoring. The USGS National Stream Quality Accounting Network, which annually monitors and assesses concentrations and loads of nitrogen, phosphorus, carbon, silica, dissolved solids, selected pesticides, and suspended-sediment to coastal waters of the United States, has been reduced from about 500 sites in the 1980s to 18 stations along the coasts at the present time. Smaller rivers and streams measured by the USGS National Water-Quality Assessment Program have been reduced from more than 500 sites measured annually in the early 1990s to 113 stations, with most stations measured only one year in every four.

State monitoring programs also are being reduced despite increasing regulations for managing state waters. State monitoring is critical to the overall monitoring framework of the nation because they measure water use and water quality conditions at more local scales while contributing to an assessment of conditions over broader basins and regions.

A national commitment to monitoring over the long term within a historical hydrologic context is critical to achieve the goal for an integrated approach to watershed and coastal protection and management of sustainable ecosystems. Specifically, long-term monitoring is needed to track the effectiveness of best management practices, conservation programs, and other approaches for controlling land-based sources of nutrients, contaminants, and invasive species. The long-term, hydrologic context is also important to separate the effects of natural variability from the effects of man's activities on the landscape. Natural events and short-term climate cycles, including excessively wet and dry periods, can overwhelm human influences and mask effects of land-based activities. Only by understanding the patterns within the historic hydrologic record are we likely to recognize underlying changes that are taking place because of human activities.

The good news is that while networks have been reduced, technological innovations have created powerful new tools for observing and measuring a variety of physical, chemical, and biologic phenomena with a scale and resolution that were unimaginable just a few decades ago. The acoustic Doppler current profiler, for example, permits the rapid and highly detailed measurement of flow velocity profiles and circulation patterns needed to track the uptake, transport, and deposition of water and water-borne constituents and aquatic life. New *in situ* sensors on the basis of florescence and smart-sensor technologies are revolutionizing water quality monitoring with many constituents now measured continuously and reported in real time so that diurnal processes throughout the water column can be quantified and modeled, where heretofore observations at seasonal frequencies were the best that could be expected. In addition, miniaturization of sensor packages also permits the deployment of mobile instruments and rapid, temporary densification of observation networks so that relatively rare events, such as hurricanes, can be observed continuously and from many vantages simultaneously. Continued development, testing, and deployment of this new generation of technology has the potential to greatly increase the level of information needed for science-based decision making.

Assessing the Effects of Land-Based Activities to Coastal Water Quality and Habitats

Mapping and monitoring are informative activities, but they are far from an adequate basis for defensible decision making. Integrating mapping and monitoring with conceptual and (or) mathematical models and multidisciplinary assessments is essential for informed decision making. These models are critical to extrapolate and forecast conditions in unmonitored yet comparable areas, thereby leveraging the value of our existing observations and our understanding of the hydrologic system and water conditions at multiple scales. In addition, models are important tools to help estimate conditions that often cannot be directly measured and to 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.

Reductions in monitoring affect the confidence in predictive modeling, such as through the USGS Spatially Referenced Regression on Watershed (SPARROW) attributes model. SPARROW integrates long-term monitoring data with spatially extensive geographic maps of hydrologic and watershed characteristics and contaminant sources. Continuation of critical “on-the-ground” water monitoring provides the needed credible, comparable, and comprehensive data that are used to verify predictions across large regions, such as the Mississippi River Basin. The USGS network of long-term monitoring stations available for use in the USGS SPARROW model has declined from about 425 to 35 stations from the early 1990s to today.

Continued advancements in modeling and assessing conditions will also depend on dedicating resources to gather ancillary data needed to interpret water data and understanding terrestrial impacts on coastal waters, including chemical sources of contamination, land use changes, water use, land management practices, geomorphology and stream networks, geologic setting, and other natural landscape features that control hydrologic transport. Advances in remote sensing may provide cost-effective ways to enhance and spatially extend data associated with the landscape, human activities, and environmental settings. Ultimately, application of observations, remote sensing, models, and research-derived understanding requires a comprehensive geospatial framework that describes the physical, political, social, and environmental setting needed for policy and management. Unless we continue to develop a robust and accessible geospatial framework for watershed, coastal, and marine systems, we will make little progress in translating scientific understanding to tools that describe current conditions and assess future vulnerability and response to natural and human-driven change.

Common Data Infrastructure

One of the widespread obstacles to integrated science and understanding is the lack of a common infrastructure for data management and communication. Data networks, whether they service data from unmanned vehicles, remote sensing platforms, buoys, or rivers, need to be better integrated for direct use in mapping, statistical, and modeling applications and for timely dissemination of data and information products to a broad community of users. The infrastructure needs to be cohesive, unified, and robust, and yet increasingly flexible as an ever increasing number of data collection and processing systems come on line. Critical components of the infrastructure are metadata, consistent data collection and reporting protocols, quality assurance procedures, and comparable methodology.

Much progress is ongoing with the development of water quality data-exchange networks reaching from the land to the sea, such as through the Open Geospatial Consortium. The Open Geospatial Consortium standard for water data is intended to extend the existing data standard on observations and measurements and a respective data retrieval service standard called sensor observation service. The broader standards can generalize concepts of space and time enough to satisfy different scientific disciplines (crossing terrestrial to ocean science), but at the same time have enough specificity to support interoperability between disciplines. Specific applications will be the test; USGS and NOAA intend to test the system through the Great Lakes observation system within which USGS water observations for rivers will be integrated with NOAA buoy sensors that already serve data according to sensor observation service.

Concluding Remarks

In conclusion, well-defined data management systems, monitoring and mapping strategies, and scientific and modeling analyses are needed to connect watershed and ocean science and technology and support critical decisions for sustainable and healthy coastal and oceanic ecosystems. Complexities in the natural and climatic environment, constantly changing human needs and water uses on the landscape, and data infrastructure challenges confirm that collaboration and integration of all of our expertise to achieve a land-to-sea understanding of the natural and man-made factors affecting our coastal waters is highly desirable. Working together—federal partners, states, tribes, universities, industry, and the public— through an integrated approach to watershed and coastal management is necessary to attain long-term commitments and improvements in coupling water quantity and quality networks to support critical decisions essential to ensure sustainable and healthy coastal and oceanic ecosystems.

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Partnerships Move Us Forward

Coordination and integration across the federal government and local, state, tribal, and regional partners is ongoing to achieve an improved integrated approach to watershed and coastal protection and management of sustainable ecosystems. For example, the Interagency Ocean Policy Task Force took on the charge to develop "a comprehensive, ecosystem-based framework for long-term conservation and use of our resources," resulting in a National Ocean Policy that calls for development of a broad portfolio of scientific research, mapping, monitoring, observation, and assessments (http://www.whitehouse.gov/administration/eop/ceq/initiatives/oceans).

In addition, the nation's Integrated Ocean Observing System (IOOS®) supports, through partnerships with governmental and nongovernmental organizations, a coordinated national and international network of observations and data transmission, data management and communication, and data analyses and modeling for coastal waters (http://ioos.gov/). Associated with IOOS are 11 strong regional associations that make up a broad community of data providers and users, including coastal states, federal agencies, Tribes, researchers, and nongovernmental organizations (http://ioos.gov/partners/regional.html and http://www.usnfra.org/).

The Interagency Working Group on Ocean and Coastal Mapping (IWG-OCM), which is comprised of federal, state, and private sector providers and users of geospatial data and products, is working to ensure that the required data, maps, and derivative products are developed and effectively provided to decision makers (http://www.csc.noaa.gov/iwg/). Efforts are linked to those of IOOS, the Federal Geographic Data Committee, and others.

Finally, a solid plan has been developed by more than 80 participants from government and nongovernmental organizations for a "National Water Quality Monitoring Network for U.S. Coastal Waters and Their Tributaries" (hereafter Network), which provides information about the health of our oceans and coastal ecosystems and inland, land-based influences on coastal waters for improved resource management (http://acwi.gov/monitoring/network/index.html). The Network is, in reality, comprised of a "network of networks" and represents an integrated, multidisciplinary, and multiorganizational approach that leverages diverse sources of data and information, augments existing monitoring programs, and links observational capabilities in nine crucial environmental compartments from terrestrial to oceans—including estuaries, the near shore; offshore and the exclusive economic zone; Great Lakes; coastal beaches; rivers and coastal streams; wetlands; groundwater; and the atmosphere. Network data—including observations on biological, chemical, and physical features—help document inputs, sources, amounts, timing, and severity of natural and man-made stressors on coastal ecosystems.