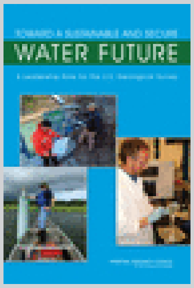

Toward a Sustainable and Secure Water Future: A Leadership Role for the U.S. Geological Survey

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TOWARD A SUSTAINABLE AND SECURE WATER FUTURE

A Leadership Role for the U.S. Geological Survey

Committee on Water Resources Activities at the U.S. Geological Survey

Water Science and Technology Board

Division on Earth and Life Studies

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Preface

In the coming decades of this 21st century the United States faces serious and complex water resources problems. Constraints on the availability of water—quantity and quality—will impact "what we do" and "where we do it" as a society. To face these problems the nation will need more, new, and improved water science, information, and tools to manage and adapt to these constraints. Since its inception in the late 1800s, the U.S. Geological Survey (USGS) has become a major national contributor of scientific data, investigations, and information about the nation's waters. At the turn of the last century, the USGS provided the first scientific insights and assessments needed to begin understanding and managing the vast resources of the United States. At the beginning of this new century, the nation will need a major national science agency to help address the water resource challenges that await.

This report is one of a series of studies that the National Research Council's (NRC) Water Science and Technology Board's (WSTB) Committee on U.S. Geological Survey (USGS) Water Resources Research (CWRR) has organized. Through these studies, the CWRR has provided advice to the USGS Water Resources Discipline (WRD) on water-related issues and programs relevant to the USGS and the nation since 1985. Over nearly 25 years the CWRR and related committees have overseen reviews of nearly every WRD program and initiative, some on a rotating basis. Earlier studies have concerned the National Streamflow Information Program, the National Water Use Information Program, the National Water Quality Assessment Program, and the National Research Program, as well as areas of research such as river science, groundwater, hazardous materials in the aquatic environment, hydrologic hazards science, and watershed research.

This study, however, was different from most of the previous studies. Past studies focused on a particular program and addressed technical and scientific components of the programs. This study considered the entire range of water resources activities at the USGS. The statement of task for this study does not address focused technical questions rather it calls for an evaluation of the broader aspects of leadership and management to conduct the scientific and technical mission of the WRD. To address this task the WSTB and CWRR formed the Committee on Water Resources Activities at the U.S. Geological Survey, to carry out this study and prepare this report.

The USGS asked this committee to address specific questions about WRD's past and present performance, leadership and management, their interaction with other agencies and stakeholders, as well as areas for improvement (for complete statement of task see Box 1-1). The committee felt evaluating the past and present balance among the USGS's water programs would prove an incomplete task without a complementary look toward the future to provide suggestions to help the USGS move toward a more dynamic vision to address society's growing water resources issues. Thus, we approached the charge by assessing the past and present in the context of a vision for the future challenges ahead. The report is primarily directed to the leadership of the Water Resources Discipline (WRD)—one of four major scientific sectors of the USGS. However, many findings and recommendations also need to be considered by the leadership of the USGS and the Department of Interior (DOI), because their support is necessary for the WRD to respond to the water needs of the nation.

The members of this committee brought a wide range of water resources expertise and considerable experience interacting with the USGS. This made for enlivened and enlightening discussions throughout the deliberative process and ultimately led us to the forward-looking recommendations. Disciplinary specialties ranged from hydrogeology and engineering, to the ecological sciences, and contaminant chemistry to meteorology, with professional experience encompassing basic research, water science and policy, and management of water utilities.

The committee also had extensive experience with the USGS programs; some had served with the USGS in a past portion of their career, others had managed operations as formal cooperators with the USGS WRD programs, and some members had no direct experience with the agency. All members were users and consumers of the USGS data and reports. Geographically, the committee's experience ranged from coast-to-coast and with national and international experience. Among the committee members were some who had direct service on nearly every major

NRC review of the USGS WRD's water programs—and even broader studies of the USGS strategies—that has taken place over the past decade. This contributed important institutional understanding and perspective. The consistent characteristic of this committee was a clear dedication to water science and the understanding of the importance of water to the functioning of our society and economy. This wide-ranging expertise afforded the clear understanding of the rapidly growing pressures on the nation's water resources and the stress this will exert on the social and economic security of the nation.

The committee held five working meetings; at four of these meetings the committee heard presentations from, and engaged in discussions with USGS leadership, program scientists, and representatives from other federal, state, and local agency cooperators and users of USGS products. The committee did so to gather testimony and an assessment of the status of USGS programs, their accomplishments, successes, as well as perceptions on shortcomings and where the opportunities existed to improve WRD programs and its contributions to the nation. With the USGS and DOI leadership, the committee reviewed management issues including organizational details and budget and staffing data to understand the status and health of the organization over time. Many on the committee have been involved in the management of other agencies, businesses and utilities, or academic institutions, and are versed in review of such "management" information.

Throughout the course of the study, outside of the deliberative meetings, committee members also visited with other USGS staff and other colleagues in academia; industry; or other local, state, and federal agencies in applied areas of the water resources field, casting a wide net for input to the deliberative process. The committee members also collectively have reviewed many USGS WRD reports.

The committee thanks many people external to the USGS who gave of their time to provide highly informative and useful presentations and dialogue regarding their collective experiences with the USGS Water Resources program including: Timothy Petty, Deputy Assistant Secretary of Interior for Water and Science; Sue Lowry, State of Wyoming; Jack Byers, State of Colorado; Van Lindquist, West Dakota Water Development District; Eric Senter, California Department of Water Resources; Curt Schmutte, Metropolitan Water District of Southern California; Richard Nelson, Bureau of Reclamation; Michael Soukop and William Jackson, National Park Service; Jerry Brabander, Fish and Wildlife Service; Thomas Graziano, National Weather Service; and Cynthia Dougherty, Jim Jones, and Susan Holdsworth U.S. Environmental Protection Agency.

We also thank the many USGS staff who talked with us and, particularly, senior leadership staff who met with us to provide insights, including: Mark Myers, Director, U.S. Geological Survey, Dave Hamilton (BRD), Randy Updike (GD), William Alley, Stephen Blanchard, Timothy Miller, Steve Ingebritsen, William Sexton, William Horak, Michael Reddy, James Kircher, Mark Anderson, and Mike Shulters. Our special thanks go to Robert Hirsch, Matt Larsen, and Ward Staubitz, who not only gave generously of their time and insight but also facilitated the gathering of answers to our many inquiries and sometimes unreasonable requests for data, reports, and documents that we felt were necessary to our deliberations.

The committee also thanks the NRC WSTB staff for their support and leadership. Without the competent staff of the WSTB these reports would not be possible. Throughout most of the time of this study, Will Logan was the study director. When Will moved on to new challenges in 2008, Laura Helsabeck stepped in as project director—a challenging role to assume in a study approaching conclusion. In particular, we thank Laura for her significant contributions to the report and her efforts to bring the report to completion—and her patience with the committee. Anita Hall provided excellent staff support throughout the study.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the NRC in making its published report as sound as possible and that will ensure the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report: Kenneth Bradbury, University of Wisconsin; Yu-Ping Chin, The Ohio State University; Joan Ehrenfeld, Rutgers University; Gerald E. Galloway, Jr., University of Maryland; George Hornberger, Vanderbilt University; Jeanine A. Jones, California Department of Water Resources; Soroosh Sorooshian, University of California, Irvine.

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Henry J. Vaux, University of California, Berkeley. Appointed by the National Research Council, Dr. Vaux was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsi-

bility for the final content of this report rests entirely with the authoring committee and the institution.

The committee hopes that this report will help to strengthen the Water Resources Discipline and the USGS. Our recommendations are not "answers," but hopefully stimuli to promote the further discourse and planning needed to help USGS meet the problems facing the nation today and more importantly to prepare for the challenges of tomorrow.

George R. Hallberg, *Chair*
Committee on Water Resources Activities at the U.S. Geological Survey

Contents

Summary

Water is our most fundamental natural resource, a resource that is limited. Challenges to our nation's water resources continue to grow, driven by population growth, ecological needs, climate change, and other pressures. The nation needs more and improved water science and information to meet these challenges. In this report we review the United States Geological Survey's (USGS) Water Resource Discipline (WRD), one of the nation's foremost water science organizations. This report provides constructive advice to help the WRD meet the nation's water needs over the coming decades. Our report is primarily directed to the leadership of the USGS WRD. However, many findings and recommendations also target the USGS leadership and the Department of Interior (DOI), because their support is necessary for the WRD to respond to the water needs of the nation.

The USGS, established in 1879, has historically been regarded as a primary source for scientific data to describe and understand Earth systems and provide assessments to facilitate the management of the nation's resources. The WRD, one of four scientific disciplines within the USGS, fills this mission by assessing the quality and quantity of the nation's surface water and groundwater. Since its conception, the WRD mission has remained "to provide reliable, impartial, timely information needed to understand the nation's water resources". With no regulatory or management responsibilities, the WRD is recognized as a source of unbiased hydrologic data and scientific information.

The Committee on Water Resources Activities at the U.S. Geological Survey, a committee of the Water Science and Technology Board of the National Research Council (NRC), was asked to carry out a review of the USGS WRD programs. The statement of task (SOT; Box 1-1) presents a

bipartite charge. The first is a performance review of the WRD, on topics ranging from leadership to cost-effectiveness. The second and more important undertaking was to look to the future, so we provide recommendations that will aid the USGS in being dynamically responsive to society's pressing water resource needs. This Summary includes the major findings and recommendations of the committee. Additional conclusions and recommendations can be found in the individual chapters.

The USGS WRD: A PERFORMANCE REVIEW

Leadership

The USGS can justly claim credit for past leadership in many areas of water science and technology. The USGS WRD was the major national employer of hydrologists in the first half of the 20th century. Since 1889, the USGS has operated a streamgaging program that evolved into The National Streamflow Information Program (NSIP). As new needs for streamflow data emerged this program made real-time streamflow data widely available, a novel advancement. The WRD developed methods to measure and predict streamflow and sediment transport and the science of fluvial geomorphic systems, leading to the development of water science and fluvial engineering in the United States. WRD scientists and engineers were leaders in developing the foundations of groundwater hydrology; they developed approaches to understand the chemical and isotopic evolution of natural groundwater; and they pioneered the integration of field data with groundwater modeling. In the 1960s, the WRD established the interdisciplinary National Research Program (NRP) to support pioneering hydrologic research to help analyze and manage water resources and aquatic ecosystems.

External stakeholders praised the WRD's leadership and commitment to long-term data collection, fundamental to water science studies of other parties and critical to understanding the nation's water resources. The committee and collaborating agencies both note that the USGS WRD provides leadership in very fundamental areas such as standardizing data collection methods across the nation. A few examples discussed are:

- *Measurement technology, sampling protocols, and other standard method development*—The WRD standardized tools to assess frequency and magnitude of streamflow and field and laboratory methods for monitoring. The consistency of methods developed by the WRD promotes regional and national synthesis internally and among other entities.

- *Data collection and delivery*—The USGS's National Water Information System provides a comprehensive digital gateway to water data—both quantity and quality—at over 1.5 million sites throughout the nation and now provides real-time information for many sites. This has opened up many new and important applications for water data users.
- *WRD data and interpretive studies are used as key performance indicators by other agencies and institutions, such as* USEPA, the Heinz Center, and the National Weather Service.

WRD has used its unique position in the USGS, incorporating water, solid Earth, ecosystems, and geographical information systems to promote large-scale interdisciplinary assessments of water resources. Some examples include studies of how surface water and groundwater interact in the Florida Everglades and around Chesapeake Bay or how water circulation and sediment deposition affect biological habitats in San Francisco Bay. Topical examples include:

- National syntheses of nutrient, pesticide, and volatile organic compound occurrence,
- National studies of emerging contaminants,
- Groundwater-surface water interaction and its relationship with water quality and aquatic ecosystems,
- Integration of biological assessments into water quality monitoring,
- Sedimentation and fluvial geomorphology,
- Development and technology transfer of groundwater flow and transport and geochemical models,
- Watershed water-quality modeling.

This legacy of leadership in addressing the nation's key problems in water provides a rationale for a strong USGS presence in the water-science arena today and tomorrow.

Coordination and Collaboration

There are some 20 federal agencies with responsibilities in water management and/or water science located both within the Department of Interior (DOI) and across the government, hence, coordination is a necessity. In speaking to the committee, other USGS Disciplines, DOI agency partners, and external agencies praised the coordination and collaborative efforts of WRD as well as the importance of the WRD's work to their own programs.

Developing interdisciplinary work in the last decade, the USGS WRD has been part of coordination within the USGS and DOI. There are fundamental impediments to more cooperation of the Disciplines within the USGS, including that their offices are not co-located, and the Disciplines evolved with different missions and organizational structures, as well as different clients. Yet many examples can be noted, including collaborations on hydrologic and ecologic science of the Platte and Missouri Rivers, the assessment of groundwater resources and earthquake hazards in the Los Angeles basin, and the study of groundwater resources of the middle Rio Grande basin.

The USGS WRD has done an admirable job of working to coordinate its activities with outside federal agencies to foster external collaboration, in the committee's observations. The USGS provides a scientific and observational foundation for many relevant national water programs run by other federal agencies. The WRD provides leadership in coordinating federal water activities through the Advisory Committee on Water Information and the Subcommittee on Water Availability and Quality (under the National Science and Technology Council, Executive Office of the President), for example.

One especially important example of coordination and collaboration is the hydrological science and streamflow observations that undergird flood watches and warnings provided by the National Weather Service's (NWS) River Forecast Centers. The NWS and WRD closely coordinate the provision of these products and services. The WRD also collaborates with the U.S. Environmental Protection Agency, with examples of activities including co-sponsorship of the biennial National Monitoring Conference, joint work on the "National Hydrography Dataset Plus," and extensive work on water quality and emerging contaminants. EPA uses WRD monitoring data as part of their own performance measures. Another recent example is WRD's collaboration with multiple federal, state, and local entities to address complex water management issues in the San Pedro, Arizona area, including the growing issue of competition for water between public water supply and ecosystem needs.

Program Balance

The SOT poses questions about WRD program planning, goals, and balance. The WRD program areas and balance measures are based on funding, and derived from a WRD *Strategic Directions* plan, and individual program plans, that are nearly a decade old. Producing a list of basic program accomplishments that address these past program goals and balance would not be particularly useful. Also, the USGS has a new strategic plan *Facing tomorrow's Challenges—U.S. Geological Survey science in the decade 2007-2017* which will presumably drive development over the coming years. The committee considered reviewing the WRD budget by categories defined in the *Strategic Directions* plan, but the USGS has introduced a new budget system which made that impractical. With that perspective, we offer this recommendation:

In the past, the USGS WRD program balance was assessed through the *Strategic Directions* plan (USGS, 1999; see Box 2-5). If it is judged important for the USGS, DOI, or OMB to review program balance by these particular metrics, the budget system should be adjusted to accommodate such summaries.

In the committee's view the primary issue to address is not program balance of the past; instead, we suggest looking ahead. Future planning needs to balance program goals with a coherent view of how each advances the national understanding of major water problems.

Cost Effectiveness

Addressing the cost-effectiveness of a program such as the WRD is difficult. There are not well-defined metrics to evaluate the cost-effectiveness of their scientific and intellectual programs. A recent NRC report (NRC, 2008) found that Office of Management and Budget did not use or accept the same type of metrics for all federal agencies for similar problems, such as "research efficiency." The NRC report recommended that expert panels be used to evaluate the performance of such programs. We assessed whether the WRD programs are "well-managed and conducted in a cost-effective manner" based on our best professional judgment, as an expert panel, and various semi-quantitative measures. We looked at indicators of product demand, efforts to optimize field programs, and the use of expert panels, as the NRC recommended to OMB.

We begin with "product demand." The testimony from other agencies and stakeholders regarding the demand for WRD data may be viewed as one indicator of cost-effectiveness. The only area of the WRD budget that has increased since 1990 is state and local contributions to the Cooperative

Water Program, further highlighting demand for WRD products. Even amidst cost concerns, cooperators note that they need the quality and independence of the USGS products; independent monitoring and data analyses are vital to provide unbiased input to their management programs and for "government performance and review." In a related example, the National Hydrologic Warning Council noted nine points of how the streamgaging program was "beneficial to society." In addition, NWIS averages 30-40 million downloads per month; the WRD's MODFLOW is one of the most widely used groundwater flow models worldwide, more than 23,000 copies of MODFLOW were downloaded from the USGS web site over the past decade.

The WRD has put substantive effort into optimizing its human and financial resources in past years. The WRD streamgaging network has undergone numerous assessments (based on statistical optimization techniques) to evaluate which gages could be abandoned with the least loss of hydrologic data to meet regional and national needs. A prior NRC review of the NAWQA program (NRC, 2002) found that, despite the significant reduction in study units for Cycle II that NAWQA could still maintain good coverage of the nation's streams and groundwater resources, because of the commendable, rigorous planning effort that the WRD management team employed. In both cases, however, some of this optimization was in response to shrinking budgets, and some substantive national coverage was lost in these reductions. The NRC review noted, for example, that "NAWQA cannot continue to be downsized and still be considered <u>the national</u> water quality assessment that the nation needs."

The WRD has an excellent record of utilizing external, independent expert panels to evaluate the effectiveness of their programs. The NRC's standing Committee on USGS Water Resources Research has conducted studies that have reviewed essentially every WRD program over the last two decades. WRD has also engaged others in program reviews including the National Hydrologic Warning Council, the Advisory Committee on Water Information, and Interstate Council on Water Policy.

In summary, we find that the WRD has shown effective leadership in water science and that the WRD is managed in a cost-effective manner. The WRD has done a good job fostering internal cooperation, external collaboration, and coordination. Our performance review shows that the USGS WRD is well-positioned to add value to water resource challenges both in the present and future.

PREPARING FOR TOMORROW

Water Resource Trends—"Predictable Surprises" Await

To provide the context to look toward the future, we discuss some of the water resources problems the USGS WRD will face. Trends of increasing stress on water resources form "predictable surprises"—problems that are becoming recognized but require action, (they will not resolve themselves).

- *Problems of water availability will become increasingly more serious and prominent.* With a projected population increase of 50 percent by 2050 in the United States, population demands on water will grow and become regionally acute. Even in the humid southeast, Georgia struggles to manage water for its growing metropolitan areas, and coastal cities throughout the country face salt water intrusion problems. The areas of greatest population growth are where water withdrawals are already unsustainable—the west, southwest, and coastal regions. Further exacerbating this problem is the link between water and energy—both key components to societal health.
- *Climate change will make water resource challenges more difficult.* Estimates of future climate change project greater environmental variability that will likely catalyze changes in the frequency and magnitude of floods and droughts. Changes in the hydrologic cycle will have economic effects, as have been documented in the past. New tools will be needed to forecast, design, and manage water resources and infrastructure that is sensitive to these environmental changes.
- *Water quality impairments will continue to demand innovative science.* Water availability is limited by water quality. While some components of water quality have improved in the U.S., with various environmental regulatory programs, there still are growing issues such as nonpoint source pollution and emerging contaminants.
- *Water prices will rise.* Water users in the U.S. pay less for their water than most other developed countries. With the need to repair aging infrastructure, increased competition for water, the need for restoration of ecosystem values, and increases in energy costs, prices will rise which will have other societal impacts.
- *Resolving water conflicts and policy debates will demand more water science.* Water policy debates will continue to occur at all levels of government, and between our nation and its neighbors. The debate will include arguments about transboundary issues, ecosystem versus other

societal needs, the impact of rising water prices, and the effect of climate variability on water resources. Amidst policy debates water resource decisions will be made. But will they be adequately informed to meet the coming uncertainties and constraints that society will face? To effectively manage evolving water trends, new science, more data, and new approaches will be needed to develop adaptive management strategies.

WRD Planning, Priorities, and Stakeholders

The WRD, like all federal agencies, has a "top-down" component of management where broad national priorities are set by the Washington level management with input from national stakeholders. The WRD also has a unique and important "bottom-up" component to its planning process with Science Centers in every state. The Science Centers operate with direct input from state and local stakeholders, providing insights to local water issues and identifying new and emerging issues. Appropriate issues then surface to the regional and national level and become incorporated into "top-down" programmatic thrusts. This mix of top-down and bottom-up input to management and priority setting has served the USGS well. However, the committee is concerned that the balance between national priorities and local needs has become skewed as a result of budgetary issues.

WRD Budget and Staffing

The SOT asks questions that require understanding of the operational and budgetary climate within which the WRD is operating, and recommendations for future directions should be viewed within this context. The WRD budget trend over the past 16 years is flat or slightly downward. The only major component that has risen since 1990 is the state and local funding for the Cooperative Water Program (Coop program). There is a growing wedge of disparity between cooperator and federal contributions to the Coop program, from a 1:1 ratio in 1990 to almost a 2:1 ratio in 2006. The increase in funding provided by state and local cooperators may be an encouraging measure of WRD product demand by supporters. However, this trend raises some concern about the balance between national/regional and local/state priorities in the Coop program and the ability of the Science Centers to address regional and national priorities.

WRD staffing, both science and non-science employees, has declined by one-third since 1993 as a result of flat-to-declining budgets and mandated salary increases and promotions. NRP research hydrology staff has been reduced by 30 percent while WRD headquarters staff has been reduced by 60 percent. Amidst the overall decline in staff, there has been an increase in research grade hydrologists in Science Centers. This increase was largely the result of a shift in positions; resulting in a net decrease in research positions and a de-centralization of the WRD research capacity. The redistribution of research grade staff has promoted a higher level of science in the field offices but possibly to the detriment of the NRP. The percentage of non-hydrologists employed has increased, reflecting the increasingly interdisciplinary challenges faced by WRD. Coupled with these large reductions in staff there have been limited new hires, resulting in an aging workforce, particularly in the NRP where the modal age is now 51-60 years old.

The USGS, even with these budgetary and staffing reductions, has a large number of experienced water scientists and technicians. They stand on a long tradition of studying the impact of human activities on water resources and ecosystems. Whether society can manage water resources sustainably in light of the growing interdisciplinary issues such as population growth, wealth production, ecosystem needs, and climatic uncertainty, has become the signature environmental issue of our age. The USGS WRD is well suited to play a critical leadership role in a national strategy for water resource management.

WATER FOR TOMORROW

Leadership

The USGS WRD has provided leadership to the nation in water science, and while that leadership continues, it has lost ground. The WRD is stretched too thin—it cannot address all water resources issues particularly given the current budgetary climate. The WRD and USGS have the range and quality of scientific resources to take the lead in providing the interdisciplinary understanding required to address many of our pressing water problems. But it needs to re-focus its vision concentrating on its strengths to address not all, but the critical, water challenges facing the nation.

The WRD should re-focus its vision on critical national priorities to lead the nation in water science. This vision should bring their data acquisition arm, science and interpretive programs, and research arm to a common focus on key national priorities.

The USGS Strategic Science Directions

The new USGS strategic plan, *Facing Tomorrow's Challenges—U.S. Geological Survey science in the decade 2007-2017,* outlines the agency's plans to move into the future, identifying six strategic directions. While the committee did not do an in-depth evaluation of this plan, we do concur with the importance of the national issues outlined and agree that the USGS has the skilled personnel to address these issues. The strategy notes "[The USGS's] role is larger than the traditional one of providing expertise in mapping, geology, water, and biology. … The USGS should transform its approaches to problem solving not only to address the issues of today but also to prepare for those of tomorrow." We concur and put our recommendations in the context that the WRD focus on the problems society will face in the coming decades. Water science is a key component in each of the six USGS directions, demonstrating the necessity of an integrated strategy. By integrated we mean ensuring that all the WRD programs understand the component contributions they must make to answer critical national questions. There are two dominant themes of the plan that can relate to all areas of water availability—climate variability and change and a water census.

The WRD needs to clearly redefine its role within the context of the USGS strategic science directions and its vision of critical national water priorities. This redefinition should highlight the WRD's role in the USGS strategic science directions and within an integrated strategy and programmatic approach to address their defined national water priorities, emphasizing scientific support for decisions that society will need to make in the coming decades. This approach should include two key issues of water availability—the water census and climate variability and change—particularly forecasting and predictions, evaluating uncertainty, and developing enhanced monitoring systems to assess the nature of the problem with respect to water resources.

A Water Census of the United States: Quantifying, Forecasting, and Securing Fresh Water for America's Future

The Water Census (strategic science direction number six) is an initiative already in development, and can be used to illustrate the committee's recommendations. The Census is a needed and worthy activity, especially considering its subtitle to "quantify, forecast and secure fresh water for America's future." The Water Census needs to plan for establishing an on-going accounting of water availability in a program on par with the social and economic censuses that support national decision-making. There is little value in developing a sparse, simplistic accounting system, while there is relevance in building a dynamic Water Census. This would involve many efforts that go beyond the current scope of the USGS programs, efforts that are discussed and recommended in this report, such as:

- **Coordination and Collaboration with External Agencies.** It will be critical to build and extend consensus and cooperation among federal and non-federal agencies involved in water resources management. This must include collaboration on innovative data collection conducted by other agencies as well as new science.
- **New Approaches and New Water Science**. The USGS WRD will have to expand hydrologic analysis to develop new science—new approaches to its analysis. We concur with the NRC committee on the National Water-Use Information Program that recommended: "The NWUIP should be viewed as much more than a data-collection and database management program. The NWUIP should be elevated to a water-use science program, emphasizing applied research and techniques development in the statistical estimation of water use, as well as the determinants and impacts of water using behaviors."
- **Forecasting with Uncertainty**. Forecasting and predictions of water availability that identify and quantify uncertainty over time are critical for decision makers. Programs need to support interpretive activities for syntheses, forecasting, and predictions to address regional and national priorities.
- **Definition of a Comprehensive, Integrated Long-Range Water Census Strategy.** The Water Census should become more than unconnected water indices. Similar to the way that prediction skills have been gradually been built into and improved for weather or economic forecasting, a strategy should incrementally elaborate the Water Census.
- **New Resources**. An effective, dynamic Water Census cannot simply be grafted on to current USGS activities. Such efforts will require more focused leadership and organizational approaches than in the past coupled with adequate resources. Clearly, at a national level, the need for a Water Census is now recognized and advanced, not only by the USGS but by the interagency NSTC and Congressional committees.

Strategic Approaches

To focus on key national problems in an integrated way requires hard decisions about how programs like the Water Census are developed and integrated across the WRD. This will require active management, development of common strategic questions and a common intellectual approach. Priorities should be promoted aggressively at the highest level of leadership, managed at this level to ensure implementation, using teams capable of making important scientific contributions of national and international relevance. Overall, the single most important trait that WRD management will need to demonstrate in the next decade is willingness to actively lead the agency's scientists in the new directions required by the nation's needs.

The USGS and WRD leadership should refocus their vision to define the national water priorities that they will address and develop a management approach to integrate the WRD programs to meet these needs and lead the nation in water science.

Pressing national issues will require integration of WRD programs, from the Groundwater Resources Program, to NAWQA, and NSIP, the NRP and the Coop program. While many of the WRD programs have line-item budgets and defined missions, they can still be integrated to address questions that address key components of water priorities. Many of these national issues will also require new science, thus the approach to integrate WRD's focus on national priorities must also better leverage the science and technical prowess of the NRP and the operational capabilities within the Science Centers. Two difficult challenges, in the committee's observations, will be to define and manage the role of the NRP and the Coop Program and Science Centers in these programs.

The National Research Program

With the decline in the number of scientists, the aging of its workforce, and the decentralization of research capacity, the NRP has lost some measure of its scientific leadership. The NRP needs to play a renewed, significant role and have the flexibility to refocus on significant water science. This may require refocusing its operations to redirect its talent and resources to address new and emerging national priorities.

To meet the nation's water science needs, the WRD's National Research Program should be aligned around its refocused vision of national program priorities.

The USGS should also revisit its review and reward system for research grade personnel which should ensure that priorities for career advancement are aligned with agency and national priorities. It should provide incentive for team-oriented work, and substantive contribution to and leadership of projects that address critical national priorities.

The Cooperative Water Program and Science Centers

There needs to be improved alignment of the Coop program and the Science Centers to address regional and national priorities. New science needed to address national water problems often must be tested and tailored to the wide range of climatic, hydrologic, cultural, and industrial-economic conditions that exist throughout the United States. The presence of the Science Centers and Coop program in every state is an important resource to accomplish this and to contribute to regional and national objectives if projects are coordinated to do so.

The WRD's Cooperative Water Program needs to be better integrated with the WRD's focused vision of regional and national water program priorities. The WRD is encouraged to develop a process for defining national merit for Coop projects as a means of balancing Coop program commitments with meeting regional and national priorities.

National and regional priorities need to help shape these programs; national programs cannot simply be a collection of Science Center projects. WRD has good models for integrating local efforts into regional and national programs. This must be done with care, considering state needs; as WRD focuses more on regional and national-scale problems, it is important that the best aspects of their contributions to local problems not be undermined or abandoned. This may involve establishing flexible means for temporarily shifting funding and associated staff to follow projects with the most national merit.

While states have the authority to manage their water resources, conflicts among states, with or without interstate compacts, are becoming more prevalent and challenging. Another goal for the USGS and its Science Centers could be to minimize the potential for states' disagreement on the extent and characteristics of their shared water resources. A commitment to this responsibility fits well with the USGS interest to "understand the nation's water resources."

Science Center research grade scientists will need to be considered for integration in project teams coordinated around the national strategic directions. This may require flexibility in being able to assign research grade staff in one Science Center to work temporarily on a team for another Science Center. Hence, some of the same issues discussed for realignment of NRP staff may apply to the research grade staff in the Science Centers.

The USGS WRD should involve all research grade personnel in staffing teams to address regional and national research priorities, regardless of location, to increase the agency's flexibility.

Concluding Remarks

The USGS WRD has a history of distinguished service to the nation. Despite the declining resources and staff reductions, the WRD has made adjustments to continue its role as a national leader, particularly related to water quality and water availability. But to adequately address the nation's growing water science needs, the WRD and USGS leadership will need to provide a more focused vision of the national water priorities that they will address and a management approach to integrate WRD programs and the interdisciplinary character of the USGS.

The committee advocates a more targeted selection of water science projects that address critical national needs. Programs and projects should be integrated at a high level with teams capable of making important scientific contributions. The approach should better leverage the interdisciplinary science and technical prowess of the NRP with the operational capabilities found within the Science Centers. Interpretive activities will need to better focus on regional and national syntheses and forecasting and predictions to address national priorities. To successfully meet the water and energy challenges the United States is facing the USGS will need to provide new and improved water science. As stated in the USGS 2007 strategic plan—"The USGS must transform its approaches to problem solving not only to address the issues of today but also to prepare for those of tomorrow." The sharper focus on critical priorities described in our report will help to address these problems, but to adequately meet the challenge will clearly require new and additional resources.

To ensure a secure water future for the nation, sufficient funding should be provided for the USGS to perform its function as a major

science agency: to ensure high quality data collection, interpretive programs, and development of essential forecasting and predictive tools to support effective management of the nation's critical water resources.

1

Introduction

Our nation's water resources are increasingly becoming limited in the face of population growth, climate variability, increasingly valued ecological needs, and other pressures. These limitations—especially considering the nexus between water and energy—portend an impending crisis in the coming decades that could impose conflicts and constraints on the nation. The NRC voiced the same concern four years ago (text box below) and the problem has continued to intensify.

> "Nothing is more fundamental to life than water. Not only is water a basic need, but adequate safe water underpins the nation's health, economy, security, and ecology. The strategic challenge for the future is to ensure adequate quantity and quality of water to meet human and ecological needs in the face of growing competition among domestic, industrial-commercial, agricultural, and environmental uses. To address water resources problems likely to emerge in the next 10-15 years, decision makers at all levels of government will need to make informed choices among often conflicting and uncertain alternatives."
>
> SOURCE: National Research Council (2004b).

The Committee on Water Resources Activities at the U.S. Geological Survey (USGS) was appointed to assess the programs and accomplishments of the Water Resources Discipline (WRD) at the USGS. The committee's charge, as laid out in the Statement of Task (SOT; Box 1-1),

BOX 1-1
Statement of Task

This study will help the USGS evaluate the relationship between Water Resources Discipline (WRD) research and information collection and dissemination activities and its overall WRD agenda. It will cover all of the major topical areas of WRD activities: groundwater and surface water, water quality and quantity issues, hydrologic hazards, water availability, water use, and aquatic ecology. Key aspects of WRD science and operation will be covered, including long-term data collection and dissemination, interpretive studies, methods development, including development of hydrologic models, and basic research. The following questions will be addressed:

1. Where has the USGS shown leadership in water science and technology in recent years and has it successfully met its goals, as they are described in the WRD- and individual program-5-year plans?
2. Are USGS water activities relevant to societal needs, and are they addressing emerging hydrologic issues? What are some of these emerging issues that are being addressed well and which issues are receiving too little attention?
3. How should WRD identify priority water issues? Are there important water issues that are not adequately addressed by the current suite of WRD programs?
4. Given the current budget climate (i.e., with limited resources), is the current content of the USGS water science portfolio appropriate? If not, what changes should be made? What areas of science should receive higher or lower priority? What is the best balance among: a) collection of long-term data, interpretive studies, methods development, information dissemination and research; and b) groundwater and surface water; water quality and quantity?
5. Are USGS water activities well managed and conducted in a cost-effective manner? In what areas/topics is improvement possible?
6. Are the USGS water activities engaging important stakeholder groups? Are there stakeholder groups that could be better engaged? If so, who are they and how could they be better engaged?
7. Are USGS water activities coordinated well among other USGS programs, among federal agencies? Are there areas in which interactions and coordination could be improved?

calls for a review of both past accomplishments of the WRD as well as the health and ability of the USGS water program to accomplish its mission today and, more importantly, tomorrow. The committee provides such an evaluation of the WRD program relative to the nation's water resources future.

Established in 1879, the USGS has a distinguished history of leadership serving the nation by providing scientific data to describe and understand Earth systems and by providing unbiased assessments to facilitate management of the nation's natural resources. Since its beginning, the USGS has been the primary federal agency responsible for assessing the quantity and quality of the nation's surface water and groundwater. Hydrologic research and hydrologic data collection and analyses are implemented through the USGS Water Resources Discipline, one of four broad earth science Disciplines around which the USGS is organized (Biology, Geography, Geology, and Water, and a directorate for geospatial information). At present, the Water Resources Discipline has a workforce of about 3,300 water scientists and technicians working in 181 offices throughout the country. The USGS maintains Water Science Center offices (or integrated Science Centers offices) in every state and three major regional research offices (western, central, and eastern). The Water Resources Discipline has evolved throughout the history of the agency, yet Water's mission has remained constant—"to provide reliable, impartial, timely information needed to understand the nation's water resources."

Because the USGS is a science agency with no regulatory or management responsibilities, the Water Resources Discipline is recognized as a source of unbiased scientific information and hydrologic data. USGS research, studies, and data are used by other federal agencies; state, local, and tribal governments; the private sector; and academia as a basis for a wide range of water resources research and water planning and management decisions, including: water infrastructure design and maintenance, flood monitoring and emergency notification, drought monitoring, water rights administration, water quality management, and other related services. The USGS is also a trusted source of hydrologic data and science for resolving inter-jurisdictional disputes, such as water disputes between states.

The USGS carries out its water resources mission through several individual programs (Box 1-2) that cumulatively support the nation's hydrologic data network and provide hydrologic assessments at the national, regional, state, and local scale. USGS data and information from these programs are integrated into the National Hydrologic Information System and provided freely to all parties via the internet. These data are used by a wide audience for many purposes and serve as an important national resource of hydrologic information.

Most of these WRD programs are familiar to water resources interested parties; most are also identified as budget lines for the agency. To

BOX 1-2

Cooperative Water Program (Coop program): Partnerships between the USGS and more than 1,500 state, local, and tribal agencies to provide water resources information.

National Water-Quality Assessment (NAWQA) Program: Long-term assessment of water-quality conditions and trends in 42 river basins and groundwater systems nationwide.

National Streamflow Information Program (NSIP): Collection and dissemination of streamflow information that is essential for meeting federal hydrologic information needs.

Toxic Substances Hydrology Program: Field-based research to understand behavior of toxic substances in the nation's hydrologic environments for development of strategies to clean-up and protect water quality.

Groundwater Resources Program: Groundwater data collection and the evaluation of controls on regional aquifer systems due to pumping and other stresses.

Other Water Quality Activities: Analytical capabilities (National Water Quality Laboratory), and data from major rivers (National Stream Quality Accounting Network), from pristine watersheds (Hydrologic Benchmark Network), and from atmospheric deposition (National Atmospheric Deposition Program).

Hydrologic Instrumentation Facility: Instrument development, testing, calibration, and repair; technical support, training, and equipment supply to support hydrologic field activities

Water Information: Physical and chemical data available through the web through the National Water Information System (http://water.usgs.gov/NWIS); web-based information by states or subjects (http://water.usgs.gov).

National Research Program (NRP): Conduct basic and problem-oriented hydrologic research in support of the USGS mission, including investigations of small watersheds (Water, Energy, Biogeochemical Budgets Program).

Climate Variability: Understanding the variations in hydrologic conditions due to atmospheric changes and human activities.

Priority Ecosystem Studies: Integrated investigations in large ecosystems of national interest that are impacted by human activity.

International Program: Hydrologic data collection and analysis in support of the global hydrologic community.

Water Institutes: Support of university-based Water Resources Research Institutes in 54 states and territories through grants.

manage these programs, the WRD headquarters leadership is organized into the following units:

- Office of Surface Water,
- Office of Groundwater,
- Office of Water Quality,
- Cooperative Water Program (Coop program),
- Office of Water Information, and an
- Office of the Chief Scientist that oversees research and development functions and groups such as the National Research Program (NRP).

Components of the various programs (Box 1-2) often cut across the offices, related to their focus and function. The Science Centers (located in every state) are the key operational units of the Coop program, and they also interact with all of the organizational units and participate in the field operations, and often the management and design of some or all of the programs noted in Box 1-2.

In this report the committee puts forward critiques, findings, and recommendations that will help the USGS WRD focus its programs to facilitate effective management of the nation's water resources. The findings and recommendations presented in the report are primarily directed to the leadership of the Water Resources Discipline of the USGS. The WRD is integral to, but only a part of the USGS, a federal agency that resides within the Department of the Interior (DOI), a cabinet level department, headed by the Secretary of Interior. Hence, many of the findings and recommendations also address the USGS and the DOI, because support from this hierarchy of leadership will be necessary for the WRD to fulfill its role of providing needed water resources information. Other members of the audience for this report would be the examiners of the Office of Management and Budget. Clearly, many of the questions posed in the SOT are related to performance reviews conducted by OMB. Further, we hope these findings will be useful for others in the administrative branch of the federal government and congressional staff who provide support and direction to face the water problems that will constrain this nation if not resolved. Lastly, we hope that the federal, state, and local agencies that depend on the technical and scientific input of the WRD would review this report. Many of the concerns raised, as well as many recommendations, pertain to their needs or the need for them to address their collaborative work with the USGS to collectively meet the needs of this nation.

REPORT ROADMAP

Many questions in the SOT (Box 1-1) have multiple parts; with part 1 of a task calling for a review of past performance and the subsequent parts of the tasks probing the relative health, past and present, of the water programs, and requesting suggestions for improvement and directions for the future. In the following chapters, we will first review the WRD past performance, then set the stage for suggestions for the future (Chapters 2 and 3). In Chapter 4, *Water for Tomorrow*, we propose organizational adjustments and recommendations that we hope will aid the USGS to produce the information and understanding of water resources needed for the nation's future.

2

The USGS WRD: A Performance Review

A performance review can provide context for the WRD's ability to meet the nation's future water science needs. The statement of task (SOT) asks the committee to review various aspects of the USGS WRD's performance related to such topics as leadership in water science, coordination with other agencies, and balance and cost-effectiveness of programs. These past performance issues are addressed in this chapter.

LEADERSHIP

In the formative years of water science in the first half of the 20th Century, the USGS was the major national employer of hydrologists. The agency developed methods to measure and predict streamflow and sediment transport and the science of fluvial geomorphic systems, leading to the development of water science and fluvial engineering in the United States. Scientists and engineers in the USGS also were leaders in developing the foundations of groundwater hydrology. USGS scientists did the first integrated studies of the hydraulics associated with aquitards and confining beds, related how aquifers respond to aquifer stresses and land subsidence, and how water overpressuring may induce earthquakes. They developed approaches and methods to understand the chemical and isotopic evolution of natural groundwater, salt-water intrusion; and they pioneered the integration of field data with groundwater modeling.

Since 1889, the USGS has operated a streamgaging program. The National Streamflow Information Program (NSIP), as it is now known, evolved as new needs for streamflow data emerged and new technologies for data collection, analysis, and dissemination were developed, including the recent advancement of making real time streamflow data widely available (waterdata.usgs.gov). Currently, the USGS has an extensive network of over 7,000 gages, and streamgaging is probably its most broadly supported program. Most stakeholders and collaborating agencies consistently cite the commitment to long term hydrologic record keeping through the WRD's streamgaging program as a key leadership element and an important component of the WRD's charge to provide hydrologic data.

In the 1960s, the WRD leadership further evolved when the WRD established the uniquely interdisciplinary National Research Program (NRP) that pioneered scientific hydrology as an Earth science to analyze and manage water resources and aquatic ecosystems. Today, the NRP remains a powerful and unique resource. WRD has used its position within the interdisciplinary USGS, incorporating water, solid Earth, ecosystems, and geographical information systems to promote large-scale interdisciplinary assessments of water resource-related topics. Examples include how surface water and groundwater interact in the Florida Everglades and around Chesapeake Bay; how water circulation and sediment deposition affects biological habitats in San Francisco Bay; how sediment delivery and crustal subsidence affects the sustainability of the Mississippi Delta; and how flood and sedimentation hazards evolve around active volcanoes.

Water science—including water management—has become a major field of practice. Specialists from academia, the private sector, state and local agencies, and some 20 federal agencies have missions related to water science and management. In contrast to the USGS, many other agencies have distinct statutory and legal authority for selected water resources issues and problems. For example, the U.S. Army Corps of Engineers maintains river navigation and the U.S. Environmental Protection Agency has statutory influence over much of the nation's water quality. Yet, within this context the USGS still shows national leadership in hydrologic science and is considered by many water resource users to be the nation's principal water science agency. Various examples are summarized below.

During the committee's information gathering efforts and deliberations, collaborating and cooperating agencies praised the USGS for its efforts. WRD data collection programs were noted as essential to other agency water resources related missions. The quality and integrity of USGS data, and its status as an independent agency, give its data greater credibility compared to that collected by regulatory agencies with a perceived vested interest. External stakeholders praised the WRD's leadership and commitment to long-term data collection, which are fundamental to the water science studies of many other parties and critical to understanding and managing the nation's water resources. The committee and collaborating agencies both note that the USGS WRD provides leadership by standardizing data collection methods across the nation among federal, state and local agencies, and in the private sector. Some examples follow:

- *Measurement technology, sampling protocols, and other standard method development*—The WRD standardized the analytical tools used to assess frequency and magnitude of streamflow, and these approaches are used by water managers throughout the nation. The USGS leads in field and laboratory method development for water analysis and monitoring for dissolved substances, ranging from heavy metals to pesticides to emerging contaminants. USGS scientists have worked with other federal and state agencies and partners to standardize these analytical protocols to share data and improve cost-effectiveness. Regional and national syntheses of data collected by various agencies are possible because of the consistency of methods developed and promoted by WRD.
- *Data collection and delivery*—The USGS's National Water Information System (NWISWeb; http://waterdata.usgs.gov/nwis/) provides a comprehensive digital gateway to groundwater and surface water-resource data—both quantity and quality—at over 1.5 million sites in 50 states, the District of Columbia, and Puerto Rico. NWIS now handles about 25 million requests per month. Although the USGS has struggled to keep the system current with rapidly advancing database technology, it is truly a world leader in making large volumes of water data, some of it 100 years old, freely available to users as diverse as researchers, flood forecasters, drought managers, water planners, regulators, and recreationists, such as canoeists. Most of the current NWISWeb sites provide real-time information, depicting graphics and maps of real-time streamflow compared to historical streamflow for the day of the year (http://water.usgs.gov/waterwatch/). This has opened up many new and important applications for water data users.
- *WRD data and interpretive studies used as key performance indicators by other agencies and institutions*—USGS water data are used as metrics: in USEPA's *Report on the Environment* (e.g., USEPA, 2008) to the Congress and the nation; in the multi-agency, public-private sector collaborative evaluation of the *State of The Nation's Ecosystems 2008* (Heinz Center, 2008); and in international reviews of water issues (e.g., Global Water Research Coalition, 2004). WRD data are integral to more formal "Program Assessment Rating Tool" (PART) measures of other agencies (e.g., USEPA for several water-quality measures and the National Weather Service related to flood hazard warnings) used by the U.S. Office of Management and Budget. On the down side, the Heinz Center notes that the long term integrity of USGS water related data for as many

as 25 national environmental indicators will be affected because USGS (WRD and the Geography Discipline) will be unable to provide consistent data because of budget cuts.

Collaborators and cooperators valued WRD interpretive studies for their science and unbiased execution. Examples cited often illustrate the multidisciplinary science that WRD can apply to problems, their capability to mobilize and address regional and national issues in a consistent framework their modeling technology and technology transfer. Some areas of note are:

- *National syntheses of nutrient, pesticide, and volatile organic compound occurrence*— their relationship to natural processes and human activities. The USGS's National Water-Quality Assessment program (NAWQA) led the way to an ongoing critical and relevant national assessment of the quality of the nation's waters including trends and causes of change. NAWQA's national syntheses have provided unique insights on the unexpected frequency of pesticides in urban streams, the occurrence of gasoline oxygenates, and identified decreases in phosphorus loading related to Clean Water Act control programs (e.g., NRC, 2002a). But, NAWQA cannot continue to be downsized because of budget reductions and still remain a <u>national</u> water quality assessment program (NRC, 2002a).
- *Emerging contaminants*—The USGS leads the nation in identifying, tracking, and doing research on newly identified synthetic or naturally occurring pollutants; chemical or microbial (Kolpin et al., 2002; Focazio et al., 2008). Its national investigations of the occurrence of these emerging contaminants produced one of the highest cited papers in the journal, Environmental Science and Technology (Kolpin et al., 2002), that was also noted as one of the Top 100 Science Stories of the Year by *Discover* magazine. The USGS continues to work on improved analytical methods to detect and measure these emerging contaminant compounds, characterize their sources, and evaluate their ecological effects.
- *Groundwater-surface water interaction and its relationship with water quality and aquatic ecosystems*. The USGS leads the nation in studies of groundwater-surface water interactions associated with rivers, lakes, and wetlands. One product of this effort, USGS Circular 1139 (Winter et al., 1998), a review of surface water and groundwater interaction, has sold 50,000 copies. Recent studies cover a wide breadth of activities including how groundwater recharge occurs under ephemeral streams in the arid Southwest (Constantz et al., 2007), how to use heat and specific conductance as groundwater tracers near streams (Cox et al., 2007), and circum-

boreal wetlands affected by seasonal freeze and thaw cycles (McKenzie et al., 2007). USGS hydrologists, geologists, geochemists, and ecologists from three regional USGS offices do research on the complex physical, chemical, and biological interactions among lakes, wetlands, streams in the Shingobee Headwaters Aquatic Ecosystems Project (SHAEP) in northern Minnesota. This research site, also used by academic collaborators, has become a model for multidisciplinary studies on lake-stream-groundwater interaction.

- *Integration of biological assessments into water quality monitoring*—The USGS through NAWQA and other programs has begun integrating biological assessments, including microbiological and pathogen monitoring, with traditional physical and chemical measurements. Research in this new program already has led to improved understanding of the ecological effects of urbanization (Coles et al., 2004). NAWQA Cycle I studies suggested a threshold response to ecological impacts that could have significant impacts on water management and restoration programs.
- *Sedimentation and fluvial geomorphology*—The WRD has the nation's largest database of information on sediment characteristics, sediment transport, and river channel form and behavior (http://water.usgs.gov/nrp/). Assessments by USEPA and the states show that sediment remains the primary cause of impairment in the nation's streams and rivers and more needs to be done to make use of this USGS knowledge and scientific talent. Various reports from the NRC (2002a, 2004a, b, and 2007) have noted the growing decline in these capabilities.
- *Development and technology transfer of groundwater flow and transport and geochemical models*—For decades, the USGS has provided high quality hydrologic and geochemical computer applications to the nation and scientific public free of charge (http://water.usgs.gov/ software/). Some examples of these USGS models in the public domain include the three-dimensional groundwater modeling code MODFLOW which is one of the most commonly used groundwater flow models worldwide, the 3-D multiphase water and heat flow numerical codes HYDROTHERM and SUTRA are widely used for variable-density problems such as salt-water intrusion. PHREEQC is probably the most commonly used model for understanding rock-water interactions. Others have developed more sophisticated models for research and more specialized purposes, but models such as MODFLOW have become the standard for many applications.
- *Watershed water-quality modeling*—The SPAtially Referenced Regressions on Watershed Attributes (SPARROW) model is an important watershed-scale modeling tool and is becoming an important support tool

for the states and Environmental Protection Agency (EPA) total maximum daily load (TMDL) programs. SPARROW incorporates in-stream water-quality measurements with spatially referenced characteristics of watersheds, including contaminant sources and factors influencing terrestrial and stream transport. USGS WRD scientists using SPARROW have made substantive contributions to the understanding of nutrient sources and transport in the Mississippi River system related to concerns with the Gulf of Mexico hypoxia (Alexander, et al., 2008). The ability of the model to quantitatively evaluate the origin and possible fate of contaminants in streams has opened up a new way to investigate watersheds.

The science done by USGS WRD scientists and engineers, represented in these and other examples, receives major professional recognition in the scientific community. USGS scientists are awarded about half of the O. E. Meinzer awards of the Geological Society of America that recognizes authors of publications that have “significantly advanced the science of hydrogeology...” (see http://gsahydro.eas.ualberta.ca/OEMeinzer.htm for a list of recipients). In a recent analysis of the 200 most-cited papers published in the journal *Water Resources Research,* approximately 10 percent were written by USGS authors (http:///water. usgs.gov/dispatch/2008/wrr-pubilcations.html). These 200 papers were among more than 6,500 papers published between 1975 and 2001; the citations were from the period 1996-2007. These papers were noted for their in-depth contribution to the progress and practice of hydrologic science.

COORDINATION AND COOPERATION

The U.S. Geological Survey (USGS) does not operate in an institutional vacuum. There are some 20 federal agencies with responsibilities in water management and/or water science located both within the Department of Interior (DOI) and across the government. Hence, coordination of water program activities is not just a “nicety,” it is a necessity. Many of these agencies roles are defined narrowly in the context of their regulatory functions and/or management responsibilities for water in specific regions. The USGS provides a scientific and observational foundation for many relevant national water programs run by these other federal agencies. The committee evaluated the degree to which the Water Resource Discipline (WRD) collaborates with other USGS disciplines and works together with other federal bureaus and agencies to answer SOT question 7: *Are USGS water activities coordinated well among other USGS programs, and* *among federal agencies? Are there areas in which interactions and coordination could be improved?* Beyond "coordination" of programs, as exemplary as that can be, the committee was also looking for evidence of cooperation and collaboration—programs where the WRD and other disciplines and agencies were working together toward common goals, in a common intellectual effort.

In testimony before the committee, other Disciplines within USGS, DOI agency partners, and other external agencies praised the coordination and collaborative efforts of WRD as well as the importance of the WRD's work relative to their own programs. Virtually all agencies recognize the need for more data, information, and coordination from WRD to meet the water resource challenges facing the nation. Some of these other agencies' have noted the WRD's leadership in coordinating federal water activities through the Advisory Committee on Water Information (ACWI) and the Subcommittee on Water Availability and Quality (SWAQ, under the National Science and Technology Council, Executive Office of the President).

External evaluators frequently recommend more cooperation and collaboration within and between federal agencies. However, such activities are not as simple as they often appear to outsiders. There are costs involved, because it takes staff time to affect cooperative efforts, and often considerable time to maintain communications among different parties. Some difficulties are incurred partly because of either the overlap or differences in agency missions resulting in turf-battles and even conflicts of interest that must be resolved. While keeping these constraints in mind, the committee presents and discusses examples of coordination within the USGS and then continues with a discussion and examples of cooperative efforts between the USGS and other agencies.

Coordination with Other USGS Disciplines

Overall, the WRD has been part of an encouraging trend with respect to collaboration within the USGS and within the DOI; the last decade has brought a distinct emphasis on interdisciplinary work at the Survey. Interdisciplinary programs at the USGS can be driven by individuals or small teams of investigators, often from the National Research Program (NRP) or collaborators in the Geologic Discipline, for example. Other programs may be driven by management, from the top-down, in response to either internal assessments of critical issues or external mandates, for example, the National Water-Quality Assessment Program (NAWQA). Finally, interdisciplinary programs can be customer-driven by management agencies such as the Fish and Wildlife Service, the National Park Service, the Bureau of Reclamation, or a local agency (see Boxes 2-1 and 2-2), or as part of multiagency regional efforts such as the Everglades (NRC, 2007, and next section) and Chesapeake Bay restoration (http://chesapeake.usgs.gov/).

There are various examples of success in these collaborative efforts. Those described in Boxes 2-1 and 2-2 were feasible because of multidisciplinary cooperation. There are also a number of river science collaborations (NRC, 2007), including:

- Developing successful strategies to sustain or rehabilitate the riparian ecosystem of the central Platte River through an understanding of the linkages among hydrology, river morphology, biological communities, and ecosystem processes; and
- The Long Term Resource Monitoring Program along the Upper Mississippi River System, which incorporates data on fisheries, macroinvertebrates, vegetation, water quality, land cover, bathymetry, sedimentation, water levels and discharge, and wildlife.

The regional offices, which coordinate most USGS activities in their respective regions, are working to better knit the disciplines together and have had some success. For example, at a state level, the Alaska Science Center and Florida Integrated Science Center are experiments in the integration of biological, geological, geographic, and water science. Such efforts should continue, to the extent they are cost-effective and realistic to manage.

However, there are institutional obstacles within the USGS that impede collaboration among the Disciplines. One fundamental factor is the lack of co-location of their scientists (NRC, 2001b; NRC 2007). Most Geology Discipline scientists are in Reston, Virginia; Denver, Colorado; and Menlo Park, California; while many Geography Discipline scientists are at the Earth Resources Observation Systems (EROS) Data Center in Sioux Falls, South Dakota or the Mid-Continent Geographic Science Center in Rolla, Missouri. WRD scientists are located at these regional centers but also in 48 water Science Centers throughout the country. And most of the Biological Resources Discipline scientists are located at 18 science and technology centers and, to a lesser extent, in cooperative research units at 40 universities around the country. This physical separation does not encourage frequent, informal discussions that often lead to interdisciplinary projects.

BOX 2-1
Groundwater Resources and Earthquake Hazards in the Los Angeles Basin

Periodic earthquakes and omnipresent water scarcity are two of the greatest challenges faced by Greater Los Angeles. Groundwater from the Los Angeles Basin supplies much of the drinking water for the area. As part of a cooperative project with the Water Replenishment District of Southern California and the Los Angeles County Department of Public Works to map the faults and the strata of the basin, the USGS drilled more than 30 monitoring wells. Scientists from the Geology Discipline and WRD were involved. They examined issues such as the rates of recharge of water infiltrated into groundwater from spreading ponds, and saltwater intrusion into freshwater aquifers along the coast.

The project resulted in new interpretations of the basin, including the recognition of ongoing tectonic deformation throughout most of the past several million years that has impacted the geometry and character of the sediments. These faults provide potential pathways for vertical migration of seawater and surface contaminants into the producing aquifers. This new framework should prove valuable in the design and operation of aquifer recharge projects, improve operations of seawater barriers, and identify areas of aquifer vulnerability. Overall, these efforts provided crucial information for sustainably managing the area's groundwater supply while also locating areas especially susceptible to earthquake shaking.

SOURCE: USGS Fact Sheet 086-02. Available online at http://pubs.usgs.gov/fs/2002/fs086-02/.

It is important to note that the USGS Disciplines evolved somewhat separately with different missions and organizational structures, as well as different clients. Therefore it is unrealistic to expect full integration of the various Disciplines. Full integration refers to the idea that you might make water resources or some central theme "the organizing principle for everything." However, one cannot reorganize the federal government to align each agency with every priority; hence entities must learn the arts of coordination, cooperation, and collaboration on complex objectives over a sustained period of years.

BOX 2-2
Groundwater Resources of the Middle Rio Grande Basin

The Middle Rio Grande Basin Study was a six-year effort (1995-2001) by USGS and other agencies to improve the understanding of the hydrology, geology, and land-surface characteristics of the Middle Rio Grande Basin to provide the scientific information needed for water-resources management. The basin previously had been declared a "critical basin" by the New Mexico Office of the State Engineer; it provides water for about 700,000 people in the City of Albuquerque and surrounding communities. Geologists, hydrologists, geophysicists, geochemists, and geographers from federal, state, and local agencies were all involved in the project. The goal of the study was to improve the scientific understanding of the hydrologic system and its relationships with geology and land use in the region as a foundation for water-management policy.

Surface, airborne, and borehole-geophysics played a major role in improving understanding of the geologic framework of the aquifer system. They were used to help define the boundaries of the aquifer system, faults, and areas underlain by more permeable materials. This information was used in the construction of a three-dimensional groundwater flow model of the basin.

The study results were highly important, in that they showed that the aquifer is less connected to the Rio Grande and overall receives less recharge than previously believed. This would tend to decrease the sustainable yield of the aquifer. Further, parts of the aquifer system were found to have lower than expected permeability, which suggests areas that would locally yield less water through wells. Many faults were also found cross-cutting the sediments.

SOURCE: USGS Circular 1222. Available online at http://pubs.usgs.gov/circ/2002/circ1222/.

Coordination and Collaboration with Other Agencies

In the committee's observations, and from dialogue with other agencies, the WRD has done an admirable job of working to coordinate its activities with other federal agencies—both directly with the agencies and through WRD's leadership in various federal coordinating bodies such as ACWI and SWAQ. The USGS develops and maintains the scientific and observational foundation for many critical national services that are provided by other federal agencies, including the National Park Service, Bureau of Reclamation (and other Interior Department agencies), U.S. Army Corps of Engineers (USACE), Environmental Protection Agency (EPA), and the National Weather Service—National Oceanic and Atmospheric Administration (NOAA). These are important functions and services that USGS provides to the nation and to these other agencies, and on balance WRD provides more effort to facilitate coordination, and actual collaboration than some of its partner agencies, from our observations.

Because of the WRD's mission and reach, it also is involved in the coordination of many regional water issues such as ecological restoration efforts in Chesapeake Bay and the Everglades (discussed further below) or the Gulf of Mexico Hypoxia work groups. The following sections provide a few examples where the USGS is fulfilling its role in providing scientific data, information, and analysis in coordination with other agencies to develop solutions to regional or national problems.

Real-time Streamflow Information for National Weather Service Flood Forecasts

The USGS makes streamflow information available for a host of applications. One especially important example is the hydrologic science and streamflow observations that undergird flood watches and warnings provided by the NOAA National Weather Service's (NWS) River Forecast Centers. The NWS and USGS closely cooperate and coordinate the provision of these products and services. The NWS properly acknowledges the pivotal USGS role and works with cooperators to advocate for stable, long-term support of the National Water Information System.

Nevertheless, this USGS role, though vital, is not very visible to the public or to policy makers, largely because NWS makes the actual forecasts that the public receives. USGS and their cooperators, such as NWS, need to ensure that credit for the USGS role is more visible and explicit. Some of this might be accomplished by making such federal services more visible on the agencies' web sites, as a start.

Hydrologic Monitoring to Support Everglades Restoration

The USGS is highly involved in the major ecological restoration efforts around the country, such as their work with the Chesapeake Bay restoration program as well as the Everglades restoration. The preponderance of scientific evidence indicates that a return to hydrologic characteristics of the historical Everglades is a precursor to ecological restoration of the remaining Everglades ecosystem. Thus, the Comprehensive Everglades Restoration Plan, jointly managed by the USACE and the South Florida Water Management District (SFWMD), aims to achieve ecological restoration of the Everglades by reestablishing hydrologic characteristics as close as possible to their pre-drainage conditions. Thus, 753 stage monitoring stations, 512 groundwater wells, and 434 water flow sites operated by the USGS, SFWMD, and the Everglades National Park (ENP) comprise the current hydrologic monitoring network in the Lake Okeechobee, Everglades ecosystem area. The data supplied are direct measures of hydrologic stage, water flow velocity, or groundwater levels that provide a way to (1) assess if restoration activities are meeting hydrologic targets and (2) provide a common metric that allows trade-offs to be assessed within the natural system and between the more natural and the highly managed environments (NRC, 2006).

There is concern, however, that the current hydrologic monitoring program may be inadequate to allow an evaluation of trade-offs between hydrologic management options. This is in part because a large portion of the restoration agencies' Management and Assessment Plan (MAP) depends on preexisting monitoring programs conducted by various agencies and institutions. Thus, the USGS is currently reviewing the surface-water monitoring network for its adequacy and suitability for the MAP. The Everglades Depth Estimation Network (EDEN), established in 1999, consists of hourly water-level data from 253 gaging stations operated by the USGS, SFWMD, ENP, and the Big Cypress National Preserve (BCNP), from which data are transmitted to the USGS and then entered into the USGS National Water Information System (NWIS) database from which they can be accessed on-line by scientists and managers.

In addition, regional hydrologic models such as the South Florida Water Management Model and the Natural Systems Model that are being used to provide targets for hydrologic restoration have a resolution (2 × 2 mile grid cells) too coarse to predict the ecological effects of the hydrologic conditions they model. The flat topography of south Florida has subtle variations in terrain that create ecological niches related to the frequency, timing and depth of inundation. As a result the USGS has developed a helicopter-based instrument, the Airborne Height Finder (AHF), designed to measure the terrain surface elevation at the subdecimeter level. The AHF has collected more than 50,000 elevation points in a 400 × 400 meter grid pattern to support the hydrologic models. It is hoped that these elevation data, coupled with new versions of LIDAR (Light Detection and

Ranging) imagery, will provide the resolution needed for the hydrologic models.

WRD Collaboration with the Environmental Protection Agency

WRD collaboration with EPA is extensive and generally very productive, from co-sponsorship of the biennial National Monitoring Conference to joint work on the "National Hydrography Dataset Plus," (NHD+; an integrated suite of geospatial data sets that incorporate elevation, land cover, and watershed boundary datasets with the original NHD). The EPA takes a keen interest in the USGS's work on emerging contaminants, water-quality models, and stressor-gradient research to help them focus their efforts. WRD has worked with EPA to adapt programs and models, such as SPARROW to make it more useable to EPA and states for EPA's TMDL program.

WRD's National Water-Quality Assessment (NAWQA) Program provides an understanding of water-quality conditions and how those conditions may vary locally, regionally, and nationally; whether conditions are getting better or worse over time; and how natural features and human activities affect those conditions (http://water.usgs.gov/nawqa/). Overall, as noted in NRC (2002b), NAWQA has done an excellent job of establishing cooperative relationships within USGS and with external stakeholders, such as EPA. NAWQA is playing a vital role in balancing its good science with responsiveness to policy and regulatory needs of agencies such as EPA. It has long been a policy maxim that good water quality monitoring is needed to assess status, trends, and understanding, and that such monitoring is best performed by a science agency rather than a regulatory agency. Regulatory agencies seldom have the authority to monitor or address any measures that go beyond the immediacy of their regulatory program, such as emerging water-quality problems. They are typically viewed as biased to address only their programmatic needs. Independent monitoring and data analyses by the WRD are vital to provide unbiased input to "government performance and review."

NAWQA data and information are widely valued, as evidenced by their widespread usage. Many other organizations seek to make linkages with the NAWQA program, including "add-on" studies to help meet their additional information needs. The EPA's Office of Pesticide Programs has had an especially productive interagency relationship with the NAWQA program (Box 2-3). In fact, it can be too much of a good thing as NAWQA tries to

BOX 2-3
EPA's Pesticide Programs' Collaborative Activities with NAWQA

The EPA's Office of Pesticide Programs (OPP) is the gateway to the $11 billion/year pesticide market, and makes over 5,000 regulatory decisions annually. The OPP has worked closely with the NAWQA Program since its beginning in 1991. NAWQA assessments provide occurrence and trend information of pesticide levels in the environment, provide evidence to evaluate the effectiveness of OPP regulatory programs, inform the risk management process, help prioritize OPP's future efforts, and serves as a credible source of data to stakeholders. NAWQA Assessments help EPA develop statistical models for predicting exposure to humans as well as to aquatic life, birds, and small mammals.

For example, OPP looks at measured trends in relationship to their regulatory programs to answer questions such as, Is the pesticide increasing or decreasing in the environment?, Are OPP regulatory programs working?, and How can protection of vulnerable areas of the country be improved? USGS-EPA collaboration has paid off in improved statistical models for predicting exposure to pesticides, such as the WARP (Watershed Regressions for Pesticides) model for predicting atrazine distributions in rivers and streams. Trend analysis of USGS data has shown that levels of the most persistent pesticides (organochlorines) are decreasing in the environment; those that had exceedances in NAWQA studies have been subject to stringent mitigation measures to reduce exposure. And NAWQA data will be used to evaluate reduction of pesticide levels in water as a means to protect aquatic life; by 2011, urban watersheds that exceed OPP's aquatic life benchmarks for diazinon, chlorpyrifos, and malathion are targeted for a 60 percent reduction.

SOURCE: Jim Jones, Director, Office of Pesticide Programs, EPA, written communication, October 26, 2006.

maintain its design to meet national goals while addressing the diverse needs of those who seek to work with it.

To foster coordination and communication with EPA, the WRD and the NAWQA program at one time detailed several staff to work in EPA offices and serve as liaisons. This was a very productive practice according to testimony of agency personnel and evidenced by the success highlighted in Box 2-3, but these liaison positions were terminated.

Multi-agency Collaboration for Water Management

Box 2-4 outlines an example of WRD collaboration with multiple federal, state, and local entities to address complex water management issues in the San Pedro, Arizona area. In particular, WRD provides key technical expertise to collect needed data, assess, and synthesize the information, and apply various models to provide forecasts and predictions for water managers and stakeholders to use in a consensus-based resource planning process. This example, addresses the growing issue of competition for water between public water supply and ecosystem needs. The USGS has a unique perspective that is valuable to other agencies; the USGS does not manage water distribution projects, makes no regulations, and manages no federal lands, so its science is generally viewed as unbiased. The USGS as a whole can bring a broader array of scientific disciplines—hydrology, biology, geology, geography, and geospatial information—to a problem than most other agencies. Other agencies and groups utilize USGS data and interpretive products as metrics to gauge their own program performance and/or for evaluating and forecasting the condition of the environment. The USGS can utilize its interdisciplinary strength and its broad national reach through the Science Centers and Coop program, to foster more coordination and collaborative efforts needed to meet the nation's growing water problems. The SOT includes the questions: *Are USGS water activities coordinated well among other USGS programs, among federal agencies?* We have shown here that the USGS water activities are generally well coordinated among USGS, DOI, and other agencies, and it should continue to utilize this ability to foster improved water science.

BALANCE

The SOT poses evaluation questions about Water Resources Discipline (WRD) program planning, program goals, and balance. The SOT asks whether the WRD has successfully met its goals, as they are described in the WRD- and individual program-5-year plans? Question 4 of the SOT (Box 1-1) poses the question whether the balance of the U.S. Geological Survey (USGS) water science portfolio is appropriate: "Given the current budget climate...is the current content of the USGS water science portfolio appropriate? If not, what changes should be made? What areas of science should receive higher or lower priority? What is the best balance among a.) collection of long-term data, interpretive studies, methods development,

BOX 2-4
Regional Groundwater Management:
Balancing the Water Needs of Communities and Natural Systems

Urban water use demands are steadily increasing throughout the country as our larger population centers continue to grow. In the Western states, millions of new residents now rely upon regional groundwater resources to meet their needs. This increase in demand directly competes with the water needs of sensitive wetland and riparian habitats in the region. The integration of strategic monitoring programs, the application of decision-support tools and predictive models based on empirical data, and collaborative, consensus-based planning processes that engage a wide array of stakeholders are all essential components for effective groundwater management at regional scales.

The San Pedro Riparian National Conservation Area (SPRNCA) is located in southeastern Arizona, near the U.S./Mexico border, and is managed by the Bureau of Land Management. It supports a number of federally listed threatened and endangered species by the U.S. Fish and Wildlife Service (USFWS), some of which are directly reliant upon groundwater discharge that sustains lush streamside habitats. The USGS, Bureau of Land Management (BLM), and USFWS are active members of the Upper San Pedro Partnership, a consortium of 21 local, state and federal agencies and organizations who are working together to attain sustainable yield of groundwater resources in the area through an adaptive management approach.

The USGS provides key technical expertise in this partnership effort through extensive field data collection, and simulation of the groundwater system using MODFLOW 2000 (MF2K) (Harbaugh and others, 2000a, 2000b) resulting in information such as Figure 2-1. This 5-layer numerical groundwater flow model represents multiple hydrogeologic units to simulate seasonal and long-term variations in groundwater flow. Although some USGS streamflow records in the area go back as far as 1903, additional data collection by the USGS from the 1990s until 2004 helped to address critical information gaps regarding the behavior of the groundwater system, and its interactions with streamflow. Previous modeling efforts had been constrained by a lack of data describing rates and locations of recharge, hydrogeologic factors such as the location of silt and clay layers, the vertical distribution of hydraulic head, and other factors.

As a result, elected officials and decision-makers who have been engaged in this partnership effort have increased their abilities to make informed decisions as a result of model development, and find themselves refining their metrics of success for managing groundwater resources from a simple "bottom line" water budget approach toward a more sophisticated spatial water management perspective. The location of groundwater recharge and extraction can be just as important as their volumes in terms of effects on baseflow in the river. This understanding of the groundwater systems using data syntheses such as Figure 2-1 provides a framework for consideration of additional strategies and management options not previously contemplated. It also increases confidence regarding the most effective methods to sustain riparian resources.

This is a good example where USGS WRD has actively moved into "forecasting and prediction" information in concert with water managers and stakeholders (see Chapter 4).

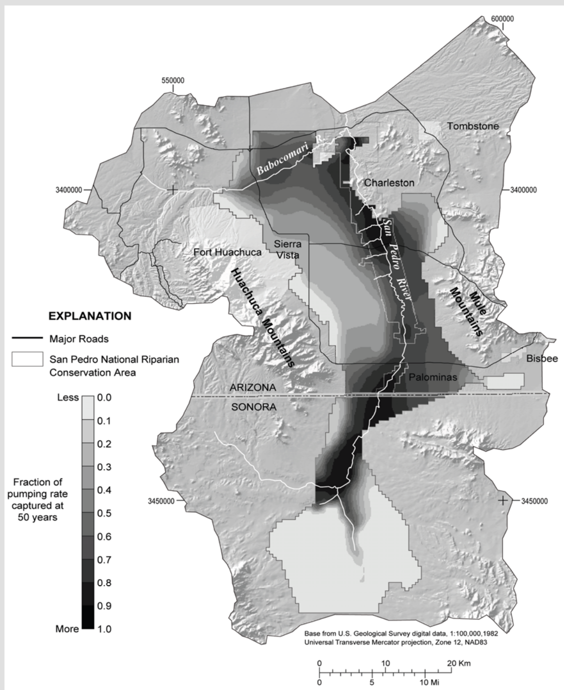


FIGURE 2-1: Map of San Pedro Riparian National Conservation Area groundwater capture. SOURCE: Leake et al. (2008).

information dissemination and research; and b.) groundwater and surface water; water quality and quantity."

The framework for these questions is derived directly from a former WRD strategic plan, *Strategic Directions for the Water Resources Division, 1998-2008* (USGS Open-File Report 99-249; referred to as the *Strategic Directions* plan in the discussion below). Hence, to address SOT 1 the WRD *Strategic Directions* plan, as well as individual program (5-year) plans for the Coop Water Program, the Hydrologic Networks and Analysis Program, the Hydrologic Research and Development Program, the National Streamflow Information Program, the NAWQA Program, the Toxic Substances Hydrology Program, the Water Resources Research Act Programs, the Ground-Water Resources Program, and the National Water-Use Information Program were reviewed and then related to the balance of the USGS WRD portfolio (SOT 4). However, questions regarding program planning, goals, and balance are difficult to answer. In general, when they have the resources to carry them out, the WRD and its individual programs have successfully met their basic goals. It is easy to state that basic objectives and operational functions were met, but not necessarily the full intent of the WRD plans.

While we could produce a long list of projects and basic accomplishments that address stated "goals" in WRD and individual program 5-year plans, this would not be particularly useful. Many USGS plans are nearly a decade old; for example, the *Strategic Directions* plan is ca. 1999. Although many plans have been updated with annual operating guidance and memos, trying to catalog and characterize specifics related to these older plans does not provide much insight or guidance to the WRD. Also, the USGS now has a new strategic plan, *Facing tomorrow's challenges—U.S. Geological Survey science in the decade 2007–2017* (USGS, 2007) which presumably will drive program development for the coming years. This new science plan has important drivers for the WRD program to help to address many pressing problems for the nation. Therefore, our suggestions and review are offered in the context of this new plan (see Water for Tomorrow, Chapter 4).

SOT question 4 about the *content of the science portfolio and program balance* and where the USGS currently focuses its efforts comes from former ways in which the WRD programs and budgets were tracked. The *Strategic Directions* report (USGS, 1999) provides some background; relevant sections are summarized in Box 2-5. The committee examined the possibility of reviewing the WRD budget by these categories to extend this analysis to the current condition. However, the USGS introduced a new budget system, and it is now difficult to re-produce these figures, so the committee did not pursue a detailed budget analysis of "program balance" as outlined.

Recommendation: In the past, the USGS WRD program balance was assessed through the *Strategic Directions* plan (USGS, 1999; see Box 2-5). If it is judged important for the USGS, DOI, or OMB to review program balance by these particular metrics, the budget system should be adjusted to accommodate such summaries.

The committee judges that the WRD continues to work to find balance among its basic program activities, and this is a worthy struggle. For example, the WRD understands the importance of long-term data collection. As outlined in NRC (2004a), many key long-term water monitoring systems have been in substantial decline or functionally eliminated. While "stationarity" may be "dead" (Milly et al., 2008) and as a result our nation needs new science to forecast future hydrologic conditions, the nation needs long-term records as a basis to understand its water resources, and the changes and challenges we are facing, to evaluate future conditions. The USGS must continue to find a way and develop resources to maintain long term records so vital for future analysis.

COST-EFFECTIVENESS

Here, we will discuss the "cost-effectiveness" of the U.S. Geological Survey (USGS) water activities, SOT question 5. It is very difficult—perhaps impossible—to address the "cost-effectiveness" of programs such as the USGS Water Resource Discipline (WRD). Except perhaps for the basics of their streamflow measurement program, the WRD does not produce simple products. Furthermore, there are not well-defined "industry-wide" metrics to measure the "cost-effectiveness" of their scientific and intellectual products. Therefore we ask how do we measure the cost-effectiveness of leadership the WRD has provided in water programs for the country, or the relevance of their programs dealing with emerging issues?

The Office of Management and Budget (OMB), who often asks such questions, has itself struggled with concepts such as "research efficiency." A recent National Research Council study, NRC, 2008c, on evaluating research efficiency at the U.S. Environmental Protection Agency, for example, concluded that OMB was not recommending or accepting the same methods for different federal agencies. That report noted that metrics based on ultimate (i.e., long-term) outcomes of research are not feasible for evaluating research efficiency because such outcomes cannot be known in advance, may occur long after the research is completed, and may depend on many other factors than the effectiveness of the program in question. It recommended that expert panels be used to evaluate the relevance, quality, and performance of the research, for example, whether an agency is "doing the right research and doing it well" (NRC, 2008c) as considerable expert judgment is required.

BOX 2-5
Relevant Sections of "Strategic Directions for the Water Resources Division, 1998-2008" (USGS Open-File Report 99-249)

"Ideally, the percentages of total available funds for the three components should be about 40 percent for long-term data-collection, about 45 percent for interpretation and assessment, and about 15 percent for research and development. The relative proportion of these three components will be out of balance if either long-term data collection or interpretation and assessment funding falls below 30 percent of total program or if research and development falls below 15 percent.*

"The history of the mix among program activities is as follows:

Percentage of Overall Funds	1982	1990	1998
Long-term data collection[1]	37	36	34
Interpretation and assessment	47	45	48
Research and development	16	19	18

[1]Long-term data collection is defined as data that are collected consistently over a period of at least 5 years and typically for a much longer period of time. Thus, even though almost all projects collect basic hydrologic data, only those sites that are monitored continuously for at least 5 years are included in calculating the percentage of funds spent on long-term data collection.

"From 1982 to 1998, there was only modest funding growth above inflation for streamgages and real declines in funding for NASQAN and ground-water monitoring. This is of special concern because of the importance of long-term data collection for water-resource management and to determine the effects on water resources of climate variability and land-use changes on water resources…WRD will work with DOI, Office of Management and Budget (OMB), and Congress to begin to shift its overall program to increase the funds available for long-term data collection…

"WRD must also maintain a balance among the water-resource discipline areas. Ideally, this balance would be about 30 percent of total program funds spent for data collection and investigations that are related to surface-water quantity (includes floods), and about 25 percent for data collection and investigations that are related to ground-water availability. Of the remaining funds, about 25 percent would be spent for data collection and investigations of surface-water quality, including geomorphology, and ecology, and about 20 percent for ground-water quality. The ideal funding level for surface water is higher than that for groundwater because of the extent of surface-water monitoring needed for flooding and hazard warning. Overall, there is a bias towards quantity and availability of water resources because of WRD's unique position as the Nation's primary collector of these data. WRD's overall program will be out of balance if any one of the four components falls below about 20 percent or rises above about 35 percent.

Percentage of Overall Funds	1982	1990	1998
Groundwater	20	20	15
Surface water	32	32	32
Water quality	22	23	25
General hydrology	26	25	28

"During the last 8 years (1990-98), there has been growth in the water-quality area. This growth primarily results from increased work for the Department of Defense and the growth of the NAWQA program. The surface-water component has stayed constant between 1982 and 1998 but the number of interpretive studies, which were never a large percentage of the surface-water component, has had an overall decrease. The discipline that had the most significant decrease was groundwater resources, primarily because of completion of the Regional Aquifer-System Analysis Program."

In the following paragraphs, three different approaches are taken to help provide an answer to whether overall WRD programs are "well-managed and conducted in a cost-effective manner." This evaluation of the term is based on a combination of best professional judgment and semi-quantitative measures. Metrics include examining the demand for USGS products and services, and formal efforts to use expert panels (as recommended in the report to OMB) to optimize USGS WRD programs. We also refer the reader to Chapter 3 where a brief look at the budgetary climate is linked to cost-effectiveness in relation to the staffing and optimization of various programs.

Demand for USGS Products and Services

As a first step we evaluate product demand. The testimony from other federal and state agencies and other stakeholders about the need and demand for USGS data support may be viewed as one indicator of the cost-effectiveness of their efforts.

The Cooperative Water Program. The only area in the WRD budget that has risen significantly, in inflation-adjusted dollars since 1990 is the state and local funding for the Cooperative Water Program (Coop), as will be highlighted in Chapter 3. This represents funds that a local cooperator—such as a state, county, city, or tribal government—pays the USGS to work on projects of mutual interest. These consumers are increasing their funding for the WRD products, and now exceed the USGS federal Coop program capability to match their money. A substantial portion of these costs are to maintain hydrologic infrastructure, such as stream gages, as well as Coop interpretive studies. Cooperators often note that USGS gaging programs are costly. Some states and local governments supplement the USGS program with their own gages—but these sites were often set up with USGS supervision to ensure that the engineering installation meets appropriate specifications for data quality. Even amidst the cost concerns, cooperators note that they need the quality and independence of the USGS products; that independent monitoring *and* data analyses are vital to provide unbiased input to their management programs and for "government performance and review."

A related measure, the Coop portion of the streamgaging program is discussed in the analysis put forth by the National Hydrologic Warning Council (NHWC, 2006) that came forward to outline the "Benefits of USGS Streamgaging Program." The NHWC is comprised of cooperators and stakeholders that utilize these data. They do not put their assessment in terms of "cost-efficiency" but rather in terms of societal benefits, and societal need for the streamflow data, partly in response to concerns for continued budget reductions for these programs. The report outlined nine distinct beneficial categories of uses for the USGS streamgaging network:

1. Planning, designing, operating, and maintaining the nation's multipurpose water management systems,
2. Issuing flood warnings to protect lives and reduce property damage,
3. Designing highways and bridges,
4. Mapping floodplains,

5. Monitoring environmental conditions and protecting aquatic habitats,
6. Protecting water quality and regulating pollutant discharges,
7. Managing water rights and transboundary water issues,
8. Education and research, and
9. Recreational uses.

Water Data, Models, and Publications. USGS water data are in huge demand. Requests for data fulfilled from the on-line National Water Information System average between 30 and 40 million downloads per month as of mid-2008 (waterdata.usgs.gov). As noted earlier in this chapter, WRD's MODFLOW is one of the most widely used groundwater flow models worldwide, and exemplary of that fact, more than 23,000 copies of MODFLOW were downloaded from the main USGS web site from 1990 to 2000 alone.

As noted earlier, one of the most highly cited papers in the journal *Environmental Science and Technology* was a result of USGS national studies evaluating the occurrence of emerging contaminants (Kolpin et al., 2002). This work also was considered one of the Top 100 Science Stories of the Year by *Discover Magazine*. In a recent analysis of the 200 most-cited papers published between 1996 and 2007 in *Water Resources Research,* approximately 10 percent were written by USGS authors. They were noted for their in-depth contribution to the progress and practice of hydrologic science. Certainly, this should be considered another measure of "effectiveness" (along with leadership).

Efforts to Optimize Their Program

Over the last several decades, the WRD has put much time, effort, and thought into optimizing its human and financial resources. Two examples are the Streamgaging Program (NSIP) and the National Water-Quality Assessment (NAWQA) Program. Also, WRD has maintained a nearly continuous program of reviews by expert panels, the NRC's Water Science and Technology Board and other organizations, which have provided significant feedback on nearly every major water program and initiative over that period of time.

Optimization of the Streamgaging Program (The NSIP). Over many years, the USGS has conducted repeated exercises to "optimize" its streamflow data collection network—to be as cost effective as it can to meet both national and cooperator needs. The majority of the gages are funded through the Coop program, in which 50 percent or more of the cost is provided by a state or local cooperator—many of the remaining gages are completely or partially funded by other federal agencies such as the U.S. Army Corps of Engineers and the Bureau of Reclamation. The USGS has only partial control over the locations of such gages. It has, however, gone through numerous assessments to optimize network design, in terms of both location and numbers of gages, to effectively address water management needs and to ensure it can optimize its network to address regional and national needs. This work was developed in the 1970s and 1980s using statistical regression and other optimization techniques (e.g., Moss, 1982; Moss and Tasker, 1991). Such techniques also have been applied in a context of shrinking federal budgets to evaluate which gages could be abandoned with the least loss of hydrologic information generated.

Some of these optimization techniques have proved difficult to apply over large, heterogeneous regions with varying geology, soils, topography, land-use, and biota—especially at the national scale. The NSIP, therefore, took the alternative approach of designing a network to meet a defined set of federal goals (http://water.usgs.gov/nsip/federalneeds. html). Optimization also has been applied to this approach with some success and research continues at the USGS in this area (Lanfear, 2005).

Optimization of the NAWQA Program. Another example of the WRD's management efforts toward cost-effectiveness was reviewed in the 2002 NRC report *Opportunities to Improve the U.S. Geological Survey National Water Quality Assessment Program,* which assesses the first cycle of the NAWQA program and planning for the second cycle. National coverage and representativeness are issues fundamental to the success of NAWQA. Cycle I was planned for 59 study units (SUs), but eight were not initiated because of budget constraints and the number of SUs in Cycle II was reduced to 42. The report expresses concern with how representative of the nation's waters NAWQA would be with the ongoing reduction in SUs. While the NRC study concluded that NAWQA had done an exemplary job of dealing with downsizing to 42 planned SUs for Cycle II, it also noted that NAWQA cannot continue to be downsized and still be considered the national water quality assessment that the nation needs. Despite the significant reduction in Cycle II, the study concluded that NAWQA could still maintain good coverage of the nation's streams and groundwater resources, largely because of the commendable, rigorous planning effort that the WRD NAWQA management team employed.

Program Review. The USGS has made extensive use of external expert panels to evaluate the effectiveness of their programs; a practice that another NRC committee (NRC, 2008c) has recommended OMB should ing basis for the last two decades (see Box 2-6). In addition, the WRD engages other organizations in reviews of its programs that have led to reports such as the National Hydrologic Warning Council's 2006 report on the streamgaging program (NHWC, 2006), and the Advisory Committee on Water Information's 1999 and 2004 reviews of the Coop program (see USGS [1999] and ACWI, 2004—http://acwi.gov/ coop2004/CoopTFRpt.pdf, respectively). The Coop program receives extensive input from entities such as the Interstate Council on Water Policy (http://www.icwp.org) through cooperators' round-tables, and through myriad discussions between cooperators and USGS science center personnel. While these reviews are generally oriented toward societal relevance and science leader-

BOX 2-6
Reports on USGS WRD Programs and Initiatives by the National Research Council

1990	Review of the USGS National Water Quality Assessment Program: The Challenge of National Synthesis
1991	Preparing for the Twenty-First Century: A Report to the U.S. Geological Survey [Review of overall WRD activities]
1992	Regional Hydrology and the USGS Steam Gaging Network
1996	Hazardous Materials in the Hydrologic Environment: The Role of the U.S. Geological Survey
1997	Watershed Research in the U.S. Geological Survey
1999	Hydrologic Hazards Science at the U.S. Geological Survey
2000	Investigating Groundwater Systems on Regional and National Scales [Ground-Water Resources Program]
2001	Future Roles and Opportunities for the U.S. Geological Survey
2002	Estimating Water Use in the United States: A New Paradigm for the National Water-Use Information Program
2002	Opportunities to Improve the USGS National Water Quality Assessment Program
2004	Assessing the National Streamflow Information Program
2006	River Science at the U.S. Geological Survey

All of these reports are available from http://www.nap.edu.

ship questions, they often touch on management approaches and cost-effectiveness issues as well.

Considering the available metrics for analysis we find that the USGS is managed in a cost-effective manner. Demand for the USGS WRD product is apparent, both in the stakeholder contributions to the Coop program, and popularity of USGS publications and real time water data. The Discipline diligently optimizes its programs and seeks external review both from the NRC and other entities. The USGS pioneered the field of water science in the 20th century; and now some 20 other federal agencies have water science and/or management in their mission statement. The USGS, particularly because of its unbiased nature, successfully facilitates coordination and external collaboration. The SOT questions on "program balance" relate to an older strategic plan employed by the USGS, that cannot be fully tracked using the current budget system. If these are program measures that USGS, DOI, or OMB still deem important, the budget system should be adjusted accordingly to track these measures. A performance review by these metrics judges that overall the USGD WRD programs continue to meet their basic goals and objectives, but many signs point to a decline in their capacity and ability to meet the future needs of the nation.

3

Preparing For Tomorrow

In chapter 2, we reviewed various aspects of WRD's performance, as requested in the statement of task (SOT; Box 1-1). In chapter 4, Water for Tomorrow, we will address the SOT questions that look to the future, outlining recommendations for organizational adjustments and leadership to address the water resource problems facing the nation. To set the stage for tomorrow and provide context to look to the future, in this chapter we describe problematic trends and water resource issues that will shape the priorities that USGS water programs need to address to meet society's needs. We also briefly review components of the WRD's planning process, working with stakeholders to identify and establish priorities. This process is an important component to define directions that are relevant for future needs. Lastly, we review WRD budget and staffing, which provides necessary context on the operational and budget climate, related to past and present performance issues, but more importantly, this also must be understood as a starting point in preparing for tomorrow.

WATER RESOURCE TRENDS "PREDICTABLE SURPRISES" AWAIT

"*Our Cup Runneth Dry*"

"Henceforth, North Americans will have to give up their assumption of an easy abundance of water, transcend their fears of future scarcity, and manage their water resources sustainably with due regard for their full value – ecological, economic, and social."

SOURCE: Mehan (2009).

Future water needs cannot be precisely known, yet there are trends of increasing stress on water resources that are widely recognized. These trends are "Predictable Surprises" (Box 3-1) with respect to water resources in the near future (Bazerman and Watkins, 2004). These "surprises" are problems that can be recognized but they will not resolve themselves. For example, aquifers will not quickly recharge and "naturally resolve the problem" of aquifer depletion after they are overpumped (e.g., Ogalalla Aquifer). In many regions, water allocation conflicts already occur and will become worse in the future because of over-allocation of water coupled to increasing population growth and foreseeable droughts. As these predictable water crises occur the USGS remains in the position to assist the nation in understanding, predicting, and minimizing the impacts of these crises. But changes are needed for the USGS to successfully meet the nation's challenges. For perspective, we outline some key trends for water resources that must be faced in the coming years.

BOX 3-1
Predictable Surprises

In "*Predictable Surprises: The Disasters You Should Have Seen Coming, and How to Prevent Them,*" Bazerman and Watkins (2004), describe the characteristics of Predictable Surprise*s* that may affect society or businesses:

1) A shared trait of predictable surprises is that leaders knew a problem existed and that the problem would not solve itself.
2) Predictable surprises can be expected when organizational members recognize that a problem is getting worse over time.
3) Fixing the problem would incur significant costs in the present, while the benefits of action would be delayed. (We discount the future.)
4) Addressing the surprises typically requires incurring certain cost, while the reward is avoiding a cost that, while uncertain, is likely to be much larger. (Hence, leaders know they can expect little credit in the short run for preventing them.)
5) Decision-makers, organizations, and nations often fail to prepare for predictable surprises because of the natural tendency to maintain the status quo (when a system still functions, there is no crisis to catalyze action).
6) A small vocal minority benefits from inaction and is motivated to subvert the actions of leaders for their own benefit.

PROBLEMS OF WATER AVAILABILITY WILL BECOME INCREASINGLY MORE SERIOUS AND PROMINENT

The U.S. Census Bureau projects the population of the United States to increase almost 50 percent from 282 million people in 2000 to 420 million in 2050 (U.S. Census Bureau, http://www.census.gov/ipc/www/ usinterimproj/). The amount of water available of appropriate quality for these people is limited. The hydrologic regimen of any given region of the country is influenced by regional climate, but also design and operation of our infrastructure, including water and wastewater collection, storage and distribution, electric power generation, residential and commercial buildings, roads and bridges, and agriculture. Access to sufficient water has become and will continue to be a difficult problem throughout the United States, not only in the southwestern states that rely on well-recognized, declining surface water and groundwater resources (Figure 3-1).

> "*Why You Should Worry About Water. How this diminishing resource will determine the future of where and how we live.*"
>
> SOURCE: The cover page and headline for U.S. News and World Report, June 4, 2007.

In the relatively humid Southeast, Georgia struggles to manage water to support its growing metropolitan areas, resulting in conflicts with the downstream states of Alabama and Florida. Salt water intrusion from overpumping has reduced usable groundwater resources available to coastal cities from Florida, to Bainbridge Island in the Pacific Northwest, and Cape Cod in the Northeast. Irrigated agriculture has been modified or abandoned in parts of the High Plains because groundwater levels have dropped.

Water constraints are becoming both more chronic and widespread, as well as regionally acute (Figure 3-2). The areas of the greatest projected population growth are where water withdrawals are already unsustainable, exceeding available freshwater resources (the limit on recharge and renewal of water) by 5 to >500 percent. Water supply and demand are linked inextricably to energy supply and demand, key components of societal and economic health. "The availability of adequate water supplies has a profound impact on the availability of energy, while energy production and power generation activities affect the availability and quality of

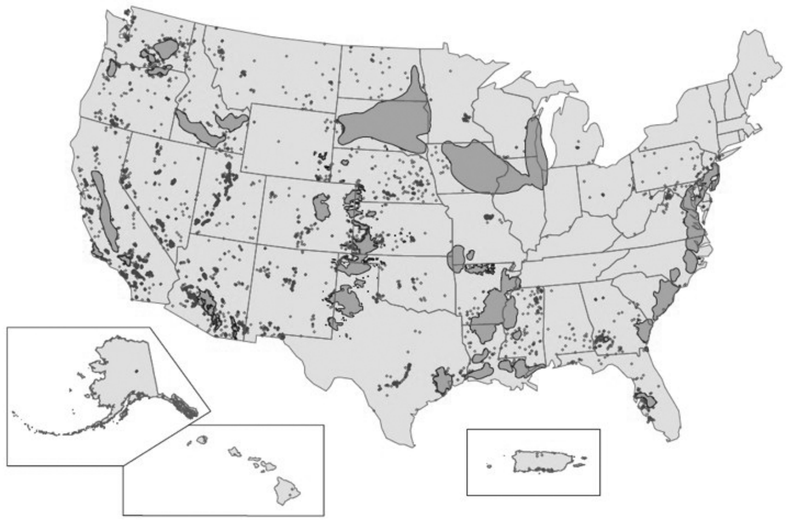


FIGURE 3-1 Water-level declines in the U.S. Darker regions show major regions with declines of 40 feet in at least one confined aquifer, or 25 feet in an unconfined aquifer, since predevelopment. The dots are individual wells where the measured water-level difference over time is greater than or equal to 40 feet. SOURCE: Reilly et al. (2008).

water" (Pate et al., 2007). When combining fresh and saline water withdrawals, the energy sector accounted for nearly 50 percent of withdrawals in 2000 (Pate, et al. 2007; Hutson et al., 2004).

There are regional issues in water availability resulting from the water-energy nexus. Power plants have already had to limit generation because of insufficient water (Pate et al., 2007) and concerns about water availability have generated opposition to new power generation and fuel processing facilities. Nationally, about three percent of U.S. power generation supports water supply and treatment. In California, where water is distributed long distances, 19 percent of electricity and 32 percent of natural gas consumption goes for water supply and treatment, end uses, and wastewater treatment (California Energy Commission, 2005).

CLIMATE CHANGE WILL MAKE WATER RESOURCES CHALLENGES MORE DIFFICULT

Climate change and its projected impact on hydrologic "stationarity" (that the climatic and anthropogenic controls over the hydrologic cycle

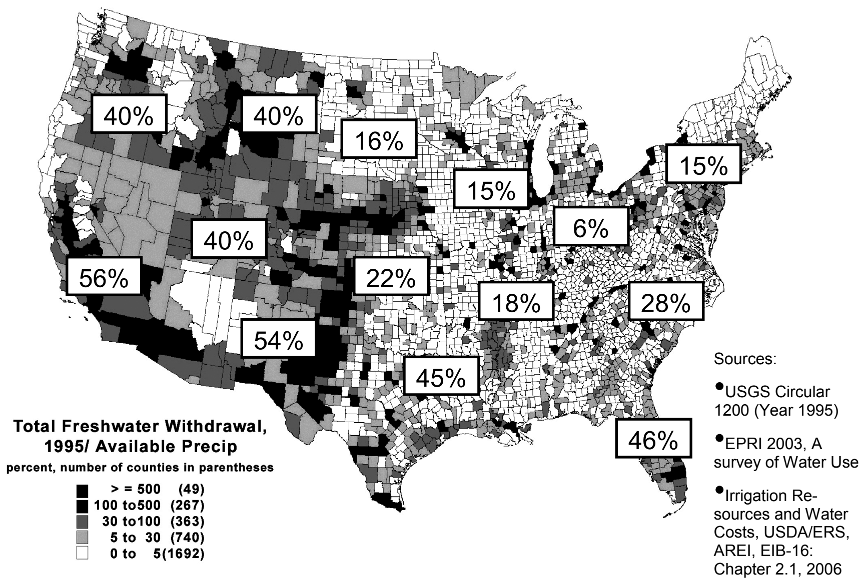


FIGURE 3-2 Emerging Water Stress and Projected Population Growth. The gray shading indicates the counties where 1995 water withdrawals already exceed replenishment by precipitation by 5 percent to > 500 percent. The text boxes indicate the regional projections for the percentage population increase from 1995-2025. The areas of greatest expected population growth (the southwest, west, and coastal regions) coincide with the areas that already have excessive water stress on available, renewable water. SOURCE: Pate et al. (2007). Modified, with permission, Xeriscape Council of New Mexico, Inc.

are invariant) probably will result in greater environmental variability than has occurred in the recent past. Estimates of future climate change lead the hydrologic community to expect greater temporal variation in the availability of water because of enhanced evaporation related to increasing temperatures, to precipitation declines in the interior western region of the country, to decreased snowpack storage of water, and to increased storm intensity in some regions (Bates, 2008). Almost all computer-model projections of future change from the Intergovernmental Panel on Climate Change suggest a hotter climate throughout the nation, coupled to further drying in the American west. These projected trends portend future difficulties the country will face with respect to availability and distribution of water resources.

> "The future water crisis is unlikely to materialize as a monolithic catastrophe that threatens the livelihoods of millions. Rather it is the growing sum of hundreds, perhaps thousands, of water problems at regional and local scales (and not just in the semi-arid West…)."
>
> SOURCE: National Research Council (2004b).

Foreseeable droughts will exacerbate water availability problems (Figure 3-3) in areas where, due to historic water allocation, water is already overly or fully allocated. Historic water allocation decisions were made without current knowledge of water amount and reliability (i.e., flow regime of rivers, the refilling of lakes and reservoirs, or recharge and storage capacity of aquifers). In some areas freshwater withdrawals are already in excess of available precipitation by a factor of more than five (Figure 3-2).

Another effect of greater variability of hydrologic events is increased flooding, in both riverine and coastal zones. Serious flooding impacts range from residential areas, croplands, infrastructure development and operations, to bridge clearances, urban storm water management, highways, railroads, and dams. Most of our infrastructure has been designed assuming that the frequency and magnitude of runoff events will not change in the future. However the accumulation of longer records and the extension of climatic and hydrologic records through paleohydrologic proxies and historical records show that persistent, non-random fluctuations of weather, associated with the changing states of the global atmosphere and oceans may drive hydrologic processes in the future in ways not reflected by our historic instrumental record. Therefore, infrastructure needs to be designed and managed to be sensitive to the risks of these unfamiliar environmental changes (i.e., "stationarity is dead") that broadly can be forecasted. Recognizing and exploring the hydrologic significance of these changes requires both a vigilant monitoring program and a sophisticated water science monitoring agency such as the WRD.

In 2003, the U.S. Government Accountability Office (GAO) surveyed state water managers and determined that even under normal or non-drought conditions, 36 states anticipated water shortages in the next 10 years. Under drought conditions, 46 states expected shortages in the same time frame. The economic impacts of such changes in the hydrologic cycle have been documented. The GAO (2003) reports that eight water shortages from drought in the past 20 years each resulted in ≥ $1 billion in monetary losses. The most severe of these droughts resulted in an estimated loss of $40 billion to the economies of the Central and Eastern U.S. in 1988.

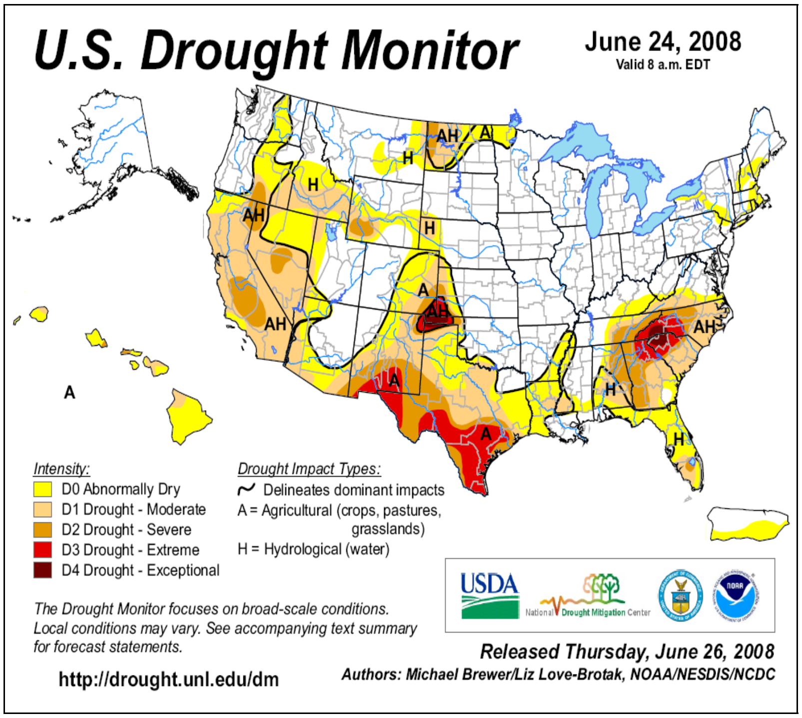


FIGURE 3-3 A snapshot of drought conditions in the United States in June 2008. SOURCE: National Drought Mitigation Center/University of Nebraska, U.S. Department of Agriculture, and National Oceanic and Atmospheric Administration (2008). Available online at http://drought.unl.edu/dm /monitor.html.

WATER QUALITY IMPAIRMENTS WILL CONTINUE TO BE A DIFFICULT ISSUE

Water availability is constrained by both water quantity and water quality. Impaired water quality may limit the quantity available for various purposes. Water quality has improved in U.S. waters with the implementation of the Clean Water Act and the Safe Drinking Water Act (and other environmental protection programs); rivers are no longer catching fire and phosphorus loading has been reduced, for example (NRC, 2002a). But nonpoint source contamination of surface water and groundwater from agricultural and urban lands remains widespread. More than one-third of the rivers and streams in the U.S. are listed as impaired or polluted (USEPA, 2008b) and by some estimates the trend of improving water quality is being reversed (Palmer and Allan, 2006).

The 2007 Gallup Earth Day poll found that Americans are more concerned with water than global warming or other environmental issues. A majority of those polled said they "personally worry…a great deal" about four different problems related to water:

Pollution of drinking water (58%),
Pollution of rivers, lakes, and reservoirs (53%),
Contamination of soil and water by toxic waste (52%), and
Maintenance of the nation's supply of fresh water for household needs (51%).

SOURCE: http://www.galluppoll.com/content/default.aspx?ci=1615&pg=2.

The Mississippi River system drains approximately 40 percent of the conterminous United States to the Gulf of Mexico (see Figure 3-4). The transport of nitrogen and phosphorus through the Mississippi to the Gulf contributes to expanding hypoxic conditions that now threaten aquatic life and the seafood industry in the Gulf (USEPA, 2007). The sheer magnitude of the problem makes resolution difficult and also requires federal involvement to define and comprehend it (NRC, 2008d). Hypoxia related to nutrients in runoff is not limited to the Mississippi River basin but is an expanding symptom of nutrient enrichment around country, around the world (Diaz and Rosenberg, 1995; Boesch, 2002; UNEP, 2006).

Increased detection of organic constituents at low concentrations has highlighted an emerging concern with respect to ecological and human health. The EPA's redefinition of its Contaminant Candidate List for drinking water (USEPA, 2008a; http://www.epa.gov/ogwdw /ccl/ccl3.html) and the USGS WRD's assessment of pharmaceuticals and personal care products (PPCPs) in water (e.g., Kolpin et al., 2002; Focazio et al., 2008) document that the number of identified water contaminants is growing faster than the determination of their effects on human health and ecosystem function. Combinations and co-occurrence of contaminants may pose threats equal to or greater than individual substances acting alone (Schwarzenbach et al., 2006; Brian et al., 2005; Altenburger et al., 2004).

As the demand for water increases towards the limit of its availability, it will become necessary to use water of impaired quality as source water to meet society's needs, requiring more costly handling and treatment. De-

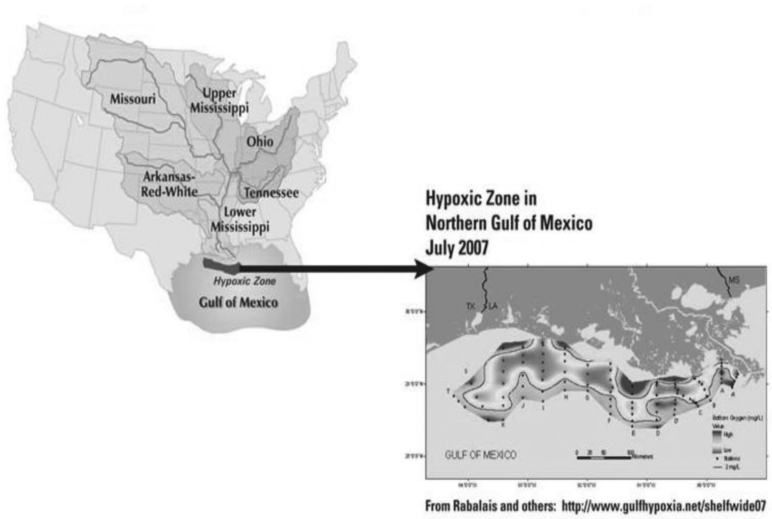


FIGURE 3-4 Mississippi River drainage and hypoxia in the Gulf of Mexico. SOURCE: USGS (2008). Adapted from http://water.usgs.gov/nawqa/sparrow/gulf_findings/hypoxia.html.

salination of seawater, treatment and use of brackish groundwater, and reuse of treated waste waters will all likely be required in various regions of the country (NRC, 2008a). Alternative energy development such as biofuel production will also demand new supplies of water, and will impact the quality of rivers (NRC, 2008b). Collectively, these developments have tremendous implications for water resources. Ultimately, society may redefine the value of water both in the ecological context, i.e., Endangered Species and Clean Water Acts, and as an economic good.

WATER PRICES WILL RISE

> "Fortunately, as each year passes, more countries, institutions and individuals are realizing that we don't just have a water problem – we have an impending water crisis. … … Finding the right balance to this dilemma – water as an economic commodity versus water as a human right – will be one of the great social, economic and political challenges of this century."
>
> SOURCE: "The State of the Water Industry 2007." The Environmental Benchmarker and Strategist, Winter 2007.

Water in the U.S. is undervalued and subsidized directly by some communities and indirectly through public water use and allocation policies. Water users in the U.S. pay less for their water, in both absolute terms (Figure 3-5) and as a percentage of household income (Job, 2008), than in most other developed countries, and enjoy a relatively high level of water quality. Water prices are rising, beyond inflationary pressures, because of the need to repair aging infrastructure, the increased competition for water (drinking vs. irrigation), increases in energy costs, the costs of bringing new water sources (desalination) on-line, and also by society's recognition of the need for restoration of ecosystem values. Over the past five years, average water rates in the U.S. have increased by 29 percent (based on annual surveys of NUS Consulting Group [http://www.nusinc.com/]) whereas the consumer price index rose only 15.7 percent during the same period (Bureau of Labor Statistics; NUS Consulting Group, 2008). The continued anticipated price increases for such a fundamental commodity as water have social equity implications. Cost increases will have the greatest impacts on the poor, which will engender other policy debates.

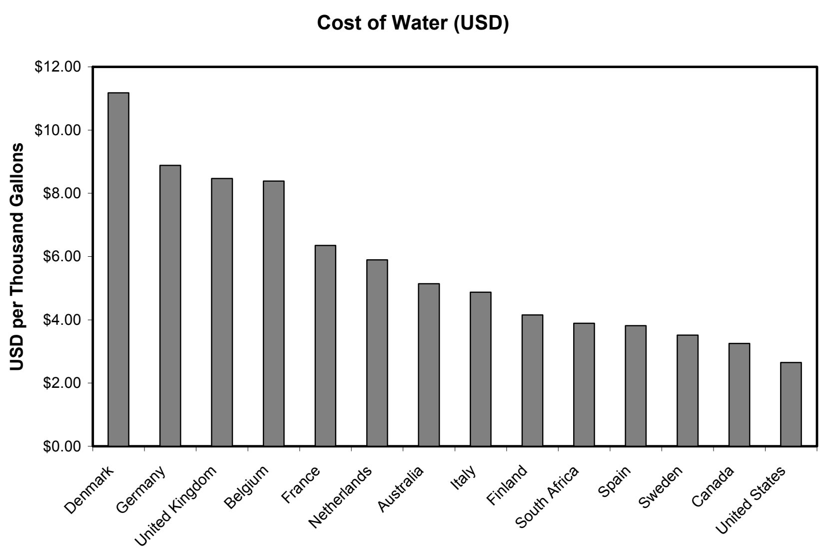


FIGURE 3-5 Cost of water (US dollars) per annum in the United States compared to other developed countries for 2007. SOURCE: Modified, with permission, NUS Consulting Group (2008). © 2008 NUS Consulting Group, Park Ridge, NJ.

U.S. cities and smaller communities are entering a time when infrastructure remediation and renewal as well as the rehabilitation of aquatic ecosystems can no longer be ignored. Dams, pipes, pumping stations, and treatment plants in many areas have reached the end of their useful lives and are in serious need of repair. Water has not been priced to accommodate such replacement costs. According to EPA's most recent drinking water needs survey and report to Congress (USEPA 2009), the U.S. infrastructure expenditure needs are projected to exceed $330 billion over the next 20 years for just public drinking water systems. The American Society of Civil Engineer's *2009 Report Card for America's Infrastructure* (ASCE, 2009), cited investment needs, over this same period, of around $1 trillion, for the broader spectrum of drinking water and waste water systems. Full cost-pricing for water is always noted as a key to developing a sustainable water-supply infrastructure for U.S. society (USEPA 2008c; Mehan 2009), and these critical infrastructure needs will continue to push a rise in water prices.

Studies for California water utilities found that better water information and forecasts are needed to assess long-range options for adaptive management given the growing variability and uncertainty on the limitations on water availability (Groves et al., 2008). These studies noted that utilities should begin management adjustments in the near-term to reduce their long-term vulnerability and to prevent unacceptable cost increases.

Accurate data, information, and analysis to forecast and quantify the uncertainty in water quantity and quality will be increasingly important to minimize the inevitable rising cost of providing water and waste water services for the nation. The USGS is well positioned to do this.

RESOLVING WATER CONFLICTS AND POLICY DEBATES WILL DEMAND MORE WATER SCIENCE

Water policy debates and disputes continue to occur at all levels of government (local, state, and federal), and between the nation and its neighbors. The debate will include arguments about the nature of water as a mixed good, having public and private elements; transboundary issues related to water allocation; ecosystem vs. other societal needs; the approach to valuing water; the impact of rising prices and social equity; the costs and benefits of a range of engineering and social solutions; the variability inherent in the hydroclimatic processes and the spatial distribution of water resources; and more.

> "Individuals, businesses, and government bodies make decisions daily about water use based on the physical, chemical, and biological properties of the water, as well as on economic, social, legal, and political considerations: Is there enough water? Is it clean enough to drink? Is the supply declining? How will climate variability and change affect future water availability? Can current water use be sustained?"
>
> SOURCE: National Science and Technology Council, 2007.

These debates are not new—"Whiskey is for drink'n and water is for fight'n over" is attributed to Mark Twain—but the debates are becoming increasingly visible and contentious and sometimes debilitating. New factors enter the debate and the competition for the resource, including the economic and social benefits of recreational water use and the need to protect ecosystems. New policy debates will occur—and water resource decisions will be made. But will they be adequately informed to meet the coming uncertainties and constraints that society will face? The USGS is in the position to provide information to help resolve disputes over water resources at regional and national levels; information that consists of both high-quality data, research to improve data collection and to provide new tools for analysis, and new analyses to provide information to inform water management decisions. For example, the USGS has played a large role in developing options for forecasting scenarios to manage the heavily regulated Missouri River to meet the new objective of protecting riparian and aquatic habitats, as well as water navigation, power generation, and water supply. USGS flow data for the Potomac River are being used extensively to optimize releases from headwater reservoirs to meet the water release requirements for water supplies, as well as for fishing, commercial raft trips, and recreational kayakers.

Federal, state, and local government managers and water resource associations, all recognize that they need more and better water data and improved water science—a subset of which is the need for improved analytical approaches that will contribute to new, adaptive strategies for management (e.g., Freas et al., 2008; GAO 2003). The GAO study showed that water resource managers, from over 80 percent of the states surveyed, ranked expanding federal water data collection as the most useful federal action that would help states meet their water information needs. Milly and others, noting "Stationarity is dead" show that improved water science may be as important as data (Milly et al., 2008, a widely cited paper in the prestigious journal *Science*) because water managers can no longer rely on previous statistical analysis of the historical hydrologic record that assumed the conditions of the past are fundamentally the same as those of the present or future (Wallis, et al., 2008). USGS science has been fundamental to flood forecasting and the design and management of water resources nationally. But the nation now needs new approaches for analysis and modeling and to incorporate new understanding of the physical causes of uncertainty to meet future design considerations.

To adapt to and effectively manage evolving water trends, new science, more data, and new approaches will be needed to develop adaptive management strategies. Since developing some of these strategies for water utilities will take decades, "waiting to adapt until climate has warmed is akin to waiting to build lifeboats after a ship has started to sink" (Wallis et al., 2008). The same can be said about failing to anticipate other, even more urgent and direct influences on water, such as those caused by development pressures in the face of the fundamental variability of the hydroclimate system.

WRD PLANNING, PRIORITIES, AND STAKEHOLDERS

The Water Resources Discipline planning process, to identify priorities and programmatic thrusts, involves interaction and input from their stakeholders at the national and regional level and also with a multitude of stakeholders at the state and local levels. Examined here, this also provides additional context looking toward the future in Chapter 4. This discussion addresses various components of SOT questions related to identifying priorities and the adequacy of these mechanisms, relevance to societal needs, and stakeholder involvement, among others.

The WRD, as with any federal organization, has a "top-down" component of management. Chapter 1 described the basic organization of the WRD; its national, or Washington level management (e.g., the Associate Director for Water, and the WRD's office directors), who interact with the leadership of the USGS and the Department of Interior, and get input from Congress, to set broad national priorities related to the WRD programs (e.g., Box 1-2). At the national level, they also work with other federal agencies and other stakeholders to incorporate stakeholder needs where appropriate.

The WRD also has a unique "bottom-up" component to its planning process. As discussed the WRD has Science Centers that operate in every state, carrying out USGS' national programs, and also cooperating with state and local agencies in hydrologic data collection and water resources investigations. This provides for "bottom-up" input, from the continual direct interaction with local and state stakeholders, providing insights to local water issues. Few federal agencies are organized in this manner. This input on water issues and concerns from managers throughout the nation, often helps to identify new and emerging issues. Some of these issues surface to become regional and national issues that, in turn, may get incorporated in national program priorities, and hence in "top-down" programmatic thrusts.

The "top-down" and "bottom-up" methods are intertwined, enabling a cyclical process that is somewhat unique to the WRD. As an example, the USGS's National Water Quality Assessment Program (NAWQA) staff in Science Center offices, in watershed-defined units request information and input at the local to regional stakeholder level to discuss NAWQA design and identify national and local priorities. This approach leads to data sharing and cooperative studies and helps identify emerging issues as priorities. Some of these are then incorporated from the "top-down" in standardized investigations across the national program, that then provide input to regional and national syntheses.

The Top-Down Process

Setting priorities and focusing the agency strategically should be explicitly a top-down process. The USGS has cooperative efforts within Department of Interior and with external agencies, such as the Environmental Protection Agency (on water quality issues) and the National Weather Service (NWS) (on flood forecasting needs) to help it identify and prioritize issues from the national level—from the top-down. Formalized interactions with other federal agencies takes place in the Executive Branch through the Office of Science and Technology Policy's (OSTP; Executive Office of The President) auspices, such as the Subcommittee on Water Availability and Quality and the Subcommittee on Hydrology. In addition to federal agency stakeholders, the list of engaged national and regional cooperators and interest groups that USGS works with is long, including groups such as: the Association of State Flood Plain Managers, the National Association of Flood and Storm Water Management Agencies, the Association of State Geologists, the Association of State Drinking Water Administrators, the Interstate Council on Water Policy, the National Water Resources Association, the National Wildlife Federation, the Western States Water Council, and many others. We recognize the strong support among these agencies for the USGS. However, much of this support seems to be focused towards the USGS providing raw data. While this is a valuable contribution, the Survey needs to be mindful that gathering raw data is often a step to meet a strategic goal, not typically a goal itself.

The USGS leadership actively seeks external, critical review of its major program thrusts and activities to enhance the strengths of its programs and to help prioritize future programmatic thrusts. The USGS Streamgaging Program was reviewed by the National Hydrologic Warning Council (NHWC) in 2006 and the WRD Cooperative Water (Coop) program was reviewed by the Advisory Committee on Water Information (ACWI). Also, almost every Water Resource Discipline (WRD) program has been reviewed by the National Research Council over the past two decades (see Box 2-6) providing input on program priorities and improvements. In some programs, such as NAWQA, a formal national liaison committee meets with stakeholders including dozens of representatives with water-resources responsibilities or interests from national professional and trade associations, federal, state, and regional organizations, academia, public interest groups, and private industry. All these inputs are factored in to USGS discussions to develop top-down priorities and plan national programs.

The Bottom-Up Process

The WRD, through its Science Centers and Coop program, has a presence in every state, as discussed. This state presence was established to conduct the federal inventory of the nation's water resources including streamflow characterization. The WRD program evolved to provide federal resources and share technical and scientific expertise with states to expand and improve needed water resource programs. This approach has also provided an effective and highly distributed network throughout the nation to engage stakeholders. The Coop Program develops and interacts on hydrologic activities and cost-shares water programs with approximately 1,500 individual cooperators—local, state, and regional entities. The USGS Science Center directors and staff interact with these stakeholders to assess water resource problems and priorities, develop yearly plans of operation, evaluate the progress of their projects and programs, and discuss future opportunities for collaboration.

Operationally, the four regional hydrologists and/or regional program officers meet with their water Science Center directors to review strategic directions, trends, issues, and water resource problems which become input for a regional summary, which then feeds into emerging national priorities. Annually, Science Center directors meet with senior WRD national leadership staff as well as with the chiefs of the Offices of Surface Water, Groundwater, and Water-Quality.

To meet national interests and strategic needs the USGS must have this local presence. The synthesis of local and statewide data gathered by co-operative initiatives is part and parcel of regional assessments. NAWQA was noted as one example of how this was done in the past; another was the USGS Regional Aquifer System Analysis Program. Staff in Science Center offices collaborated with state agencies to compile needed data and analyses on an aquifer system in their area—then the various state data were synthesized into a Regional Analysis of aquifers that span multi-state areas, to provide the overview and information for forecasts that contributed to improved management of these important groundwater resources.

As an illustration of the benefits of the bottom-up process, the awareness of pharmaceuticals in the nation's waters began at the local level when USGS and cooperating state and university scientists conducted studies and documented veterinary drugs in local surface water as a result of discharge from concentrated animal feeding operations (CAFO's). This led to the further documentation of human pharmaceutical and personal care products (PPCPs) in surface and groundwater. Research on pharmaceuticals, hormones, and other so-called organic wastewater contaminants is now a major initiative within the Toxic Substances Hydrology program of the WRD, and a national concern of many federal agencies.

This coordinated mix of top-down and bottom-up approaches of management has previously served the USGS well. However, we are concerned that the balance between national priorities and local needs has become skewed related to budget and funding issues.

WRD BUDGET AND STAFFING

The SOT (Box 1-1) asks questions that require some understanding of the operational and budgetary climate within which Water Resources Discipline (WRD) has operated. Further, any recommendations for programmatic change or future directions (Chapter 4, Water for Tomorrow) should take these resource constraints into consideration. This section provides an overview of the organizational structure of the WRD and looks at the budgetary 'climate' by examining the changes in funding over time and how this has affected the WRD from a budgetary, demographic, and scientific perspective.

> "Water resources research funding has not paralleled growth in demographic and economic parameters such as population, gross domestic product (GDP), or budget outlays (unlike research in other fields such as health). The per capita spending on water resources research has fallen from \$3.33 in 1973 to \$2.40 in 2001. Given that the pressure on water resources varies more or less directly with population and economic growth, and given sharp and intensifying increases in conflicts over water, these trends are very troubling."
>
> SOURCE: National Research Council (2004b).

In 2004, in *Confronting the Nation's Water Problems*, the NRC noted (see quote in the text box above) the overall decline in funding for water resources at this time when the nation's water resources problems are growing. The following graphs summarize trends in the WRD budget from 1990 to 2006 (Figures 3-6 through 3-9), reflecting these problematic trends. In nominal (i.e., non-inflation-adjusted) dollars, the budget trend over the past 16 years is upward (Figure 3-6), but in inflation-adjusted, i.e., real dollars, the trend is flat or slightly downward since the mid-1990s (Figure 3-7).

A further subdivision of the WRD budget (Figure 3-8), reveals that the only major component of the WRD budget that has risen significantly in real terms since 1990 is the State and Local Reimbursable Coop funding for the Coop program, (i.e., non-federal), matching funds from local cooperators. This increase is in marked contrast to the trend of the federally appropriated Coop funding (WRD Coop Appropriated, i.e., the federal matching funds), Figure 3-8. There is growing wedge of disparity between the federal and cooperator contributions from 1990 to 2006. The 1990, cooperator contribution was 54 percent—only slightly higher than the 50:50 match originally intended by Congress. This had grown to a 66 percent match—essentially a 2:1 cooperator:federal ratio—by 2006.

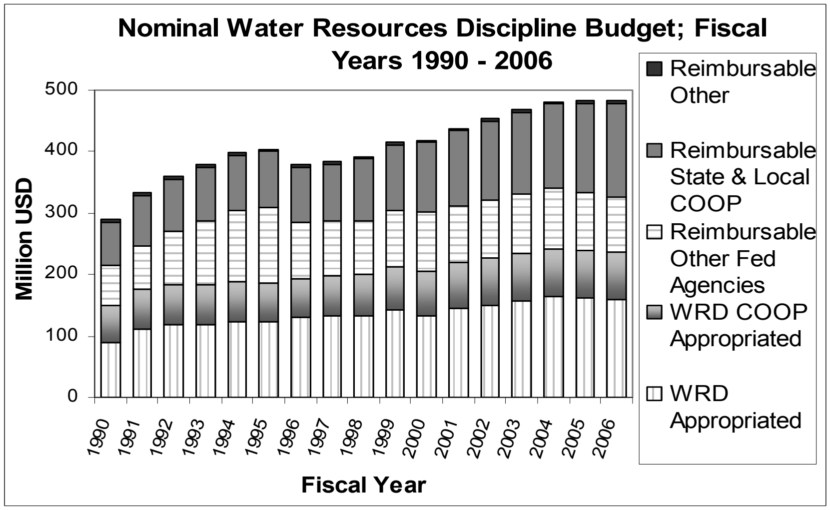


FIGURE 3-6 The Water Resources Discipline (WRD) budget from Fiscal Year 1990-2006, in nominal (non-inflation-adjusted) dollars. "Reimbursable" projects are those that provide a specific service for another agency or organization, as opposed to those that are appropriated directly by Congress. "Coop" refers to the Cooperative Water Program, defined in main text. DATA SOURCE: USGS.

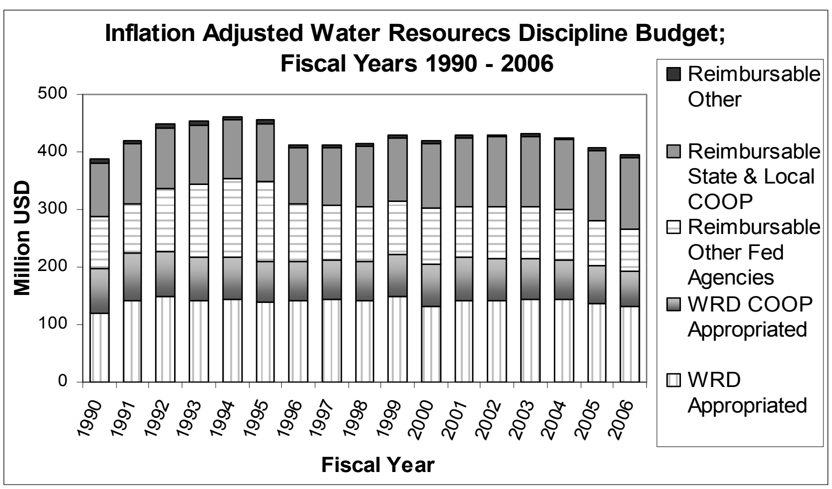


FIGURE 3-7 The Water Resources Discipline budget in real dollars (inflation adjusted to fiscal year 2000) shows the generally static nature of the budget since 1990 and a general decline since its peak in 1994. DATA SOURCE: USGS.

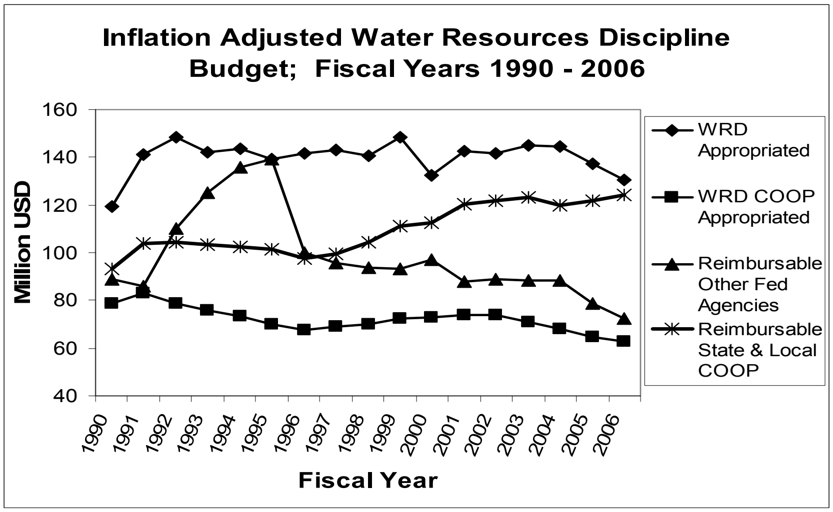


FIGURE 3-8 The Water Resources Discipline (WRD) budget in real dollars (inflation-adjusted to fiscal year 2000) showing the individual trends; only the State and Local Reimbursable Coop (i.e., the non-Federal share of coop projects) portion has risen. DATA SOURCE: USGS.

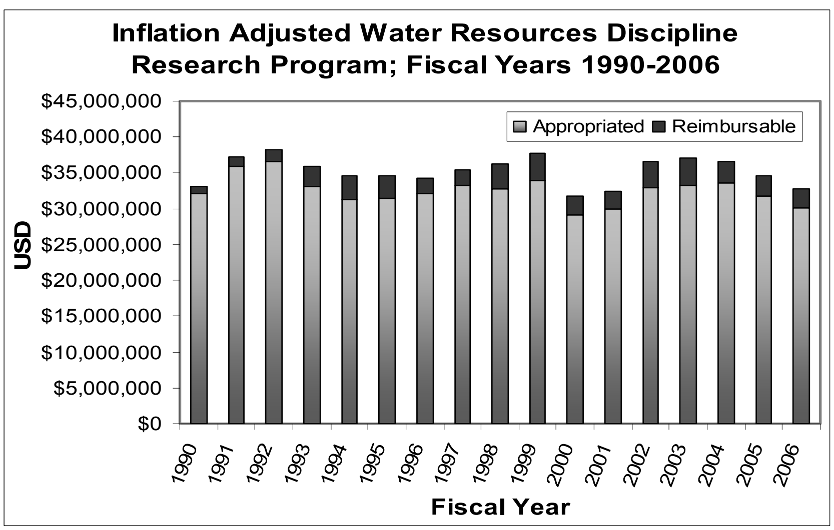


FIGURE 3-9 Inflation adjusted Water Resources Discipline research funding (adjusted to fiscal year 2000), again showing the decline through time. DATA SOURCE: USGS.

The increase in funding provided by state and local cooperators may be an encouraging measure of WRD product demand by supporters, a positive illustration of cost-effectiveness (see chapter 2). However, if USGS WRD resources and staffing continue to decrease, further program modifications will be required (NRC, 2004b). We do not mean to imply that more optimization of programs is a bad thing, in fact, it is encouraged. However, continued WRD optimization should be in conjunction with adequate resources and staffing. While some past budget reductions have produced some cost-effective program optimization, continued decreases will not provide adequate resources and staffing to meet the nation's future needs, in our judgment.

The increase in funding provided by state and local cooperators also raises concerns about the direction and scope of the WRD program. With the decline in federal funding, the WRD has, at times, turned to state and local sources to find financial support for personnel and activities. While the Coop program relationships have had widespread positive influences on the application of science to water resources, increased state and local support raises some concern about the ability to concentrate Coop resources on national to regional-scale priorities. The NRC's report on NSIP (NRC, 2004b) noted that the viability of potentially essential NSIP streamgages is intrinsically connected to whether Coop funding continues and is stable. The report argues that streamgages essential for national interest and flood forecasting should be funded by federal allocation and not tied to Coop funding and we support that view.

Figure 3-9 summarizes the portion of the WRD budget apportioned to research, divided into congressionally appropriated funds (that go to a research entity such as the National Research Program) and reimbursable funds to support joint research by the USGS and other state or federal agencies. Research funding has been static or on a slight downward trend since the 1990s as well. The flat-to-declining trend in funding is paralleled by a loss in personnel, addressed below.

Staffing and Demographic Analysis

Overall, WRD staffing has declined by approximately one-third since 1993. The data show a steady decline in both "science" employees (e.g., hydrologists, physical scientists) and "non-science" employees (e.g., budget analysts, personnel officers) in the WRD (Figure 3-10). The flat-to-declining budget over the past 16 years, coupled with salary increases and promotions, contributed to this loss of staffing.

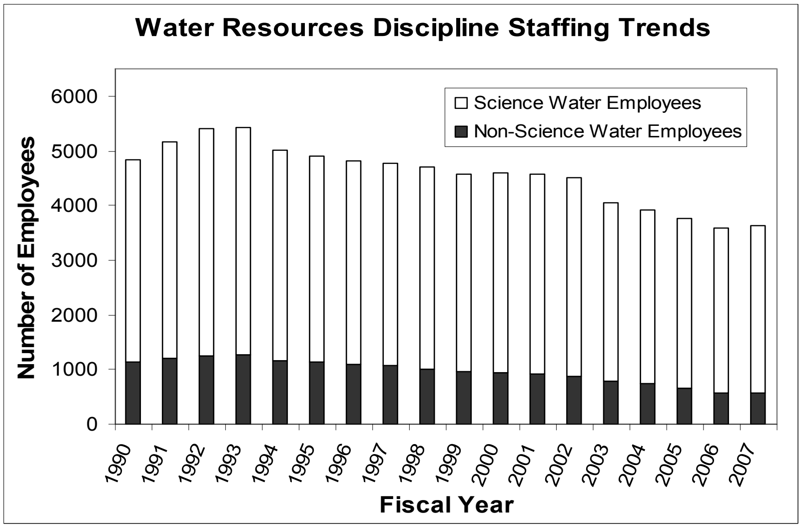


FIGURE 3-10 Number of employees in the Water Resources Discipline from 1990 to 2007. DATA SOURCE: USGS.

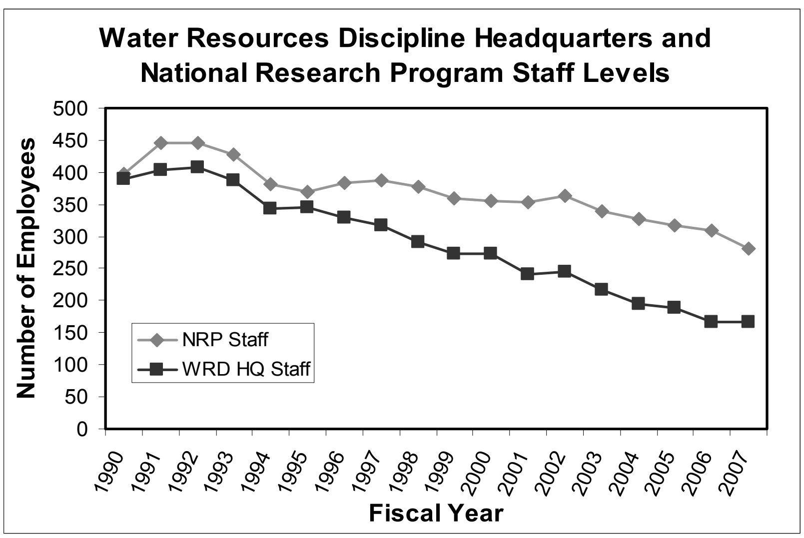


FIGURE 3-11 Staffing of the National Research Program (NRP) and Water Resources Discipline Headquarters+ (WRD HQ) staff from 1990 to 2007. NRP staff has been reduced by 30 percent since 1993, and Headquarters staff by almost 60 percent. DATA SOURCE: USGS.

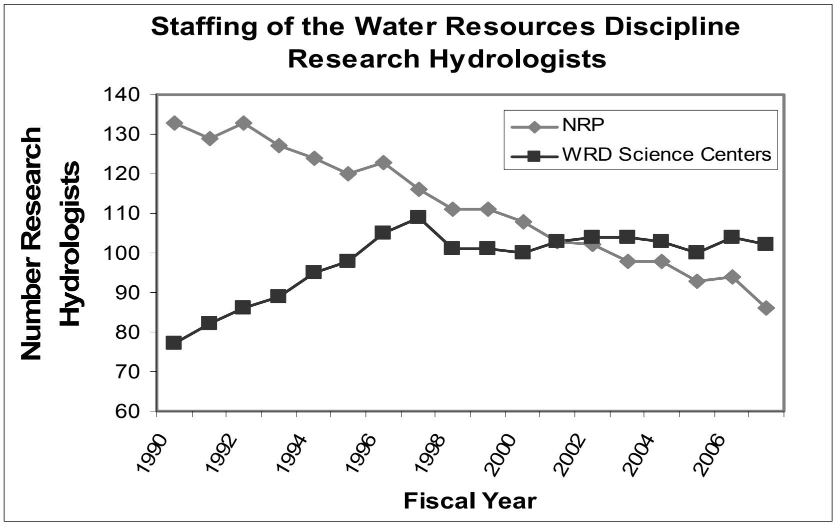


FIGURE 3-12 Staffing levels of Research Hydrologists in the National Research Program (NRP) and Research Hydrologists in the Water Resources Discipline (WRD) Science Centers; staffing has declined in the NRP, with a substantive increase (through the late 1990s) in the Science Centers—the net effect has been a decentralization of hydrologic research capacity. DATA SOURCE: USGS.

crease in the number of research hydrologists in the Science Centers during the 1990s. The net effect has been a decline in research grade staff and a decentralization of WRD's research capacity. The re-distribution of research hydrologists to the Science Centers has promoted a higher level of science in the "field," but possibly to the detriment of the NRP. In the past, how much did the critical mass of energetic research scientists, in close proximity in the NRP, contribute to novel technologies and advances? For example, major advances in geochemical and groundwater flow modeling and field investigations evolved from the close collaboration of NRP researchers during the 1980s and 1990s. Yet the percentage of non-hydrologists (e.g., biologists) among scientists has increased somewhat since 1990, seeming to reflect an attempt to answer to the increasingly interdisciplinary challenges faced by the WRD (Figure 3-13).

In tandem with the decline in staff, there also has been limited turnover. The WRD workforce has aged dramatically since 1993, especially in the NRP where the percentage of hydrologists age 51 and older has increased from 24 percent in 1990 to 58 percent in 2007 (Figure 3-14). This

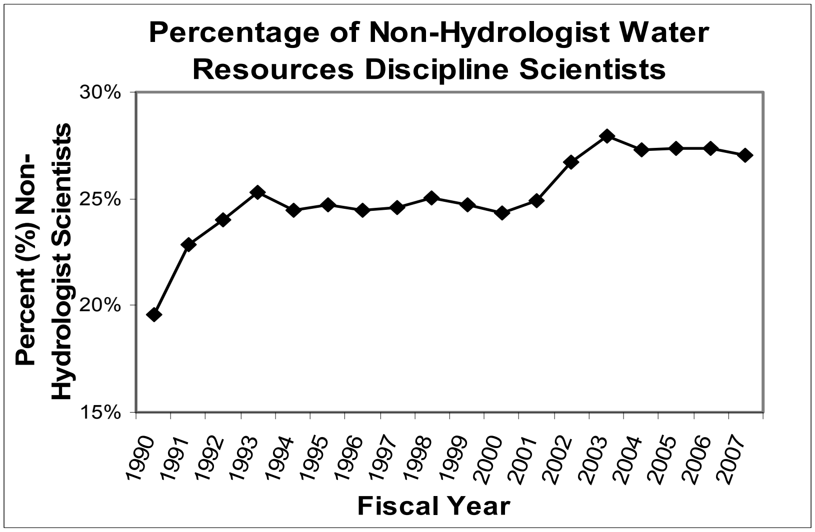


FIGURE 3-13 Non-hydrologist scientists employed by the Water Resources Discipline (WRD) as a percentage of the total number of scientists from 1990-2007. With the increase in multidisciplinary work, the proportion of scientists other than hydrologists in the WRD has increased during the 1990s and has held fairly steady since then. DATA SOURCE: USGS.

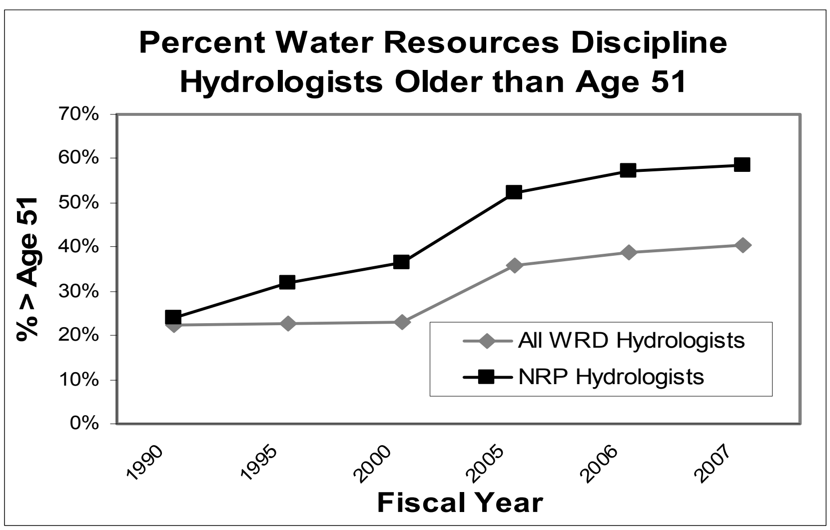


FIGURE 3-14 Percentage of National Research Program (NRP) and other Water Resource Discipline (WRD) hydrologists aged 51 and older. Note the dramatic aging of the workforce since 1993 in the NRP. DATA SOURCE: USGS.

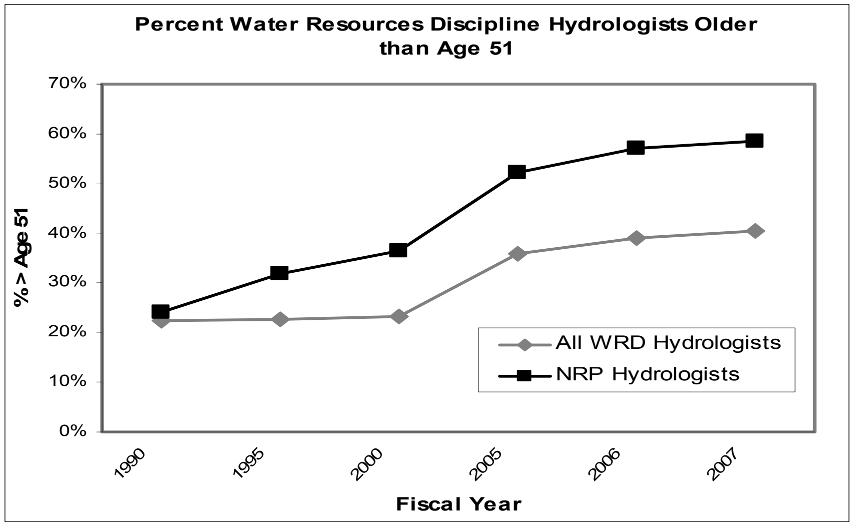


FIGURE 3-14 Percentage of National Research Program (NRP) and other Water Resource Discipline (WRD) hydrologists aged 51 and older. Note the dramatic aging of the workforce since 1993 in the NRP. DATA SOURCE: USGS.

have concluded (e.g., NRC, 2002b), and we state as well the WRD will not be able to meet their missions or the challenges ahead for nation's water resources if such trends continue.

THE USGS WRD CAN ADD VALUE TO WATER RESOURCE DEBATES

The WRD has a legacy that can enable it to provide leadership and valuable information toward resolving water resource debates and assessments in the United States. The agency, even with the reductions in staff that have taken place, has a large number of scientists and highly skilled, experienced technicians in various fields that affect water resources. These include: geologists who study the environmental conditions that affect water storage and conveyance in aquifers, lakes, deltas, and streams; geochemists and geomorphologists concerned with the origin of contaminants such as sediment, metals, and organic materials; hydrologists concerned with the processes of water storage and transfer through landscapes, and biologists concerned with the terrestrial and aquatic ecosystems that both affect and are affected by natural and managed characteristics of water resources.

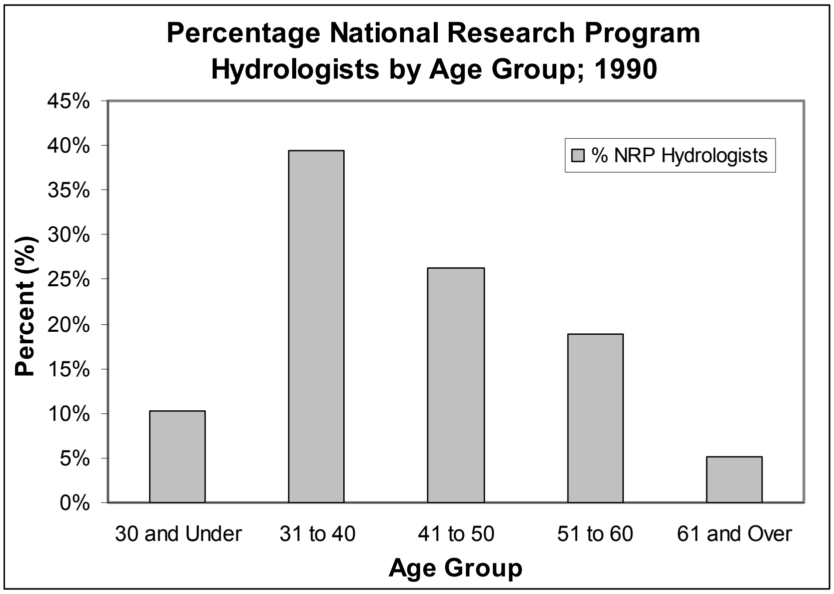


FIGURE 3-15 Percentage of National Research Program (NRP) hydrologists by age group in 1990. DATA SOURCE: USGS.

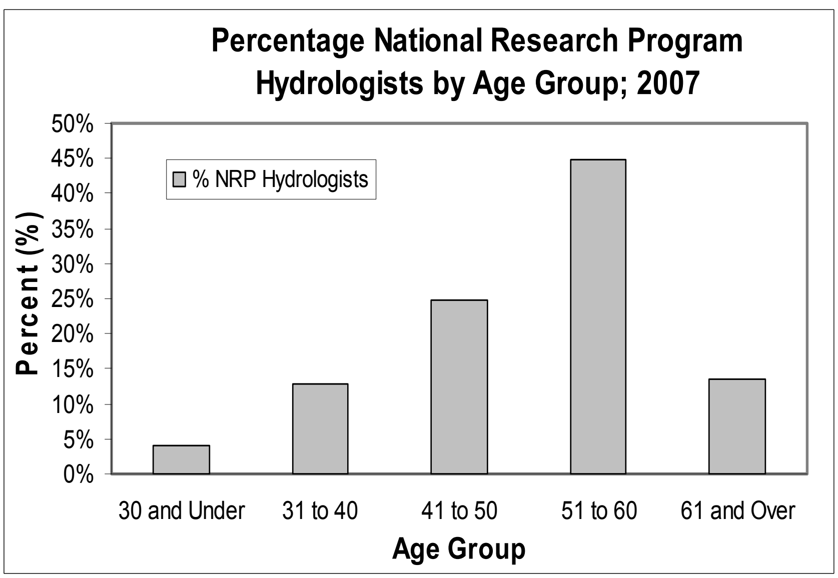


FIGURE 3-16 Percentage of National Research Program (NRP) hydrologists by age group in 2007. DATA SOURCE: USGS.

A particular strength of WRD is its capability for multi and interdisciplinary approaches to the analysis of the components of the hydrologic cycle and its management. For example, the agency monitors the quantities and quality of surface and groundwaters. In recent years, it has extended its concern "upstream" by linking these measurements with information on rainfall, snowmelt, and the conditions of watersheds through empirical analysis of data collected by other agencies and by development of its own modeling capabilities to address both land use effects and climate change on water resources. Looking "downstream" within the hydrologic cycle, the agency is involved in data collection on the water quality and ecological functioning of natural and impacted aquatic ecosystems. It continues to expand its analysis of water availability and use, as well as the functioning and restoration potential of large coastal water bodies such as San Francisco Bay, the California Bay-delta, Chesapeake Bay, the Mississippi Delta, and the Florida Everglades (Chapter 2). The involvement of WRD in the linked systems that constitute our water resources and their management problems, from climate to the sea, positions the agency as a critical contributor and potentially a leader of efforts to advise governments and the public in addressing the expanding water-related issues.

The interdisciplinary nature of the WRD can also provide flexibility, which ideally can allow the agency to adjust rapidly to emerging concerns, whether they are the environmental role of new chemicals or nanoparticles, atmospheric connections that affect regional-scale water resources, or the terrestrial and atmospheric linkages associated with warming of boreal regions. The broad geographic reach of WRD, with its offices in all fifty states also means that the agency has a means of keeping its finger on the pulse of changes in water resources and their use across the country and the potential to recognize changes and emerging issues at an early stage. The agency is also well-placed to participate in, or even facilitate constructive resolution of interstate water-resource conflicts because it is involved in monitoring and analyzing the behavior of water resources (rivers, lakes, and aquifers) that cross state boundaries.

What we are describing is a long-standing WRD tradition of studying the impact of human activities on natural resources such as land, water resources, and ecosystems. This fundamental tradition facilitates, not only thorough effective assessments by the agency itself, and it prepares WRD personnel to collaborate with and even to provide interdisciplinary leadership among other agencies, that generally have a more narrow disciplinary focus in, for example, atmospheric science, or land and wildlife management. The issue of whether society can manage resources sustainably in the face of population growth, wealth production, and climatic uncertainty has become the signature environmental issue of our age, and the USGS, and particularly WRD, are ideally suited to play a leadership role in a national strategy for sustainable resource management.

4

Water for Tomorrow

> "In the coming decades, no natural resource may prove to be more critical to human health and well-being than water. Yet, there is abundant evidence that the condition of water resources in many parts of the United States and the world is deteriorating. Our institutions appear to have limited capacity to manage water-based habitats to maintain and improve species diversity and provide ecosystem services while concurrently supplying human needs. In some regions of the country, the availability of sufficient water to service growing domestic uses is in doubt … Indeed, demands for water resources to support population and economic growth continue to increase, although water supplies to support this growth are fixed in quantity and already fully allocated in most areas."
>
> SOURCE: National Research Council (2004b).

In the preceding chapters we addressed the past performance and current status of the U.S. Geological Survey (USGS) Water Resource Discipline (WRD). Here we address questions, posed to the committee (Box 1-1), looking to the future (i.e., areas of leadership and management that can be improved to address important and emerging issues). We present leadership recommendations framed in the context of the new USGS comprehensive science strategy, *Facing tomorrow's challenges—U.S. Geological Survey science in the decade 2007–2017* (USGS, 2007), as this plan will guide the agency into the future. Then, the Water Census (Strategic Direction six) is used to illustrate how additional recommendations can be applied to various programs within the WRD. Finally, strategic approaches are suggested with recommendations specifically for the Coop program, NRP, and Science Centers.

In Chapter 3 we outline future trends in water resources that are "predictable surprises" (sensu Bazerman and Watkins (2004); Box 3-1)— trends and foreseeable problems that will not solve themselves:

- Problems of water availability will become increasingly serious and more prominent,
- Climate change will make water resources challenges more difficult,
- Water quality impairments will continue to be a daunting issue,
- Water prices will rise,
- Resolving water conflicts and policy debates will demand more water science.

Our nation's water resources, though considerable, have always been finite. Population growth, climate change, and other pressures on this finite resource will trigger conflicts and constraints on social and economic stability of the nation (Mehan, 2009). Water resource constraints are foreseeable consequences of these trends that drive the need for more and improved water science (World Economic Forum, 2009).

Almost every water-resources management issue is fundamentally and inextricably interdisciplinary, which makes the engagement of the WRD uniquely appropriate and effective in complex resource assessments. The WRD has the ability to mount interdisciplinary studies, particularly in cooperation with its sister Disciplines. While well placed to respond to predictable surprises, the USGS does operate with constraints, such as a lack of discretionary funding and an apparent (in our briefings) lack of full support for its role as "The Nation's Earth Science Agency" (the title on its website and elsewhere). Compared to its data acquisition and mapping contributions, the value of its scientific contributions is not as well recognized by the Department of Interior and other federal agency supporters, posing a problem. The WRD has the range and quality of scientific resources to take the lead in providing the interdisciplinary understanding required to help attack and resolve many of our pending water problems.

LEADERSHIP

The USGS WRD has led the nation in many areas of water resources in the past and continues to lead today in many areas that are relevant to societal needs and particularly related to water quality (Chapter 2) However, the WRD is slowly losing its ability to maintain this level of leadership because of budget constraints and loss of staff (Chapter 3). Even in the area of long-term data collection, an area of USGS expertise that other federal agencies and this committee value, the NRC four years ago (2004a) noted a serious decline of ability because of diminishing resources (see Box 4-1).

In a climate of strained federal funding there is significant competition for the mandate and assets to address water resource problems. Many other federal agencies have and continue to develop their own technology to address water problems. The USACE, for example, has a suite of numerical models to assess hydrology, river systems, and groundwater flow around dams and in river reaches. The USDOE national laboratories have their own computer simulation capability to address solute transport issues related to radioactive waste. Many of these science development initiatives from other federal agencies and federal laboratories were designed to address their specific, and often local, problems in water resources. But the broader water resources community needs and looks to the USGS WRD for the science needed to meet the broader public water management challenges.

There are promising signs that the nation's water science needs are gaining increased recognition, as are the WRD's scientific contributions by their federal agency and congressional supporters. The recent increase in appropriations for NSIP, and special funding for the USGS's pilot of the Water Census and a Climate Change initiative; the introduction of legislation such as the U.S. Senate SECURE Water Act (Science and Engineering to Comprehensively Understand and Responsibly Enhance-Water Act),

BOX 4-1

"Key legacy monitoring systems in areas of streamflow, groundwater, sediment transport, water quality, and water use have been in substantial decline and in some cases have nearly been eliminated. These systems provide data necessary for both research and practical applications. … the long-term monitoring of hydrologic systems and the archiving of the resulting data are critical to the water resources research enterprise of the nation. The consequences of the present policy of neglect associated with water resources monitoring will not necessarily remain small."

SOURCE: National Research Council (2004a).

hance Water Act), the National Water Research and Development Initiative Act of 2009, the Water Use Efficiency and Conservation Research Act of 2009, and the water provisions of the Omnibus Public Land Management Act of 2009, in the U.S. House of Representatives, are all promising signs. In recent years the USGS has been called upon to provide Washington briefings on many of their leading water programs. These have been sponsored or requested by groups such as the Environmental and Energy Study Institute and the Water Environment Federation, and also federal and congressional entities. Also, USGS has conducted more stakeholder meetings to share program planning and program findings, as well as to gather feedback. These have been successful, in our observations, in helping to educate federal partners and provide needed exposure to the WRD science contributions, as well as a means to increase stakeholder communication. To reinforce its leadership role in water science, the WRD should continue the Washington briefings that have been held in recent years, which also serve to further educate and expose WRD's federal partners to the importance of WRD's scientific contributions, beyond their important basic data acquisition programs. The Survey, and especially WRD, leadership should be mindful of and continue to aggressively communicate the potential of the agency to help address the significant water resource problems facing the nation.

For the USGS to remain healthy and provide its critical expertise to solve national water-related issues in the future, both its data acquisition arm and scientific research arm need to be strong and both should be guided by visionary leadership. In the committee's observations, some of the past water science leadership and accomplishments have arisen out of activities of individual scientists rather than systematic, strategically focused direction from the USGS WRD. This along with the current budget and staffing constraints, call for a refinement of the USGS mode of operation. In the current environment the WRD is stretched too thin—it cannot be all things, nor address all water issues. It needs to re-focus its vision, concentrating on the WRD strengths to address not all, but the critical water challenges facing the nation.

As an example, a recent paper in the prestigious journal *Science* titled "Stationarity Is Dead: Whither Water Management?" by USGS WRD authors and colleagues from other institutions (Milly et al., 2008), speaks to the agency's ability to lead and recognize that new science is needed to forecast and assess future hydrologic conditions. The concluding remarks in this paper note:

> "The world today faces the enormous challenges of renewing its decaying water infrastructure and building new water infrastructure. Now is the opportune moment to update the analytic strategies used for planning such grand investments under an uncertain and changing climate." (Milly et al., 2008; p. 574).

But it is not enough to just recognize this critical need. This excerpt also presents a prime example of a critical topic where the WRD could develop the science needed to meet these challenges. To do this, the WRD leadership should craft a more strategic focus to contribute effectively in the future for the nation. Once implemented, this strategic vision and the focused scientific response to critical water issues it will generate should catalyze appropriate recognition of the USGS WRD.

Recommendation: The WRD should re-focus its vision on critical national priorities to lead the nation in water science. This vision should bring its data acquisition arm, science and interpretive programs, and research arm to a common focus on key national priorities.

HOW CAN THE USGS RESPOND TO EMERGING WATER CHALLENGES?

The Six Science Directions

It is not possible for the WRD to adequately address all the important or emerging water issues—nor is it its purview or responsibility to do so. While we will discuss some examples of priority issues that should be addressed by the WRD, we are not in a position, and it is not our charge to present a "definitive list" of water resources priorities. Two other NRC groups were charged to address such issues: the Water Science and Technology Board prepared *Envisioning the Agenda for Water Resources Research in the 21st Century* (NRC, 2001a), and this was followed by *Confronting The Nation's Water Problems: The Role of Research* (NRC, 2004b), at the request of Congress. These reports have outlined broad, key issues for water resources and the Congress and many agencies, including the WRD, continue to review these reports as part of their on-going activities. The key issues discussed in this report are also recognized in these prior critical reviews. We would also note that the recommendations we make in this report echo those made in the 2001 NRC report, *Future Roles and Opportunities for the U.S. Geological Survey.* While there may have been some progress in adopting those recommendations, there is more to be done.

The committee advocates a process for the WRD to define a more targeted, strategic selection of water science issues, to refocus programs, that take advantage of the competitive strengths of the USGS and that address critical national needs. The USGS has issued a new comprehensive science strategy to "reflect on and optimize its strategic directions" and "critically examine [its] major science goals and priorities" for the coming decade (USGS, 2007). This committee did not do an in-depth critical evaluation of the USGS strategy. We do, however, concur with the importance of the national issues outlined in this strategy and agree that the USGS has the skilled personnel to address these issues. As noted in the strategy document:

> "[The USGS's] role is larger than the traditional one of providing expertise in mapping, geology, water, and biology. Major national issues of costly natural disasters, air and water quality, energy and materials needs, newly emerging diseases, invasive species, climate change, and even immigration form a web of linked dependencies among environment, societies, and economies. *The USGS should transform its approaches to problem solving not only to address the issues of today but also to prepare for those of tomorrow*."

The committee is in complete agreement with this statement. Below, we put our recommendations for the WRD in the context of these strategic directions, as they are important national issues and, we are assuming, will guide the agency into the future. While we understand that aspects of this strategy may change, it was an exemplary planning process that provides lessons for refocusing WRD's vision on a defined set of national priorities.

For planning considerations, aspects of the six strategic directions that are relevant to the WRD should be focused on the decisions that society will need to make in the coming decades, and the questions that need better answers to inform those decisions. Decisions will be made, with or without scientific input. In each case, there will be a component of inventory and survey with data collection and measurement, as well as a scientific approach that involves analysis to produce understanding that should be the basis for forecasting future conditions. The committee identified critical water issues that could be successfully addressed by the WRD, and organized these issues within the framework of the USGS Strategic Plan:

1. *Understanding ecosystems and predicting ecosystem change*: ensuring the nation's economic and environmental future.

- How do we define the water resource needs for sustaining ecosystem function and services, including agricultural ecosystems?
- As part of relicensing of hydropower plants with the Federal Energy Regulatory Commission (FERC), what quantity, quality, depth, and timing of releases will be needed to preserve endangered and threatened species and valued ecosystem services?

2. *Climate variability and change*: clarifying the record and assessing the consequences.

- What new tools are needed to evaluate and forecast frequency and magnitude of streamflow for water management in the 21st century?
- What enhancements should be made to monitoring systems to enable the United States to detect and project climate change impacts on water resources?
- How do we adapt or apply climate change model forecasts to the sub-regional level to support water management needs?

3. *Energy and minerals for America's future*: providing a scientific foundation for resource security, environmental health, economic vitality, and land management.

- What are the realistic water quality and quantity consequences of greater production of biofuels, shale oil, coal gas, and other alternative energy sources that are being explored?
- What are the water quality and ecological impacts of mineral and fuel extraction?

4. *A national hazards risk and resilience assessment program*: ensuring the long-term health and wealth of the nation.

- How do we improve flood frequency forecasting to include the uncertainties of non-stationarity, climate variability and change?
- What new tools are needed to forecast flood and storm effects in coastal areas where even a small rise in sea level may further alter the relative frequency and magnitude of events?

5. *The role of the environment and wildlife in human health*: a system

that identifies environmental risk to public health in America.

- Which of the thousands of emerging contaminants are widespread enough, and in high enough concentrations, to warrant further studies of human and eco-toxicity?
- What are the implications for waterborne disease as climate change promotes warming surface waters and more intense storms?
- How do trace metals released from natural and anthropogenic sources enter the food webs of humans and animals?

6. *A water census of the United States*: quantifying, forecasting, and securing freshwater for America's future.

- How large a role can technologies such as desalination and water management strategies such as reuse and managed underground storage of recoverable water play relative to other technologies, strategies, and components?
- What are the implications for optimal allocation of water supplies for the quality of those water supplies and ecological value of the affected water bodies?
- With respect to water allocation, have we allocated more water to users than is now available—or will be available in the near future?

Two dominant themes for water in the USGS six strategic directions are climate change and a water census. Climate change is the subject of the second USGS strategic direction and part of critical questions under strategic directions two and four. This multi-dimensional issue alone compels a significant and integrated treatment of the topic. Yet climate change can also be integrated within the broad theme of water availability (e.g., a water census; strategic direction six). Others note the need for an integrated strategy:

> "Another urgent need for investment at the federal, state, and provincial level is in robust water quality and quantity monitoring, data gathering, and "downscaling" of global climate models to the local watershed scale. This information will allow water managers to better adapt to climate variability, plan for uncertainty, and build resilience into their water management planning processes." (Mehan, 2009)

In *Informing Decisions in a Changing Climate,* the NRC noted that agencies and expanded federal research need to generate information that regional and local decision makers need, such as studies on which locations are most vulnerable to the effects of climate change and on ways to mitigate or adapt to these effects (NRC, 2009). The USGS provides a federal perspective in an interagency report (USGS, 2009), noting that climate change may have a large impact on water resources and water resource managers.

The USGS six strategic science areas involve all of the different disciplines within the USGS. Yet as demonstrated by these critical questions, water science is important and key to answering them. These questions also provide perspective regarding the necessity of an integrated strategy, rather than a list of projects and activities. By integration, we mean ensuring that all the WRD programs, from NSIP to the Groundwater Program, understand the component contributions they each must make to answer the critical national questions. The difference between a list of projects and an integrated strategy constitutes an important distinction and a performance metric for the agency's leadership.

Recommendation: The WRD needs to clearly redefine its role within the context of the USGS strategic science directions and its vision of critical national water priorities. This redefinition should highlight the WRD's role in the USGS strategic science directions and within an integrated strategy and programmatic approach to address their defined national water priorities, emphasizing scientific support for decisions that society will need to make in the coming decades. This approach should include two key issues of water availability—the water census and climate variability and change—particularly forecasting and predictions, evaluating uncertainty, and developing enhanced monitoring systems to assess the nature of the problem with respect to water resources.

As discussed, many of these key questions are also components of the Water Census, the last strategic direction, if it is approached within the scientific context of present and future water availability for the nation. The Water Census is an initiative that is already in development by the WRD, at least in a pilot stage; hence, a further discussion of the Water Census is illustrative.

A Water Census of the United States: Quantifying, Forecasting, and Securing Fresh Water for America's Future

"A Water Census" can convey a singular and recognizable measure of status of the nation's waters. Although the Census alone could be an eye-catching activity, it is the "subtitle" to quantify, forecast, and secure freshwater for America's future that leads to the establishment and understanding of an accounting of water availability to meet the country's future needs. Strategically, the planning of the Water Census is encouraged to look towards developing an on-going, effective tool on a par with the social and economic censuses that supports national decision making. The quality and depth of these other censuses could be viewed as a standard for the Water Census. There is little value in developing a sparse, simplistic accounting system, given the needs facing the nation.

The USGS strategic plan (2007) states that:

"The USGS will develop a Water Census of the United States to inform the public and decision makers about:

1. The status of its freshwater resources and how they are changing;
2. A more precise determination of water use for meeting future human, environmental, and wildlife needs;
3. How freshwater availability is related to natural storage and movement of water as well as engineered systems, water use, and related transfer;
4. How to identify water sources, not commonly thought to be a resource, that might provide freshwater for human and environmental needs; and
5. Forecasts of likely outcomes of water availability, water quality, and aquatic ecosystem health due to changes in land use and land cover, natural and engineered infrastructure, water use, and climate."

Associated with these goals and objectives, the USGS plan contains a list of "Strategic Actions" that can be taken in support of a Water Census program. This described scope of effort links to the even broader needs outlined in *A Strategy for Federal Science and Technology to Support Water Availability and Quality in the United States*, by the interagency Subcommittee on Water Availability and Quality (SWAQ) of the Committee on Environment and Natural Resources (National Science and Technology Council, 2007).

The SWAQ acknowledged that the nation faces far-reaching, critical decisions about allocating water of suitable quality for industrial and energy production, agriculture, municipal supply, aquatic ecosystems, and recreational uses. These decisions will have to be made in the face of large uncertainties about future technologies, economic growth, demographic change, social expectations, climatic variability and change, and land/crop transformations. Although authority to manage the allocation of water resources is largely delegated to states, tribes, and local municipalities, the SWAQ identified a federal role for providing water science and technology to inform policies and decisions for managing water resources in the public good.

To support decision making on water availability and to ensure adequate water supplies for the nation, the SWAQ defined three scientific and technical challenges, two of which lie firmly within the responsibilities and skills of the USGS. These two are: (i) measure and account for the nation's water, and (ii) develop and improve predictive water management tools.

Specific strategies proposed by the SWAQ for accomplishing these goals (among other suggestions) were:

1. Implement a National Water Census,
2. Develop a new generation of water monitoring techniques,
3. Improve understanding of the water-related ecosystem services and ecosystem needs for water,
4. Improve hydrologic prediction models and their applications.

Despite overlap in their scope, these strategies provide clear and concrete suggestions for the USGS WRD to develop a new and refocused national program that includes the need for new and improved water science. It is important that the leadership of USGS WRD and the Department of Interior (DOI) take the responsibility for promoting such a program to meet the critical needs for wise management of the nation's water resource.

To build such a dynamic Water Census program that can quantify, forecast, and secure freshwater for America's future, WRD will need to develop and integrate many aspects of the proposed census that are outside what the USGS does routinely at present, such as those listed below. However, the interdisciplinary nature of the entire USGS and the high regard most cooperators have for the quality of their technical work would allow the WRD to leverage its skills and rise to the opportunity. Again, we provide this discussion of the Water Census as a context to view our recommendations, but our suggestions are not intended to be limited to the program.

Coordination and Cooperation

For the USGS to focus work on its new six strategic science directions there will be demand for even greater coordination and cooperative efforts among the Disciplines—a mutual effort working to meet these complex objectives (i.e. the six strategic science directions). Indeed it would seem the USGS WRD is aware of this demand as the statement of task (SOT) specifically addresses the issue of coordination efforts (task 7). One of the goals of the proposed U.S. Water Census is forecasts of likely outcomes for water availability, water quality, and aquatic ecosystem health caused by changes in land use and land cover, natural and engineered infrastructure, water use, and climate. Accomplishing this task fully will require extensive interaction among scientists of the various USGS Disciplines. It is not proposed, or realistic, to attempt "full integration" of the Disciplines within the USGS (as discussed in Chapter 2), but efforts should continue to meet programmatic needs, to the extent they can be cost-effective within the USGS management structure, within the context of the multidisciplinary science directions.

Recommendation: The USGS needs to continue efforts to coordinate activities among WRD and other USGS Disciplines.

Collaboration and Cooperation

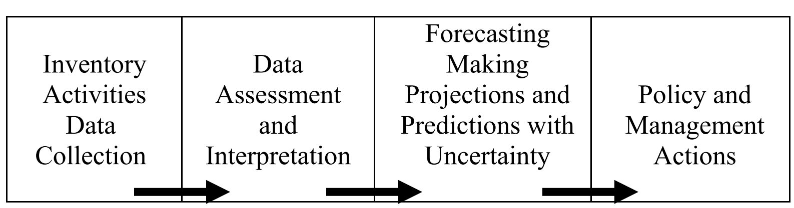
The broader effort to address water availability described in the National Science and Technology Council's (2007) discussion of *A Strategy for Federal Science and Technology to Support Water Availability and Quality in the United States* also calls for collaboration among federal agencies— such as separate entities working on mutual projects by sharing personnel, and resources, etc. to meet common goals. For example, the WRD will need to address the problem of multi-agency dispersion of water data. Water data are archived by the USGS, EPA, USACE, several divisions of the USDA, NOAA, and numerous other federal and state agencies. The USGS makes only coarse-grained estimates of water use, while sparse and unconnected studies on land use and water availability, water demand modeling, and ecological water use are being done by state, local, and regional entities; academics; and non-governmental organizations and their contractors. To make a Water Census useful and powerful, the USGS is encouraged to continue its role as innovator in data acquisition and dissemination (a recent successful example is the use of microgravity changes for monitoring water storage changes in aquifers at scales beyond the well (Flint et al., 2007)) but it will also require better collaboration to use data from all agencies and USGS appreciation of non-USGS innovative data collection techniques, such as improved remote sensing for satellite-based monitoring, or NRCS and California agencies snow pack surveys.

Methods for efficiently gaging water flux and recharge to groundwater in urban areas with proposed green development would be another example of technology that would need collaborative development and operation. WRD may also need to find collaborators in the social sciences and economics to address some water allocation and availability issues. For example, the Water Census could foster collaboration to address demographic changes and their impacts on water availability. These efforts have a real cost, in terms of staff time and energy, and all agencies must understand that and contribute. With the issues facing the nation for water and energy, agency "turf" concerns need to be put aside to address our water related challenges. The USGS has the perspective, as an independent leader in interdisciplinary water science, to lead this collaboration.

Recommendation: The USGS WRD should foster and promote collaboration with other federal agencies to meet the nation's growing water crises.

New Approaches and New Water Science

The WRD has historically been conservative in how it provides input to policy-makers. This is, in part understandable, because most water management functions are the direct responsibility of others, typically local and state agencies. This conservative philosophy has helped the USGS to preserve its reputation as a neutral, unbiased party. However, a too conservative approach may now limit the effectiveness and timeliness of the USGS's contributions to society. One may envision a simplified continuum from data collection to policy and management, that is,



A balance in activities—from inventory and data collection activities to interpretative studies and research—is always needed to meet the USGS goals. The USGS WRD, on balance of its programs, has focused on Inventory/Data Collection and Assessment/Interpretation. Many of the USGS Interpretive studies do not provide the step needed to forecast and plan for the water resource issues we are now facing. There is a place for unbiased government science half-way between data collection and policy decisions—just beyond interpretation, namely, in forecasting and predictions—to address water management needs.

The need for new and improved science and moving beyond data collection in the water use, water availability is not new. The USGS conducts a survey of water use at five-year intervals, by the National Water-Use Information Program which was the topic of an entire prior NRC report (NRC, 2002a). We concur with this committee's recommendation:

> "The NWUIP should be viewed as much more than a data-collection and database management program. The NWUIP should be elevated to a water-use science program, emphasizing applied research and techniques development in both statistical estimation of water use, as well as the determinants and impacts of water using behaviors."

Yet even now there remains little good, timely information on consumptive or non-consumptive water use, and associated forecasts of water demand based upon anticipated growth and forecasts of both land-use and climate change. The lack of dynamic and predictive information to anticipate challenges hampers effective water decision making (Mehan, 2009; Brekke et al., 2009). New science and new strategic approaches to continue data collection and address the forecasting component are required, and the USGS can fill this void. To do this, however, the USGS must still have an appropriate balance between its traditional data collection and enhanced forecasting and predictions.

We do not advocate a shift in program balance away from data collection to more interpretive studies and more information dissemination. Long-term data collection, methods development, interpretative studies, information dissemination, groundwater and surface water, and water quality and quantity activities are all needed. Indeed, forecasting and predictions are built on appropriate data collection. We do, however, advocate a change in how studies are approached and planned. So, the current question may not be to insure the programmatic "balance" of the past. Rather, future USGS planning should balance needs within program areas to meet the new strategic goals that WRD will tackle with a coherent view of how each advances the national understanding of major water problems. Development of a more coherent view of how data collection advances national understanding of the major water problems the USGS will confront is supported by feedback from forecasting and predictions. Given the growing magnitude of the nation's water problems this shift is important to delineating how all programs address their component contributions in a coherent view of its national purpose, even if the resource constraints on the agency improve.

Recommendation: The USGS WRD should refocus and integrate program activities to support syntheses, forecasting, and predictions with a coherent view of how each interpretative activity advances the understanding of regional and national priorities.

The USGS has certainly performed such work in some areas, such as the WRD's work on the San Pedro River in Arizona (Box 2-4). But there are many possibilities for USGS forecasting contributions that have not been fully realized.

The "Water Census initiative" sounds like a focus on inventory functions. Yet its full title and description, "Quantifying, Forecasting, and Securing Freshwater for America's Future," and its linkage to the NSTC's (2007) discussion of *A Strategy for Federal Science and Technology to Support Water Availability and Quality in the United States* stresses the need and importance of providing forecasting to aid current and future water management. One component would be linking land-use data, water-use data, water-quality information, and hydrologic models to address controversial issues such as water impacts of increased corn ethanol production in the Mississippi River basin (NRC, 2008d). While water allocation and management decisions are primarily the purview of state and local authorities, there is clearly a role and need here for better science to address the future uncertainties of "predictable surprises."

Other examples of an increased commitment to forecasting and predictions that would be particularly appropriate include (a) extending the results of watershed or groundwater models to the future given potential growth scenarios; (b) analyzing trends in water availability by linking water management, climate, and hydrologic models; (c) investigating—leading to prediction—the influence of climate change on regional disasters (e.g., Gulf Coast hurricane damage, Sacramento Delta levee breaks) and national security issues, (d) more proactively providing a science forum for interstate basin conflicts; and (e) providing uncertainty estimates for these scenarios.

Linkage of climate change models to regional and local hydrology is also needed (Mehan, 2009; NRC, 2009). The WRD could identify, develop, and apply valid nonstationary probabilistic models, providing measures of uncertainty. This would enable them to project multi-decadal hydrologic behavior, thus probing changes impacting water resources and infrastructure planning. This will require refocusing of efforts and research to improve approaches and models to account for non-stationarity and to better quantify and anticipate climatic and hydrologic variability and the uncertainties involved to improve planning. This role may prove to be uncomfortable in some places where state water compacts and state control over water issues has been the norm. But if the WRD is to provide water science for the nation and the federal government, there seems no fundamental reason why it cannot provide comprehensive, unbiased, regional syntheses of water issues to help guide the process to resolve regional and state water conflicts.

Improved strategies for sampling, interpolating, and predicting streamflow or groundwater levels are necessary, since it is impossible to measure streamflow or groundwater levels everywhere and continuously. More extensive application of statistical and deterministic modeling techniques is encouraged. Some of these techniques will have to be based on analysis of causes and effects, such as the effect of land cover change or of innovations in water technology on surface and groundwater volumes and quality.

Further, the committee urges the USGS to focus on how data gained in local or regional Coop funded interpretative studies can be integrated into regional and national syntheses and applied towards solving major water problems. The WRD has already developed many project models to connect and aggregate studies done in Science Centers across the country towards providing regional and national synthesis—for example, in the NAWQA, Toxics, and Groundwater programs and this development should be continued and enhanced by appropriate application to the Coop program.

The current budgetary climate does not allow the USGS to meet all the demands of the multiple objectives of its programs. Whether or not additional funding is obtained, the current portfolio of projects and activities need to be strategically reassessed and focused to address not all, but the critical, water challenges facing the nation. The nation needs an increased commitment from the USGS to forecasting studies that interpret its data and inform the nation of the message contained in their data, adding value to the scientific debate behind these critical, national water resource issues.

Definition of a Comprehensive, Integrated Long-Range Water Census Strategy

The Water Census will require substantive planning to define its scope, key scientific concepts, and new questions and challenges. The Water Census should therefore become more than an unconnected list or atlas of water-related indices, chosen because they are easily measurable and already available. Long-range strategic thinking, as well as short-run easily obtainable results, will be needed to establish a means for monitoring and understanding water use and of planning and targeting improvements over time. To adequately quantify and forecast the nation's water availability needs requires a long-term commitment to improving data collection and forecasting tools, to checking explanations and refining predictions. The need is similar to, though logistically different from, the way that prediction skills have been gradually built into and improved for weather forecasting or economic forecasting.

The SWAQ report envisioned the Water Census as a periodic exercise to update the approach and continue to inform the nation's water managers and to keep the nation's policy makers abreast of changing water resources and demands. New technique development takes time, is implemented gradually, and has to be proven before widespread deployment. The first generation of the Water Census will need to be conducted with data sources that are already available. Other needed aspects of a Water Census, such as accounting for the use of water to sustain ecosystems while simultaneously making the water available for other uses, and the tradeoffs involved in such multiple use, will require time to develop, and the earliest implementations of a Water Census might not be able to address these complexities or might need to find a way to estimate them crudely. Addressing the complex competition between human and ecosystem water use will require a multi-disciplinary treatment and should be a goal of the Water Census.

These complexities suggest an incremental strategy for gradually elaborating and improving the Water Census, thus the initial strategy should make it clear that some complexities can not, or will not be included initially. Further, the strategy should outline the components of the Water Census that need to be initially addressed and components that will be added as soon as they can be quantified. This would define, in turn, a research agenda of needed science elements that need to be developed or proved, and additional elements for coordination and collaboration among agencies. Long-term support is needed to improve data sources and analysis techniques that are the key to providing the nation with a useful Water Census. Establishing programs, such as the Water Census, in a multidisciplinary agency like the USGS can ensure that unbiased information sources can be managed and inform the nation's decision makers.

New Resources

An effective, dynamic Water Census cannot simply be grafted onto current USGS activities. The effort would be weak from the start if it has to be based on patching together support from local agencies and states willing to participate. This may be necessary in the short run, and even with new resources, program development will require more focused leadership and organizational approaches than in the past. But clearly, at a national level, the need for a Water Census is now recognized and advanced not only by the USGS but by the interagency NSTC, and Congressional committees. The time is ripe for the USGS to advance a comprehensive water strategy to meet the nation's needs and to gain the necessary resources to meet its future mission.

In summary, the USGS WRD has the appropriate range of personnel, technical resources, and history of water resources data collection, management, dissemination, and research among the federal agencies to provide leadership to develop a dynamic Water Census for the nation as well as rise to the water resource challenges facing the nation. However, the USGS will have to extend its internal and external cooperation and develop new science to enhance its forecasting and predictions capabilities. To be the lead water agency that the nation's water availability issues demand, the USGS should present a compelling vision and strategy of what would be possible. The USGS can build on its pilot water census plan, the SWAQ report, and the USGS six Directions to articulate this vision, a vision that will address predictable surprises to come.

STRATEGIC APPROACHES

A focus on critical national problems will require hard decisions about how national programs like the Water Census are developed and integrated across the WRD. Integration of WRD programs to address national priorities will require active management, or development of common strategic questions, and a common intellectual approach. They should not be designed as an amalgam of various projects and programs developed independently by various programs or state science centers, though some might be excellent models. Such programs should be integrated at a high level with leadership and a management approach capable of making important scientific contributions of national and international relevance. Thus, we expand our recommendation from above (The WRD should re-focus its vision on critical national priorities to lead the nation in water science. This vision should bring their research arm, science and interpretive programs, and data acquisition arm to a common focus on key national priorities):

Recommendation: The USGS and WRD leadership should re-focus their vision to define the national water priorities that they will address and develop a management approach to integrate the WRD programs to meet these needs and lead the nation in water science.

We are not suggesting major structural or organizational changes. However, the USGS should have a functional process to enable these integrated activities to effectively occur. This may require a process to recognize and empower science leaders to provide the intellectual leadership for priority focus areas, and then, management leadership to ensure implementation. Such a process may begin with sequentially defining the key overarching science questions that are in the national interest, in-house intellectual leader(s), definition of observations required to address the questions, integration of the program/experimental design across various programs, definition of ways to measure progress and contributions, a process for analysis and synthesis of the results, and finally a plan for outcome dissemination.

Many, if not all, pressing national issues will require integration of WRD programs, from the Groundwater Resources program, to NAWQA, and NSIP, the NRP and the Coop program, for example. As part of the integration, each program may need to define its component contributions—the science questions and observations it will address to meet the more comprehensive national issue. Some integration has begun to take shape in the presentation of the Groundwater Resources Program's outline of an approach to address groundwater availability in the U.S. (Reilly et al., 2008) related to the Water Census. To more successfully organize to address national strategic questions USGS water science will need to be more flexible at focusing diverse personnel, research units, and Water Science Centers on such projects.

The USGS has models of integrated programs that have achieved some successes with notable, timely, focused research projects of national importance; its national synthesis on pesticides (USGS, 2006c), volatile organic compounds (USGS, 2006b), fuel oxygenates in water (Moran, 2007) forecasts of nitrate occurrence in groundwater (Nolan et al., 2002) or nitrate flux (Green et al., 2008; Puckett et al., 2008), and other contaminant processing and occurrence in agricultural watersheds (e.g., Capel et al., 2008). Notable timely examples of broader interdisciplinary projects were the 2007 studies on polar bear populations (USGS, 2007b) and habitats relative to changing Arctic sea ice conditions. Past examples in the Geology Discipline would include the USGS responses to the Loma Prieta earthquake and the Mt. St. Helens eruption.

While many of the WRD programs have line-item budgets and defined missions, they still can be integrated to address national priority questions that address key components of water availability. Because many of these national issues will also require new science, the approach to integrate and apply WRD's focus on national priorities should also better leverage the science and technical prowess of the NRP and the operational capabilities found within the Science Centers. A key challenge, in the committee's judgment, will be to define and manage the role of the NRP and the Science Centers in such integrated programs.

The National Research Program (NRP)

In the past, through the NRP, the USGS has provided intellectual leadership in developing new science in water related issues. To address important and emerging water issues there are again clear needs for new water science, and the NRP needs to play a renewed and significant role. Many of the resources of the WRD are dedicated to line-funded programs. In contrast, the NRP should have the flexibility to quickly refocus on new significant water science that needs to be addressed. The significant decline in the number of NRP scientists in the last two decades has been detrimental to the health of the NRP, and it has lost some measure of its scientific leadership. Over time, more NRP support has come from other WRD programs, almost as a tax, to support it, and in turn some of its work has been focused to support other USGS programs, potentially losing some of its flexibility to align to address new water science priorities.

From the committee's observations, portions of the NRP operate mainly as an investigator-driven research center wherein individuals have developed and pursued research interests of their own definition, within the broad mission of the WRD. While historically this may have worked well when the NRP was larger, we wonder if the WRD is best served by an investigator driven research model. The independent work culture may hamper the USGS's flexibility to attack relevant, priority issues in a timely way.

Recommendation: To meet the nation's water science needs, the WRD's National Research Program should be aligned around its focused vision of national program priorities.

The NRP should be viewed as an intellectual and technical resource of the WRD—one that needs active management. Even if the funding environment improves—the USGS cannot afford a research institution that is not focused on areas of strategic concern to the USGS and the nation. But it will take active and careful management to redirect scientists of the NRP to priority topics. Changing the focus of individual scientists may be difficult within the civil service system, when there are few stimuli for changing the focus of their research programs. While it is not realistic to expect, for example, a hydrologist to become an ecologist, the nation needs NRP scientists to be flexible in their choice of research topics as society's needs evolve.

To focus the NRP, future hires of research personnel should be focused on the strategic directions for water. Current researchers should be steered toward these areas as well through incentives. Waiting for retirements to make strategic hires will only lead to further erosion of the USGS's capacity to answer the questions that society is asking. USGS may also have to revisit its review and reward system for its research grade personnel. Currently the system has placed a premium on authorship of high-quality, peer-reviewed publications. While productivity, in terms of high quality peer-reviewed publications is laudable, the USGS reward system needs to be assessed to provide incentive for team-oriented work, and substantive contribution to and leadership of projects that address critical national priorities. Although the breadth of expertise present in the USGS is certainly sufficient to address integrative national problems, the culture and reward system needs to ensure it can help align individual priorities for career advancement with agency and national priorities. Overall, the single most important trait that WRD management will need to demonstrate in the next decade is its willingness to actively lead the institution's scientists in the new directions required by the nation's needs. The actual management mechanisms may be "carrots" or "sticks," as required by the individual circumstances.

The Cooperative Water Program and Science Centers

Adequately addressing the growing agenda of national water priorities will also need to involve improved integration of the Coop program and the Science Centers on the defined national priorities. New science needed to address national water problems often must be tested and tailored to the wide range of climatic, hydrologic, cultural, and industrial-economic conditions that exist throughout the United States. Through the Science Centers and Coop Program the WRD has a presence in every state and they can be an important resource to accomplish this and to contribute more to regional and national objectives in the future if projects are configured to do so. But national priorities need to help shape and define these local programs; and national programs cannot simply be a collection of Science Center projects.

As discussed, through the Science Centers, the WRD has a good process working with water resources managers as well as other water scientists and engineers across the nation. While much of the Coop program has focused on the streamflow data collection program, the WRD's partnerships with state and local institutions in the wider ranging science programs have had a positive effect to improve the level of science applied to water resources and environmental management across the country. And this has been a two way street—the Coop program has provided symbiotic benefits; state and local agencies, and academic cooperators across the country sharing new expertise with the WRD, as well. These relationships have helped all parties to develop a greater breadth of interdisciplinary skills and has often resulted in novel approaches to both research and water management. In particular, as discussed earlier (chapter 3), WRD's distributed network of staff, interacting with local water scientists, has helped WRD to identify relevant, emerging water issues around the nation.

Many pressing national issues related to water supply, water quality, or water availability conflicts often appear as local problems, yet their resolution typically requires regional approaches and syntheses. For example, most of the American West is maintained through large artificial interbasin water transfers, and regional-scale drainage by rivers, often subsidized by the federal government. Even Eastern cities have remote mountain water catchments—see the Georgia-Florida-Alabama conflict referred to earlier in this report. These water issues sometimes appear "local," yet characterizing and resolving them requires regional approaches that fall under the logical interests of the USGS, a national water agency. The structure of the Coop program would not lead the USGS to comprehensively study the functioning of these large systems, crucial to the nation's well being. This may occur partly because of the sensitivity of the states to federal intervention in the management of water resources, and also because historically we have not fully appreciated the significance of large-scale patterns and transfers of water to the nation's productivity and health.

Related to regional characterizations, water availability conflicts between and among states, with or without interstate compacts, are becoming more prevalent and challenging. Another role for the USGS and its Science Centers could be technical facilitation as an impartial and credible intermediary to minimize the need for states needing to pursue litigation when they cannot agree on the factual understanding of the extent and characteristics of the water resource at the boundary. Science Centers could establish a unique forum to discuss regional characterizations, syntheses, and forecasts, to aid the management of shared water resources with their neighboring Science Centers and state counterparts. Such an approach fits very well with the USGS interest in achieving national leadership in addressing the water availability problems of the nation.

The management challenge with respect to the Coop Program for the Water Science Centers is to balance local cooperator needs and program designs with their national mission. This has become even more challenging in recent years. As described in chapter 3, during the past two decades, the cooperator share of the program funding has risen from about 50 percent to almost two-thirds of the WRD Coop budget. This rise is a result of a decline in federal support combined with increased desire for some cooperators to collaborate with the USGS. The increase in state and local cooperator funding, as noted in chapter 3, is a testimony to the quality of the USGS WRD product. However, part of the management challenge, is that with the decline in federal funding, the WRD has also needed to solicit financial support locally to maintain staff strength and project activities. The local funding increase seems to have increased state and local influence over how the federal dollars are spent. For example, cooperators are willing to pay the USGS to work as a high quality, non-biased, scientific expert on projects where federal priorities may not always be apparent.

This situation gives rise to two, inter-related concerns: possible inequities in Coop funding among states, and difficulties integrating the Coop program and Science Centers with national needs. Some states, like California, have been able to increase their unmatched programs substantially. But some states with limited resources but important strategic water problems might be underserved with USGS expertise because they do not have adequate Coop dollars to provide needed match.

Also, some cooperators have limited interest to fund USGS projects because they have developed substantial hydrologic expertise within their own organizations. It has been the practice of the USGS not to reallocate funds but to allow each state to retain their base Coop funding from year to year resulting in a stationary program distribution among states. This working model provides little or no opportunity for Coop funds to migrate to projects of higher national priority or greater scientific merit without the state with lower priority projects permanently losing a share of its Coop funding. Thus, it may be difficult for Coop funding to be better tailored to support regional- to national-scale analyses that we refer to frequently in this report unless cooperators can be convinced of the merit.

Integrating the Coop Program with National Needs

Evaluations of the distribution of Coop funds for gaging stations have taken place regularly throughout the past decades to maintain the most balanced and information-rich network attainable with the resources available. However, the interpretive project aspects of the Coop Program have not received comparable scrutiny. The USGS is encouraged to define how to better manage its Science Center and Coop program commitments between local interests and national priorities. Specifically, a structured, objective process for allocating Coop funds to local and state projects should be established to insure each state Coop Program has been evaluated for its merits in meeting strategic regional and national priorities and has not evolved into merely a technical service serving local interests. The USGS should also consider a process for temporarily transferring Coop funding allocations from state to state to follow projects with the most national scientific merit without permanently decreasing the Coop allocation to any state.

Recommendation: The WRD's Cooperative Water Program (Coop) needs to be better integrated with the WRD's focused vision of regional and national water program priorities. The WRD is encouraged to develop a process for defining national merit for Coop projects as a means of balancing Coop program commitments with meeting regional and national priorities.

For example, the Colorado Science Center has developed criteria for defining the relative contribution of each proposed project to national priorities and uses this when deciding which projects should be included in the cost share program and what the proportionate match should be. It is not intended to exclude state and local interests but rather provides a metric for considering to what extent the Coop Program is addressing defined regional and national priorities. We recognize this will be difficult. As the WRD concentrates more resources to national- and regional-scale problems, it is important that the best aspects of their contributions to more local problems should not be undermined or abandoned.

More flexibility may also be needed with respect to staff resources among the state Science Centers. WRD research-grade scientists at Science Centers rely on both Coop and other federal programs to meet merit criteria associated with their research positions. While redistributing research-grade scientists from the NRP to the Science Centers has elevated scientific quality in these offices, when left to their own efforts to obtain project funding, research-grade scientists may only be intermittently integrated into national research priorities, and even then, sometimes through individual collegial preferences or topical coincidences. Perhaps both Science Center research scientists and NRP scientists may need to be considered for flexible assignments as part of integrated project teams, coordinated to attack national strategic directions. This kind of change would require flexibility to assign research-grade staff in one Science Center to work on a team for another Science Center. Over time, as noted, assignment of research grade staff has increased in the Science Centers, while the NRP staffing has declined. Hence, some of the same issues discussed for realigninment of NRP staff may apply to the research grade staff in the Science Centers:

Recommendation: The USGS WRD should involve all research grade personnel in staffing teams to address regional and national research priorities, regardless of location, to increase the agency's flexibility.

> "Civilizations have failed because of their inability to provide a safe and reliable water supply in the face of changing water resource needs."
>
> SOURCE: National Science and Technology Council, Committee on Environment and Natural Resources (2007).

CONCLUDING REMARKS

Throughout this report, we have tried to illustrate that the water resources of the United States are becoming more strained and limited day by day, year by year, in the face of population growth, climate change, and other pressures. Increasing water resource constraints are predictable surprises that have foreseeable consequences on the nation's social and economic stability. To resolve these issues requires that we face up to the challenges ahead and begin to develop the science and information needed. The USGS WRD should be an important contributor to developing the needed water science the nation requires. This will necessitate an improved focus from the USGS WRD on the national water priorities that they can address and on an operational management approach to effectively integrate their programs. But to adequately meet the challenge it will clearly require new and additional resources. To that end we provide our final recommendation:

Recommendation: To ensure a secure water future for the nation, sufficient funding should be provided for the USGS to perform its function as a major science agency: to ensure high quality data collection, interpretive programs, and development of essential forecasting and predictive tools to support effective management of the nation's critical water resources.

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Appendix A

Biographical Information

Committee on Water Resources Activities at the U.S. Geological Survey

George R. Hallberg, *Chair*, is a principal with the Cadmus Group, Inc., in Waltham, Massachusetts, conducting environmental research, regulatory analysis, and management services. Previously he was associate director and chief of environmental research at the University of Iowa's environmental and public health laboratory and at the Iowa Department of Natural Resources. Dr. Hallberg was also an adjunct professor at both the University of Iowa and Iowa State University. He chaired the NRC Committee on Opportunities to Improve the USGS National Water Quality Assessment (NAWQA) Program and was on the NRC Committee on Mine Placement of Coal Combustion Wastes, Committee Assessment of Water Resources Research, and others, and served as a member of the Board on Agriculture and Natural Resources. He served on the U.S. Environmental Protection Agency (EPA) National Advisory Council for Environmental Policy and Technology and on the Office of Water's Management Advisory Group. He is a National Associate of The National Academies. His research interests include environmental monitoring and assessment, agricultural-environmental impacts, chemical and nutrient fate and transport, contaminant occurrence and trends in drinking water, and health effects of environmental contaminants. Dr. Hallberg received a B.A. in geology from Augustana College and a Ph.D. in geology from the University of Iowa.

Lisa Alvarez-Cohen is the Fred and Claire Sauer Professor of Environmental Engineering as well as the Department Chair of the Department of Civil and Environmental Engineering at the University of California, Berkeley. She received her B.A. in engineering and applied science from Harvard University and her M.S. and Ph.D. in environmental engineering and science from Stanford University. Her current research interests are the biotransformation of contaminants in the subsurface, including chlorinated solvents, MTBE, and NDMA, and innovative methods for evaluating in situ bioremediation, including molecular biology, isotope use, and direct microscopy. Dr. Alvarez-Cohen is an associate editor of Environmental Engineering Science and a Fellow of the American Academy for Microbiology. Her previous NRC service includes the Committee on USGS Water Resources Research, the Committee on In Situ Bioremediation, and the Committee on Source Removal of Contaminants in the Subsurface.

Thomas Dunne (NAS) is a professor in the School of Environmental Science and Management at the University of California at Santa Barbara. He is a hydrologist and a geomorphologist, with research interests that include field and theoretical studies of drainage basin and hillslope evolution; sediment transport and floodplain sedimentation; debris flows and sediment budgets of drainage basins. He served as a member of the WSTB Committee on Water Resources Research and Committee on Opportunities in the Hydrologic Sciences and was elected to the National Academy of Sciences in 1988 and to the American Academy of Arts and Sciences in 1993. He has acted as a scientific advisor to the United Nations, the governments of Brazil, Taiwan, Kenya, Spain, the Philippines, Washington, Oregon, and several U.S. federal agencies. He is a recipient of the American Geophysical Union Horton Award. Dr. Dunne holds a B.A. from Cambridge University and a Ph.D. in geography from The Johns Hopkins University.

William H. Hooke is a Senior Policy Fellow and the Director of the Atmospheric Policy Program at the American Meteorological Society in Washington, DC. Prior to arriving at AMS in 2000, he worked for the National Oceanic and Atmospheric Administration (NOAA) and antecedent agencies for 33 years. After six years of research with NOAA he moved into a series of management positions of increasing scope and responsibility including Chief of the Wave Propagation Laboratory Atmospheric Studies Branch, Director of NOAA's Environmental Sciences Group (now the Forecast Systems Lab), Deputy Chief Scientist, and Acting Chief Scientist of NOAA. Between 1993 and 2000, he held two national responsibilities: Director of the U.S. Weather Research Program Office, and Chair of the interagency Subcommittee for Natural Disaster Reduction of the National Science and Technology Council, Committee on Environment and Natural Resources. He is a National Associate of The National Academies. Dr. Hooke was a faculty member at the University of Colorado from 1969 to 1987, and served as a fellow of two NOAA Joint Institutes (CIRES, 1971-1977; CIRA 1987-2000). The author of over fifty refereed publications and co-author of one book, Dr. Hooke holds a B.S. (Physics Honors) from Swarthmore College (1964), and S.M. (1966) and Ph.D (1967) degrees from the University of Chicago. Dr. Hooke was elected to membership in the American Philosophical Society in 2006.

Thomas L. Huntzinger has his own consulting business which currently coordinates the watershed restoration and protection efforts for Clinton Reservoir, a water supply to 120,000 people as part of the state of Kansas non point source protection program. He was previously a Senior Hydrologist for Applied Ecological Services, Inc. He managed the firms consulting services for the Kansas City office and coordinated the engineering work on projects in the Kansas City office. His areas of expertise include hydrologic analysis, water management, water use and water quality. Prior to his consulting work, he spent eight years as the water appropriations program manager for the Kansas Department of Agriculture, Division of Water Resources directed by the Kansas Chief Engineer. He was responsible for water appropriations and water rights permits in Kansas. He worked 26 years for the U. S. Geological Survey as a hydrologist, district chief, and program manager. USGS assignments in Oklahoma, Louisiana, Kansas, and Nebraska included FEMA flood analysis, low flow characteristics, coastal flow monitoring and other coastal processes, groundwater analysis, hazardous waste site assessments, and team leader for the Platte River NAWQA project. He is a registered professional engineer in Kansas and Oklahoma and has BS and MS degrees in Agricultural Engineering.

Holly E. Richter is the Upper San Pedro Program Director for The Nature Conservancy. She has worked for the Conservancy on riparian conservation projects in the Western states for over 20 years. She was appointed to the Upper San Pedro Water District Organizing Board in 2007 by Governor Napolitano, and also serves as the Conservancy's lead representative on the Upper San Pedro Partnership, a regional consortium of 21 local, state and federal agencies including scientists, land managers, and decision-makers. She serves as chair for the Partnership's Technical Committee (2000-2008) and is Vice Chair for the Partnership's Executive Committee (2006-2008). She also assists partner agencies with coordination of regional, cross-border water management and conservation projects within the bi-national San Pedro watershed. Her professional interests include regional groundwater management, riparian ecology and conservation, and environmental conflict resolution. Dr. Richter received a Cooperative

Conservation Award from the Department of the Interior in 2008, and is a member of the Arizona Hydrological Society and the Arizona Riparian Council. She received both her BS in Landscape Architecture and a Ph.D in Rangeland Ecosystem Science, specializing in riparian ecosystem modeling, from Colorado State University.

Franklin W. Schwartz is a professor and the Ohio Eminent Scholar in hydrogeology at The Ohio State University. Dr. Schwartz's research interests encompass field and theoretical aspects of mass transport, contaminant hydrogeology, and watershed hydrology. He is coauthor of the texts Physical and Chemical Hydrogeology, published in 1990 and 1998, and Foundations of Ground Water, published in 2003. He has received various awards recognizing his contributions to hydrogeology, including the O. E. Meinzer Award, the Excellence in Science and Engineering Award, and the M. King Hubbert Science Award. He was elected as a fellow of the American Geophysical Union in 1992. In addition to his teaching and research, Dr. Schwartz acts as a consultant to government and industry, and he acts in various advisory capacities. He has served on various NRC panels and as a member of the Water Science and Technology Board. He received his Ph.D. in geology from the University of Illinois.

Rebecca R. Sharitz is professor of plant biology at the University of Georgia and senior scientist at the Savannah River Ecology Laboratory in Aiken, South Carolina, where she has been the Head of the Division of Wetlands Ecology. Her research focuses on ecological processes in wetlands, including factors affecting the structure and function of bottomland hardwood and swamp forest ecosystems, responses of wetland communities to environmental disturbances, and effects of land management practices on nearby wetland systems. Dr. Sharitz has served on several NRC committees including the Committee on Restoration of the Greater Everglades Ecosystem (CROGEE) and the Committee on Restoration of Aquatic Ecosystems: Science, Technology and Public Policy. She has also served as Vice President, Treasurer, and Council member of the Ecological Society of America, and she was recently elected a Fellow in the Society of Wetland Scientists. She received a B.S. in biology from Roanoke College and a Ph.D. in botany and plant ecology from the University of North Carolina.

Donald I. Siegel is a professor of geology at Syracuse University, where he teaches graduate courses in hydrogeology and aqueous geochemistry. He holds B.S. and M.S. degrees in geology from the University of Rhode

Island and Pennsylvania State University, respectively, and a Ph.D. in hydrogeology from the University of Minnesota. His research interests are in solute transport at both local and regional scales, wetland-ground water interaction, and paleohydrogeology. Siegel is a recipient of the O. E. Meinzer Award, presented by the Hydrogeology Division of the Geological Society of America (GSA). He recently served as a counselor of GSA, and is an associate editor of the Hydrogeology Journal. He has been a member of numerous NRC committees including the Committee on Wetlands Characterization, Committee on Techniques for Assessing Ground Water Vulnerability, and Committee on Review of the USGS National Streamflow Information Program. He chaired the Committee on River Science at the U.S. Geological Survey. He is a National Associate of The National Academies.

Roland C. Steiner is Regional Water and Wastewater Manager for the Washington Suburban Sanitary Commission. He is responsible for developing and maintaining the major functional and financial relationships between WSSC and adjacent utilities, including management and funding of cost-shared water supply reservoirs and advisory services, water curtailment agreements, and reconciliation of WSSC's capital funding at several wastewater treatment plants. Previously he was Associate Director for Water Resources and Director of Cooperative Water Supply Operations on the Potomac for the Interstate Commission on the Potomac River Basin. There, he was responsible for directing the water resources program of the Commission including covering coordinated drought supply management of river and reservoir resources for the Washington, DC region. He is a Professional Engineer in Maryland, and a member of the American Society of Civil Engineers, American Water Works Association, and Water Environment Federation. He has a B.Sc. in Civil Engineering from the University of Pennsylvania, and M.Sc. in Civil Engineering: Engineering-Economic-Planning from Stanford University, and a Ph.D. in Environmental Engineering from The Johns Hopkins University.

David G. Tarboton is Professor, Utah Water Research Laboratory and Department of Civil and Environmental Engineering, Utah State University. His research and teaching is in the area of surface water hydrology. His research focuses on advancing the capability for hydrologic prediction by developing models that take advantage of new information and process understanding enabled by new technology. This includes the use of hydrologic and geographic information systems and digital elevation models that take advantage of spatially distributed information for hydrologic prediction. His work has contributed to advances in terrain analysis for hydrology, terrain stability mapping and stream sediment inputs, geomorphology, stochastic and nonparametric statistical methods in hydrology, and snow hydrology. He has served on the NRC committees on Review of the USGS National Streamflow Information Program and River Science at the U.S. Geological Survey. Dr. Tarboton received his B.S. in civil engineering from the University of Natal in Durban, South Africa in 1981, then a M.S. and Sc.D. in civil engineering from the Massachusetts Institute of Technology in 1987 and 1990 respectively.