Research Needs in Water Resources and Environment: A Panel Discussion

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Introduction

Practicing engineers sometimes criticize researchers for answering questions that no one is asking, or at least for conducting research on questions of personal interest or in areas that funding agencies think are important. Although such research has a place in the overall picture of things, it is instructive to consider the practical issues that engineers in the field face. The fields of water resources and environment are very broad, and only a small number of research users could be included on the panel seated by the Education and Research Council at the 2004 World Water and Environmental Resources Congress. One of the panel members pointed out that the private sector was underrepresented. We hope that a future panel will correct this problem. The PowerPoint presentations given by panel members may be accessed from the Education and Research Council's Web site, http://engineering.rowan.edu/~orlins.EWRI. Because of time constraints, each participant could relate only a small portion of his or her agency's interest; consequently, this report is not intended to be comprehensive, even for the various agencies represented on the panel.

Two papers on research needs have been published by the National Research Council: *Envisioning the Agenda for Water Resources Research in the 21st Century* (2001) and *Confronting the Nation's Water Problems: The Role of Research* (2004). The latter paper gave the federal funding sources, as illustrated in Fig. 1. Both these papers can be accessed from the National Academy Press Web site, www.nap.edu.

Research Interests of the USDA/ARS

The research section of USDA is located with the undersecretary for research, education, and economics. Agriculture uses about 90% of the fresh water in the western United States. Surface water supplies about 68%, and the remaining 32% comes from groundwater. High-value crops (orchard crops, berries, vegetables, and nursery crops) account for almost 60% of the irrigation water use, which occurs on only 15% of the irrigated land.

The USDA has two major categories of research needs. The first is envisioning the agenda for water resources in the twenty-first century, and the second is determining the role of research in confronting the nations's water problems (NRC 2001). Under the first category are water availability, water use, and water institutions. The NRC report divides these into 43 specific needs. The following are examples of these research needs:

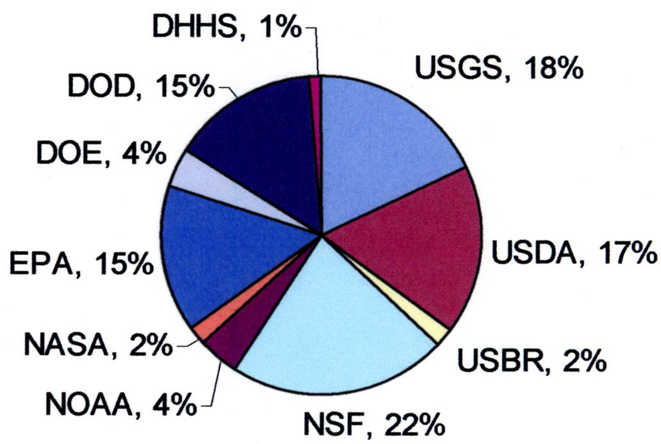

Fig. 1. (Color online) Agency contributions as a percentage of the total federal funding for water resources research in 2000; DHHS=Department of Health and Human Services; DOD=Department of Defense; DOE=Department of Energy; EPA=Environmental Protection Agency; NASA=National Aeronautics and Space Agency; NOAA=National Oceanic and Atmospheric Administration; NSF=National Science Foundation; USBR=U.S. Bureau of Reclamation; USDA=U.S. Department of Agriculture; and USGS=U.S. Geological Survey (adapted from NRC 2004)

1. Water availability
   - Improve existing supply-enhancing technologies such as wastewater treatment, desalting, and groundwater banking.
   - Control non-point source pollutants.
   - Understand impact of land use changes and best management practices (BMPs) on pollutant loading to waters.
   - Understand and predict the frequencies and causes of severe weather (floods and droughts).
   - Understand global changes and their hydrologic impacts.
2. Water use
   - Understand determinants of water use in the agricultural, domestic, commercial, public, and institutional sectors.
   - In all sectors, develop more efficient water use and optimize the economic return for water used.
   - Develop improved crop varieties for use in dry-land and irrigated agriculture.
   - Understand behavior of aquatic ecosystems in a broad, systematic context, including their water requirements.
3. Water institutions
   - Develop legal regimes that promote groundwater management and conjunctive use of surface water and groundwater.
   - Improve equity in existing water management laws.
   - Develop adaptive management.
   - Develop new methods for estimating the value of nonmarket attributes of water resources.
   - Explore use of economic institutions to protect public policies and values related to water resources.

The National Science and Technology Council (NSTC 2001) also has issued a report suggesting several important research areas. One is to determine the amount of water that is available in our rivers, lakes, reservoirs and aquifers. Another research interest is determining the amount of water that is likely to be available in future decades at current projected rates of use. In addition, a need exists to improve our understanding of the nation's water resources and their natural variability.

Another research area is to determine more precisely the amount of water that is used for human needs, agriculture, industry, and energy, and to develop scientifically reliable methods for determining the amount of water needed for the environment. The NSTC report called for evaluating alternatives to use water more efficiently, including technologies for conservation and supply enhancement. These might include water reuse and recycling, as well as factors that influence adopting these technologies. We need to know the policies that might encourage the economical use, production, supply, and exchange of water. Finally, the report suggested an improvement for predictions from days to decades of our water resources to facilitate planning and more efficient operation of the water infrastructure (NSTC 2001).

One of the newest projects in the USDA is measuring the environmental benefits of conservation practices, the Conservation Effects Assessment Project (CEAP). There are twelve ARS research watersheds and eight special emphasis watersheds. The resource concerns include water quality, water conservation, and soil quality. Later, CEAP will investigate air quality and wildlife habitat. Initially, the research also deals with such land-use categories as rain-fed cropland. Later, the research will consider irrigated cropland, grazing lands, wetlands, and agro-forestry lands.

Research Interests of the EPA

The Office of Research and Development (ORD) is the scientific research branch of the Environmental Protection Agency (EPA). It provides a solid underpinning for EPA's policies on protecting air, water, and land. ORD employs almost 2,000 people in 13 labs and facilities across the United States. It has an annual budget of $700 million; more than $100 million funds extramural environmental research.

In the past several years, the EPA has gained new responsibilities for protecting the homeland. Broadening its efforts to respond to and clean up hazardous material releases, the EPA now has responsibility for responding to and cleaning up materials released during terrorist attacks. In addition, the EPA has been named the lead federal agency for protecting the water supply. The ORD supports these functions through its National Homeland Security Research Center (NHRSC) which performs and coordinates research related to building decontamination, rapid risk assessment, and water security.

The EPA has two divisions that share responsibility for water security. The Water Security Division (WSD) provides financial assistance and technical guidance to water utilities. The NHSRC's Water Security Team coordinates and carries out short-term applied research, and develops technologies and tools for the WSD, water utilities, and emergency responders.

Working with other federal agencies and a large group of stakeholders, the EPA has formulated the *Water Security Research and Technical Assistance Action Plan* (Action Plan). The Action Plan is a comprehensive discussion of the short- and long-term research and technology developments necessary to improve the security of U.S. water systems. The National Academies reviewed the Action Plan in 2003, and a revised Action Plan was published. Some of the proposed research will be carried out by the EPA or other federal partners, but many of the research topics are well-suited for the private sector and academia. Beneficiaries of this research will include the water utilities; state, regional, and local emergency response organizations; public health organizations; laboratories with water-testing capabilities; public officials; and the general public.

The Action Plan describes research and technical activities in several broad categories discussed subsequently. The EPA is working in all of these areas in a focused and applied manner. However, the topics are quite broad and often require long-term research; therefore, many other researchers from academia and private industry also are needed to work in these areas. In addition, research in many of these areas, while focused on terrorism, could provide multiple benefits, such as improving the general water quality of distribution systems and developing methods that simplify testing for regulatory purposes.

Characterization and Detection

Research in this area focuses on detecting and characterizing contamination events in drinking-water systems. Research can be divided into two broad categories: laboratory methods and field detection methods. The EPA is currently working on improving and standardizing analytical methods for potential water contaminants, developing screening protocols to analyze for "undetermined" water contaminants, and developing methods for concentrating biological samples. Preliminary work in this area resulted in the EPA Response Protocol Toolkit, which provides guidance for responding to contamination threats (see http://www.epa.gov/safewater/security). A broad interagency effort is under way to develop early warning systems for drinking water, that is, integrated systems to detect, confirm, and warn of contamination to protect public health. The EPA is evaluating broad-spectrum and contaminant-specific sensors, piloting syndromic surveillance efforts, developing computational models to design and evaluate early warning systems, and setting up early warning system test beds.

Treatment and Containment

Research in this area is aimed at minimizing the impacts of drinking water contamination and quickly restoring a drinking water system to use. Hydraulic models are essential to predict the flow paths of contaminants in distribution systems and for designing and analyzing mitigation strategies, such as isolating portions of the system or installing chlorine boosters. In addition, a need exists to improve our basic understanding of the fate and transport of contaminants in drinking and source water; in particular, chemical reactions, degradation byproducts, interaction with biofilm and corrosion products, and biological transformations. The EPA is also working on determining the effectiveness of standard disinfection technologies against new contaminants of concern.

Decontamination and Disposal

Research in this area is focused on removing contaminant residue from pipes or other infrastructure and disposing of such contaminated materials. Research is under way to determine the contaminants that may pose a long-term decontamination challenge, as well as to develop and test standard methods for decontaminating pipes made of various materials, home appliances, and other water infrastructure. An economic analysis of the costs of replacing pipes versus decontamination, as well as a sociobehavioral analysis of public acceptance of water distributed by decontaminated pipes, would be useful. Longer-term research also is needed to develop environmentally benign decontamination agents.

Risk Assessment

Research in this area focuses on adapting standard risk-assessment methods for use during and immediately after terrorist attacks or other emergencies. Risk assessments for standard threat scenarios are being completed to predict the likely public health impacts of such scenarios, so that accurate estimates can be shared with the public immediately following an attack. The EPA is working on PC-based rapid risk assessment tools for emergency responders that link GIS information with health data and modeling tools. Finally, methods for microbial risk assessment are needed for understanding the impacts of bioterrorism.

Technology Verification

The EPA has five verification centers for homeland-security technologies: advanced monitoring, water treatment, containment/filtration, decontamination, and wastewater. These centers verify the performance of technologies through public and private testing partnerships overseen by stakeholder groups. New technologies can be voluntarily submitted for testing. For more information, see http://www.epa.gov/etv.

Physical Security

The EPA is also working to improve the physical security of water systems. Work is under way to develop guidance on protection from explosives, procedures to enhance cybersecurity, and tools to understand the interdependence of water systems with other critical infrastructure, such as power supply and telecommunications. The EPA is working with ASCE and other organizations to develop design standards and protocols for enhanced security, that is, minimum standards for incorporating security into the design and building of new infrastructure.

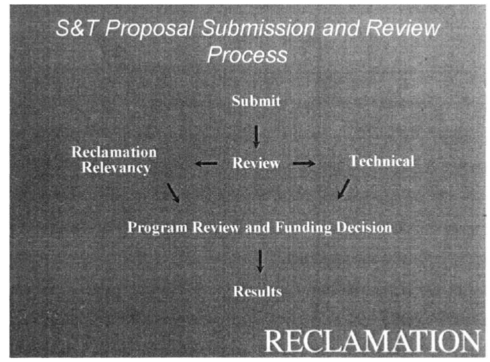

Fig. 2. USBR research proposal evaluation process (USBR 2005)

Research Interest of Reclamation

The U.S. Bureau of Reclamation's Science and Technology Program (U.S. Bureau of Reclamation, Science and Technology Program 2005) uses a competitive process to award funding. Before a research project is approved, it is reviewed by two committees, one for relevance to Reclamation's mission and the other for technical merit. These two committees submit their evaluations to the Program Review and Funding Board, which then prioritizes the proposals. The proposals are funded in order of preference until the research budget is exhausted. Fig. 2 illustrates this process.

The Science and Technology Program also recognizes that agency-wide priorities do not always match local priorities and allocates some of its funds for local priorities. This disparity can be seen in the survey results for the relevancy ranking shown in Fig. 3. The Program sorted an agency-wide relevancy survey to gain insight into how priorities change as the view is narrowed from an agency-wide perspective to the perspective of regional and area offices. The first group (shaded) shows the voting pattern for the agency-wide steering team. The second group (in white) was a subset of the first and shows the voting pattern for field personnel who face somewhat different problems. Seeing the difference of opinion between the two groups is fascinating. For example, the agency-wide steering team thought that integrating water research into management along with desalinization and water purification were the top research priorities. In contrast, the region as a whole believed that reducing water-quality impact on the various water districts was most important. Other projects that the region thought were important centered on the water districts. It appears that who are those more in contact with the water districts see projects affecting the districts as more important than projects that might have a broader administrative interest. Fig. 3 shows the survey results.

Truman conducted an informal survey of the Upper Colorado Region, that uncovered seven top research needs in the region. They are as follows:

- Tamarisk/cedar controls,
- Crop-consumptive use—remote sensing,
- Runoff forecasting,
- Desalination,
- Decision support—modeling tools,

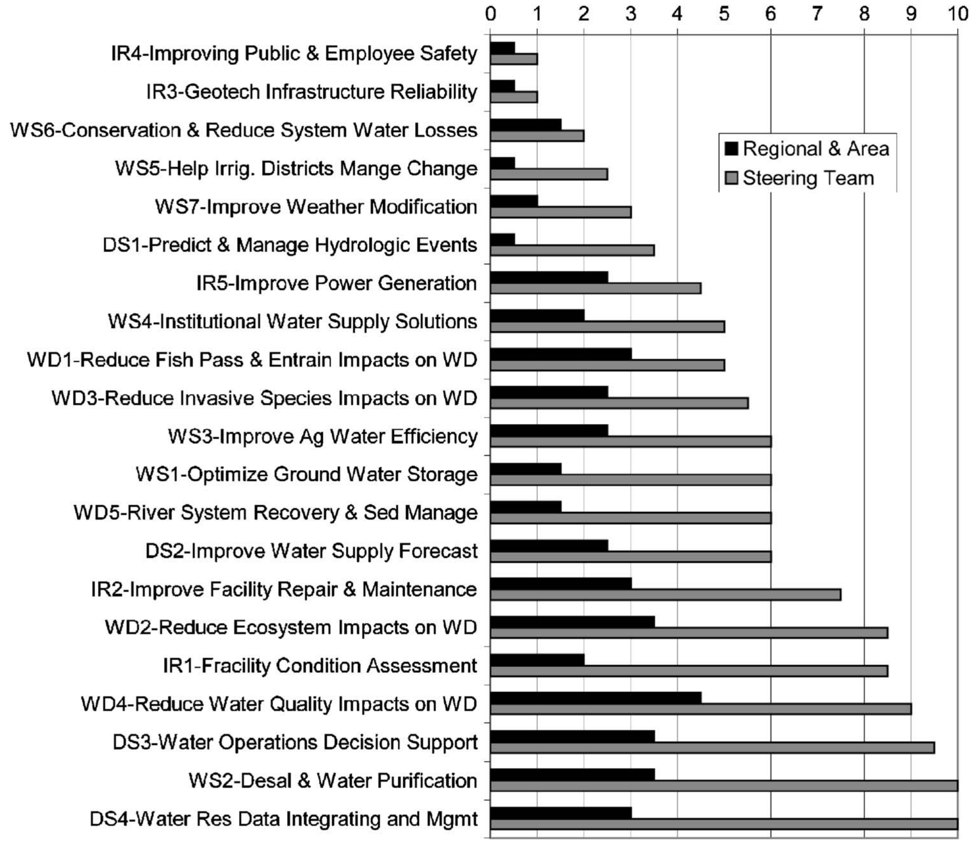

Fig. 3. Comparison of polling two groups concerning research needs in the Upper Colorado Region of USBR (USBR 2005)

- Extreme hydrologic events, and
- Geophysical tools—soil density.

Tamarisk and salt cedar trees are phreatophytes that evapotranspire a large amount of water from the river. They have become prolific along riverbanks and have displaced the original vegetation that was in place before the dams decreased the natural floods. Of course, some environmentalists are concerned that merely eliminating these trees would damage important bird and animal habitats. How to replace them with trees and shrubs that use less water is a major challenge. Biocontrols look promising.

The second item in the bulleted list deals with finding cost-effective ways to monitor the hydrologic system surrounding our river systems. Both crop-consumptive use (evapotranspiration, ET) measuring and runoff forecasting are important inputs for planning and operations. Finding cost-effective ways to measure ET is critical to understanding the water balance of the hydrologic system, monitoring droughts, and forecasting use. On the other side of the hydrologic system is runoff forecasting. It deals not only with estimating the effect of precipitation but also with the impact of snow cover on stream flow. The depth of snow and water content can be, and has been, measured for many years at a limited number of locations. Being able to measure the depth by remote sensing would broaden the sample size and improve forecast accuracy.

Improving desalination continues to be an important research area. Much has been done with both reverse osmosis (RO) and distillation plants. This technology is now becoming affordable for such high-value uses as municipal water supply and some specialized industrial uses. The cost of desalination is likely to remain prohibitively high for irrigation, given tight profit margins.

The panel's discussion session observed that simulation modeling of the Missouri rivers was being used to evaluate potential impacts. The U.S. Army Corps of Engineers (COE) has developed operating policies on energy, navigation, water supply, and the environment by using these kinds of decision support tools. As one can imagine, with these competing uses, sophisticated models are required.

As has been seen on the Colorado River, extreme hydrologic events need to be anticipated. We have gone from record-breaking wet years to record-setting droughts over the past few decades. Understanding the probabilities of these extreme events is critical to the development of reservoir operation policies. Stochastic models that look at the tails of the probability curves will become more important in future years. Integrating stochastic hydrology into big river operation models will allow us to refine our understanding of these rare, but very real, events.

Research Interests of the Private Sector

This single view from the private sector is obviously extremely partial and limited to examples of research needs in eight areas of interest. The first is hydrology, where there is a need for better tools in dealing with risk and uncertainty, such as climate variability in long-term forecasting and hydrologic analysis methods, such as regional regression equations. The analytical ability to better include drought planning for long-term reliability of water supply is important.

Concerning hydraulics, the second area, improving methods of determining channel and over-bank roughness is necessary to better determine water-surface profiles, particularly where (flexible) vegetation is present. Some European models, such as MIKE 11, use a resistance radius formulation of bed friction in Manning's equation, rather than the more traditional hydraulic radius method used in most U.S. river models, such as HEC-RAS. Comparing the development, usefulness, and ranges of use of these two methods to guide hydraulic engineers would be useful.

A third area of research deals with sediment transport and geomorphology. Science-based criteria for channel migration zones and riparian buffer strips are needed. Furthermore, improved methods would be helpful to quantify channel migration, which would include process-based roughness, sediment transport, hydrology, and hydraulics. Along with this is a need for an improved understanding of design and reliability criteria when large woody debris is used for bank protection. Finally better tools should be developed to determine sustainable approaches for flood and erosion control.

A fourth research need deals with water quality. Ways to automate calibration as part of standard models would improve the efficiency and accuracy of their use. There should be better guidance in "expert systems" for water-quality parameter selection. How many algal groups are needed or necessary for modeling lakes and reservoirs? What are the influences of riffles on water-quality processes and parameters? How does one include supersaturation mechanisms? And how much should we mow medians while maintaining their water-quality functions?

A fifth research concern involves the relatively new field of echohydraulics. Along with this field is a trend to use hydrologic indicators to more directly assess biological systems. One example is the development of normative flows. Should normative flows be purely hydraulic-based, or should they be physics-based and include hydraulics and sediment transport processes? What are the hydrologic and hydraulic conditions needed to assess long-term effects on aquatic systems? In addition, better risk-based instream flow methods are needed, along with guidance when dealing with storm water control about whether to use peak flows or hydrocycle approaches. Better understanding of sustainable restoration and rehabilitation approaches would help in designing ecohydraulic systems.

A sixth research area from a private-sector perspective is concerned with monitoring. What are the effects of dam removal? How does wetland restoration affect runoff, local ecology, groundwater recharge, and water quality? An EWRI Task Committee is examining monitoring wetland hydrology. However, even in this hot-topic area, good guidance for what constitutes adequate monitoring to support specific objectives is lacking. This type of guidance document also could be developed to look at water-quality sampling, again based on meeting specific objectives.

A seventh research interest deals with numerical models. Considerable confusion exists when determining which of the available models is most appropriate for a specific project. Standardized tests for model comparison are needed. A gap continues to exist between the models, or modules, developed as a result of research projects and these models entering consulting. Would using a type of expert-system approach to model selection be possible?

The final area considers the large view of research needs. How should proprietary versus nonproprietary models be encouraged, allocated, or used? In the United States there has been the historical development of numerous single-purpose codes, with considerable overlap in their areas of application (for example river-flow models such as HEC-RAS, FEQ, and BRANCH). By contrast, a number of European agencies have focused their development on single-purpose models—such as hydrodynamics, mass transport, and sediment transport—that "talk" to one another. When modeling rivers, for example, the number of U.S. programs in common (consultant) use that can couple these processes is very limited. The development of models that can couple processes should be encouraged for public use. What is the trade-off between open source models and limited access models? Would having standardized graphics be helpful? Is it feasible to have agreement on risk-based methodologies? International organizations need to better understand the global pressures on water resources, especially in the Middle East, where many sources have predicted future wars over water. With the rise in terrorist activities, the security of water systems has become a major concern. How can they be protected? How can attacks be communicated quickly? What can be done to mitigate attacks when they occur? Finally, considerable work on water rights is needed. Outdated laws hamper the efficient use of water and discourage innovative ways to improve water and environmental systems.

Summary

The views of the authors presented here are from their personal experiences and do not necessarily reflect official policies. We hope, however, that these limited suggestions will aid researchers and funding agencies to better focus research resources on the most pressing needs of the water and environment.

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