SCIENCE SUPPORT FOR WATER RESOURCES MANAGEMENT

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INTRODUCTION TO THE ISSUE

People feel that the water resources are threatened. Their fear has an underlying logic. Reliable sources of ample fresh water are essential for public health, economic prosperity, and quality landscaping. The water projects that deliver "ample" supplies of "safe" water can cause rivers to go dry, and waste discharges pollute what water is left. Incidents are reported where people fall ill, agriculture and industry suffer, and critical habitats are stressed.

Water managers, who are asked to deliver the ample supplies of safe water, are themselves concerned. They need to know what project and discharge characteristics cause which kinds of harm and how system operations and management practices can be modified in both the long and the short runs to protect the public interest. They seek answers in a world where public fears stem from scattered extreme events where the driving processes exhibit an inherent randomness and dynamic change is ever present. Water managers are asked to deliver dependable service in an uncertain world. They must respond to perpetual change by trying the untried in a fishbowl. The standard method to search for answers is through research, and users often feel that they are not getting the help they need.

This grand dilemma was brought to ten senior people with long experience facing water management issues. Each one was asked to assess the situation and provide advice and suggestions on what could be done so that research would make a greater difference. The preceding responses were delivered and discussed at a national conference. Our purpose here is to build on what was said and implied to take the discussions to the next step.

QUESTIONS AT HAND

Past assessments of water research largely focused on priority science issues. The deeper needs are for more effective integration of the findings of diverse studies so as to discern their holistic implications and for more effective interaction with management agencies and the public at large. Specific issues are:

1. **Research Integration** - Researchers come from quite different cultures. Strong differences exist between the "hard" and the "social" sciences, between the ecological and the engineering perspectives, and between "observers" and "modelers." Each culture resists challenges to interpretations of past work and is prone to think that accepting a more holistic conclusion would be a betrayal of its fundamental principles. People who study "water" from different perspectives work from different data bases and model different processes. They tend to be simplistic in their treatment of considerations outside the domain of their discipline. We need to put greater effort into building data bases containing information specified in a common grid in time and space that can be used generally by the "water" sciences and into experimentation and modeling that links across disciplinary boundaries.

2. **Research Administration** - The gap between the "hard" and the "social" sciences raises another issue. Present research in the "hard" sciences is managed to meet the needs of existing agencies and not to support institutional reorganization. The system is biased toward accomplishment of agency missions and neglects larger issues of broad public interest. The door must be opened to discussion of how to organize and support research on the "larger" issues. For example, research in social science is needed to craft effective institutions, and research in the "hard" sciences is needed to give those institutions management methods that work.

3. **Researcher-Agency Integration** - Science best supports agency programs for water resources management by integrating research, education, and knowledge transfer. Effective integration does not just happen, and yet literature on how to integrate the three is sparse. The papers that exist are largely from the agency rather than the research management side. One practical problem is that education in science and engineering often fails to prepare young people for practical problem solving and to assess the reasonableness of model output.

4. **Researcher-Public Integration** - The trend toward greater reliance on nonstructural measures for water resources management places a higher priority on water research to produce information that helps people as they make water use and waste discharge decisions and as they vote on large projects and public policy. Education programs must convey more holistic and integrated understanding of water problems and of the consequences of suggested management alternatives.

They must resist pressures to impart the values that have emerged from less than holistic assessments.

5. **Implementation** - A thoughtful assessment will find problems caused by past practices. Research results introduce new instrumentation for measuring water fluxes and quality, more equitable allocations of water rights, ways to increase project benefits through revised operations, descriptions of change in flood risk caused by changes in upstream land use or in climate, etc. A major research challenge is in developing criteria on when to make changes and how to go about transitioning. Changing an institutionalized system with strong vested interests is no easy matter. The difficulties are compounded by the uncertainties inherent in science (compounded for water by dealing with rare events) and the reliance of the legal system on deterministic forecasts. Other specific barriers to adoption of cutting-edge science include a)institutionalization of standard methods, b)acceptance of political decisions to resolve technical issues, and c)reluctance of vested interests to accept different outcomes.

REVIEW OF PRESENTATIONS

In the keynote paper, Vaux builds on an assessment by the Water Science and Technology Board that top priority should be given to the problem of how to sustain aquatic ecosystems during economic growth and urbanization. The rationale is that prosperous urban populations require high quality water and dependable food supplies even as they exert political pressures to preserve and enhance aquatic ecosystems and use their voting power to dominate decisionmaking.

In this context, water resource managers must both seek more reliable understanding of water science and craft institutions that can effectively deploy sophisticated physical infrastructure. They need a balanced management strategy to consider both the realities of science and subjective public perceptions in working to meet environmental and economic needs simultaneously.

Specifically, Vaux argues that management of water resources research needs to become more proactive in pursuing four long-term, interconnected needs. In considering them, I would make the following points:

1. Water Availability. Supplies of water vary greatly in timing, location, and quality. Future water managers need a classification system to use to deliver information on water availability by category in near real time. Research is needed to define categories that can support efficient conjunctive use of multiple surface and groundwater storages. Research is also needed to coordinate operations of water delivery and waste treatment systems to contain disinfection byproducts, to maintain efficient operations as infrastructure ages, and to detect and remove lower levels of pollutants from non-point sources and from historical sites for waste disposal.

2. Water Use. Contrary to popular perception, Schilling notes that water withdrawal in the USA has decreased by 10% since 1980 (largely associated with declines in industrial and irrigation uses as domestic use increases) and is projected to increase by only 7% by 2040. Rather than focusing water supply planning on relatively stable total quantities, the USA needs management practices that recognize that demands for water vary greatly in timing, location, and quality. Water managers need information that they can use to determine agricultural, residential, commercial, and public uses by category. They need the information in a form they can apply in demand management policies that expedite water recycling among uses, support food production by environmentally benign methods, promote biotechnology to improve crop water use efficiency, and meet the water needs of aquatic ecosystems.

3. Water Institutions. Research will also be needed to evaluate past policies and to craft institutions that can do better at integrating water availability and use information so as to manage water from multiple sources in a way that promotes economic use and protects water quality.

4. Research Organization. Research management should give greater attention to studies that probe fundamental issues with long-term payoffs.

Peterson takes a similar viewpoint as he describes the current central issue in water resources planning as finding a balance between human life-style aspirations and protection of ecological life-support systems. The primary challenge is in defining and resolving tradeoffs between economic and ecologic contributions.

One of the fundamental differences that must be overcome is that economic analysis works from marginal changes to average conditions and environmental assessments make their case by focusing on avoiding extreme events (Lomberg). Peterson points out that the political system may well be more responsive to the latter approach as it only makes major changes during crises.

In a similar vein, Linsky observed that environmental, social, and technical complexities are generating fears that make society more confrontational and litigious.

Decisionmakers are driven away from science. Scientists are driven to be politically correct and author pseudo research and compromise integrity to win court cases. They learn that research support comes more easily after making dire predictions. This trend drives a further wedge between research and science. Water managers, understandably cautious when they are responsible for providing water, see little solid evidence that the dire predictions will come true and are not receptive to publicity that worries the public.

One of the principal causes for exaggeration of dire predictions is the number of people, scientists included, who review situations from narrow perspectives. System management must look to complexities outside the individual disciplines and communicate limits to findings. Education is needed that provides perspectives needed to balance social, economic, and environmental considerations in viewing water and land resources and the nature of risks.

Lall may well have put his finger on the fundamental problem when he applied Maslow's hierarchy of needs in trying to understand where people are coming from on water issues. In Maslow's hierarchy, water supply would be a basic physiological need and protection from floods and pollution would be close behind as basic needs for safety. Once such pressing needs are satisfied, discussion can move to less basic levels. Water issues are extremely hard to resolve because people enter discussions at quite different levels and compromise when negotiating at different levels is all but impossible.

Three papers approached these issues through case studies. Let's consider them one by one.

1. Fontaine et al. described agency use of peer review on science issues in Florida's implementation of the Everglades Forever Act of 1994. Presentations made at public meetings indicated strong differences over the factors generating an imbalance between flora and fauna. The review process gained the focus needed to separate the effects of phosphorus from those from other factors, identified periphyton as an indicator of phosphorous enrichment, and concluded that phosphorus was the major source of the problem. Managers were then able to move on to construct stormwater treatment areas that reversed phosphorus enrichment. Scientists first complained about the burden of artificial deadlines but were later pleased by the fundamental contributions. The process addressed the important underlying issue that the public does not understand the uncertain nature of science by opening a forum where scientists and the public worked together to reduce uncertainties.

2. Peterson et al. described an approach by the Bureau of Reclamation(USBR) through which scientists and the public worked together to reduce uncertainties about the impacts of water projects on natural systems. USBR uses the approach because in moving from harnessing additional water and power resources to determining the effects of the development, the agency entered an arena with much greater uncertainty and subject to the biases identified by Linsky. The approach is to use adaptive management or experimental implementation in which the impacts of environmental practices are observed holistically across political and disciplinary boundaries, among species and projects, and over time periods covering biological generations. This paper describes involvement of 26 stakeholders below Glen Canyon Dam in assessing the environmental consequences of altered release patterns.

3. Wilson explored the planning process for the Central Arizona Project (CAP) with an emphasis on forecasting agricultural water use as water demands by urban users increase and Native Americans gain water rights. The CAP planning assumed that farmers would increase their incomes by planting large areas to high-value crops and use some of the money to purchase CAP water for irrigation. However, the amounts charged by CAP far exceeded farmer costs for pumping groundwater, and farmers ignored arguments that they should purchase CAP water for its environmental and long-term benefits. Because of smaller water sales, Arizona protected its Colorado River allotment by starting a major recharge program to store water underground. The experience shows that decisions based on political preferences will only work well when supported by market forces. However, crafting the needed institutional changes requires building trusted information bridges among public agencies, water-using firms, and scientists; and academic researchers are not used to working in this arena. The experience offers valuable lessons to use in researcher-agency and researcher-public integrations.

Campbell's paper reminds us that part of the difficulty that we are having in bridging stems from past inability to measure some parameters important to the public. He emphasizes that a successful water conservation program requires that the right information reach users in a timely manner. Information technology, obtained by wireless communication and delivered by Internet, can serve water users, regulators, makers of water-use allocations, and setters of laws and policies by providing greater accuracy, reliability, and timeliness.

Schilling notes that water resources management is shifting toward re-engineering, as is seen in all three of the above case studies, to reduce tensions between water

users and the environmental community. The challenge to water system managers is to accomplish the politically mandated changes while continuing to protect people from floods and provide adequate water on a sustained basis indefinitely into the future. With this change, the planning tools that agencies used for resource development are outmoded and particularly deficient for water-quality regulation. The development of new tools is hindered because different disciplines address common problems with different approaches. The challenge ahead is to make the information produced by different studies comparable and applicable to coordinated implementation of multiple agency programs. This will take community consensus at a time when "big" environmental fears often stem from weak evidence.

However, meeting this challenge will require coordination between innovative scientists and daring administrators. Johnson faced these issues when he focused on the upcoming change in planning personnel at the Corps and the opportunity for educating the next generation of planners. Through public meetings, the Corps identified three principal needed educational themes as: 1)integration of quantity and quality concerns in management at the watershed scale for multiple purposes, 2)sustainability of environmental quality and ecosystem functions, and 3)consensus-building to overcome gridlock. In consensus building, we need to focus on problem solving rather than selling dams or zoning laws. The problems must be faced from a broad perspective by planners who have technical knowledge, understand conflict resolution and group dynamics, and are grounded in the history and philosophy of water resources development.

Issues Remaining - Challenge Ahead

These ten papers offer a great deal of valuable guidance on where to go from here. They strongly reinforce the need for more effective strategy to integrate multiple studies to make holistic interpretations, present findings to users, voters, and youth; and receive feedbacks, and revise policies. Specific needs can be reviewed by following the outline used in an earlier section.

1. **Research Integration** - The authors strongly advocated multi-disciplinary research, but this need has been recognized for years. To make progress, we need to identify problems caused by differences among disciplines and ways to overcome them including better bridging among researchers. People who study "water" from different perspectives need to start working from a common space-time grid and with interconnected models. All disciplines must be more cautious in broadcasting research results before checking their validity from the perspectives of other disciplines.

2. **Research Administration** - Support for the shift in water resources management from structural measures to multiple nonstructural programs, largely by states and local governments, will require a strong supporting research program that existing Federal agencies are not well situated to undertake. Vaux was the most specific with an idea to coordinate research administration in the Federal government by establishing a Water Research Board and increase funding on issues of broad public interest.

3. **Researcher-Agency Integration** - The premise behind organizing this effort was that researchers and agencies are not working together as effectively as they should to promote water resources management. Peterson noted that institutional change comes through windows of opportunity created by episodic events, and these have ranged in this century from major disasters to the rise of the environmental movement. Johnson observed that the exhaustion of reservoir sites has coupled with environmental concerns to cause Federal water management agencies to change their missions even as they must also change personnel because of retirements. Similar changes are occurring in the universities. Both sides need to become proactive for greater two-way integration between researchers and agency professionals. Campbell presents technological development that agencies must deploy to routinely gather information to support both operations and research, and the resulting changes in the needed data base can facilitate needed change.

4. **Researcher-Public Integration** - The philosophical basis for making government responsible for water resources management was the need to focus on broad public needs instead of personal or monopoly interests. Our present institutions were formed to protect the public interest in the context of project construction, but now water resources management is moving to depend more on operations and to start from programs biased to favor vested interests. Wilson describes difficulties that the CAP has in changing a system to serve different users.

For this change, water research can produce a great deal of valuable information for meeting societal needs on dealing with water management decision making as water and land uses are made more and more by individuals and companies and the impacts of those decisions are found to be more and more complex. However, we walk a fine line in developing educational materials that convey a more holistic and better integrated understanding of the water cycle without

building a bias in future generations. Schilling notes that the way people think depends on their education, and education in a democratic society must be constrained in teaching values. In this regard, there is an important distinction between using science to assess how alternatives will perform in terms of their physical, chemical, ecological, and social impacts and arguing for a value system for rating these impacts.

5. **Implementation** - History tells us that water resources managers will continuously face new problems (toxic materials, climate change, environmental preferences, etc.) that must generally be defined through research. It is these new problems that open doors of opportunity for new management practices by employing new technology in positioning space-time grids, measuring new parameters, bringing new relationships into models, etc. The key to successful implementation is learning to use these opportunities well.

A CONSORTIUM OF UNIVERSITIES

Lall also introduced the effort to build more effective research infrastructure by the Consortium of Universities for the Advancement of Hydrologic Science (CUASHI). While many people in academia have advocated much more support for water resources research, the community has not fully faced the issue of how to use a substantial increase in funding effectively. Important issues here include the number of capable researchers that could be mustered, and the delays to be expected in buildup to full productivity.

The primary goal of the desired infrastructure would be to draw together work in many disciplines at different scales to focus on holistic puzzles. Identified infrastructure components would be natural laboratories that measure "watersheds" holistically and over time, advances in measurement technology and deployment that can capture information that has been missed in the past and thus constrained the ability of science to make new discoveries, and management systems that can make large amounts of reliable distributed data available to dispersed users in near real time. The National Science Foundation is encouraging CUASHI to develop these ideas and is willing to support a good proposal.

CONCLUSIONS

The introduction above noted needs for more effective integration of findings from diverse disciplinary studies and for more effective interaction among researchers, management agencies and the public at large. Each paper brought out an important aspect of what will be needed to meet these needs. Wilson saw a need to build bridges, and Schilling saw how to build them by making information more consistent and comparable. Vaux advocated establishing a national board to coordinate water resources research, and Lall presented a consortium of universities to establish an infrastructure that could respond to increases in funding more effectively. Johnson saw the need and opportunity to train a new generation of agency personnel, and Linsky advocated a program in public education on basic concepts in the impacts of land and water use and the nature of risks. Fontaine and Peterson presented two current techniques for bringing scientists more intimately into project management. These needs could be brought together by organizing data on a common space-time grid and interconnecting processes in the sort of "white" box model suggested by Schilling.

At this point, all of these suggestions need development. Three important issues are how to make people from the various disciplines effective working partners in water resources management, how to use the Internet for intellectual discourse without becoming lost in the vastness of the data, and how to manage research while stimulating innovative thinking. Many of our readers are likely to have additional valuable ideas; we would like to hear from you.