CHALLENGES TO WATER RESEARCH

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PREFACE

Forty years have passed since I earned a Masters Degree in Civil Engineering from Stanford and entered the world of water resources planning and management. I have since worked in state and Federal agencies with design and science responsibilities. I experienced problem policies, initiated research on better methods, and wrote a book collecting my ideas. I taught hydrology and water resources planning and management at universities in the East, South, Midwest, and Pacific Coast. I have interacted with many colleagues on many issues in defining and scoping academic water programs to meet social needs and in securing funding for priority projects. While the water research community has not gained all we wanted, we have accomplished much, and greater opportunities are ahead.

PERSPECTIVE

The UCOWR Board is to be congratulated for devoting this issue of *Water Resources Update* to the current status and productive directions for water resources research. I am responding in the NSF tradition by setting forth challenges and asking the academic community to respond with proposals that will gain solutions.

We can start with the premise that water resources should be managed to achieve societal goals. The corollary is that the health of water research depends on making and becoming recognized for making water resources management work better in delivering water in desired amounts by time and place. The desires come from individuals. When people are not able to meet their needs, governments respond by establishing agencies, and agencies respond by constructing and operating projects and with regulations. However, agencies encounter problems in getting their projects to perform (overcoming unanticipated adverse impacts) and in obtaining desirable compliance with the regulations. and citizens often lack the motivation, expertise, and resources for best management of project outputs. The resulting problems set water research agenda; then the knowledge acquired becomes the content of water education. A given institutional framework for this process can, for a time, deliver incremental improvements that enable a system to meet critical human needs, but periodically difficulties become too widespread for the public to accept, and political forces institute major changes.

The under current behind this issue of *Update* responds is a sense that the cross currents shaping water policy have brought us to such a time. If so, the academic community faces many knotty issues. Personally, I want to thank the UCOWR Board for generating this discussion on where we are and what we should be doing.

SEQUENCES OF EPISODIC CRISES

A few generations ago, water supply and drainage were largely an individual responsibility in rural areas and a municipal responsibility in towns. This system grew to its present state in steps. A prior system worked well until it encountered a crisis; each episode created an agency, promulgated new policies, and stimulated new academic programs. As examples, the Mississippi River flood of 1927 climaxed earlier experiences on major rivers (the Sacramento in California and the Miami in Ohio), and the Government responded with a structural program for flood control assigned to the Corps of Engineers. The inability of localities to deliver water at the scale needed to make desert lands productive for agriculture led to the irrigation program of the Bureau of Reclamation. The wide-spread loss of farm land to erosion climaxed with the Dust Bowl, and Congress established the Soil Conservation Service. Threats of water pollution led to the Environmental Protection Agency.

Once a program is created, it attracts many requests. The desired resources far exceed available budgets. People are left out. The projects that are constructed cause some harms. Agencies fall short of expectations by being neither fully able to provide expected results nor to avoid negative consequences. Research can work to correct ordinary problems, but a point can be reached where the political system must intervene.

Companion papers in this issue articulate two reactions to this sequence of events. Firth expresses doubts from the demand side and Moreau from the supply side. The demand worry is that the enormity of human expectations will overwhelm fresh water supplies essential to life on earth. Our institutions will become unable to mold water uses, direct and indirect, to achieve human justice within environmental constraints. The supply worry is that agencies and incremental responsibilities have been added to the point that our massive management system is breaking down. Coordinating mechanisms are failing to achieve holistic needs. The political response to program difficulties is to reduce budgets. The union of these two trends threatens to take water resources management into an episodic crisis of greater proportions.

However, political intervention succeeds best when coupled with technological advance. As society faces new crises, technology offers new opportunities. Past accomplishments of the Corps and the Bureau were made possible by advances in dam technology. Agricultural research gave the SCS tools to promulgate better farming practices. Advances in waste treatment technology undergirded EPA accomplishments.

FUNDAMENTAL PROBLEMS

Water resources management faces monumental difficulties, and the danger that conditions will grow worse is very real. Academia needs to understand the current crisis to become innovative in producing new technologies and in advocating arrangements to overcome. Some fundamental causes for the current problem are:

1. Management systems cope poorly with dynamic situations and natural heterogeneity. Even in the steady state, the equity gained in treating everyone the same produces inequities over the variety of conditions in our vast country. But conditions change. Agency missions and rules are set to meet conditions when they were inaugurated. A change cannot be made without hurting someone. Such people resist, and each successful resistance increases their potential losses over time.

2. Science has not been able to integrate and upscale.

    a. As to integration, in an earlier issue of *Update*, I discussed how water expertise in the academia is deeply divided among communities working in water planning (seen in the 1970s by the National Water Commission), in water sciences (seen in *Opportunities for Hydrologic Science*), or in ecological sciences (seen in *The Freshwater Imperative*). One notes that the first statement came from a political mandate, the second from the National Academy of Sciences, and the third from concerned scientists. Academia is drawn apart to the point that each tradition fails to identify with statements by others. The public is poorly served by a divided science; we must find ways to come together.

    b. As to upscaling, applications of principles of microeconomics to quantify local benefits may not lead to sums that express national interests. Inventories of minutia compiled in environmental impact assessments tell us little about consequences at the ecosystem scale. Laboratory studies in fluid mechanics may not serve watershed hydrology well in linking climate and river models. We are not even close to extracting valid watershed meanings for many areas of laboratory work.

3. Education, research, and professions are compartmentalized. Upon entering college, people join disciplines and acquire a loyalty and lingering bias to their group values. Once, a professional was expected to have a broad "liberal" background in a pre-professional degree, but our current degree of specialization recognizes people as "highly educated" even though they never gain the background essential to thinking at the interdisciplinary level. The problem is not solved by forming multidisciplinary groups. People must gain a common basis for talking; and, even when they do, committees have difficulty in thinking creatively.

4. The political process is also compartmentalized. Separate groups pursue different and often conflicting agenda. Each wants its way and does not understand the consequences to others. At best, the political process is a contentious arena for conflict resolution, and the task becomes impossible when people do not speak a common language.

Our communities can add issues and refine statements and become better positioned to move ahead.

PERFORMANCE AND VALUES

With the issues defined, the academic community next needs to consider the users of the research and education

so that different products can be designed to serve different audiences. As an initial division, academia delivers one type of product to professionals and another type to the public. The first type is to help professionals design systems that work well, and the second type is to help the public makes better choices on options. To reduce the complex concepts to single words, I will call the first "performance" and the second "values."

Let's consider this distinction more closely. Both cases have important economic, environmental, and social components. In the economic arena, the professional forecasts cash expenditures and receipts over time and organizes this information for financial planning for the nation and by diverse groups. The public evaluates national and personal economic value. In the environmental arena, professionals are trained to assess how well introduced and impacted native flora and fauna will flourish and to integrate this information so that the public can decide whether the large scale and long term environmental impacts are acceptable. The trained social professionals forecast how well people will utilize and maintain new facilities and resources given their diversity and dynamics for evaluation by the public. The point here is that academia needs separate programs to best serve both professionals and the public at large.

On the first role, science can contribute much to better forecasting and aggregation, and the funding establishment looks to the academia for good ideas. Politicians are sensitive to enthusiasm by experts. It would be a mistake for researchers to wait for bureaucrats in agencies to write announcements of research opportunity; they need to be presenting innovative ideas to administrators crying for good ideas. Politicians and administrators want to reach the stars and are savvy enough to know that they will not concoct the really good ideas themselves.

As to "value" issues, policy makers are urgently looking for a framework that society can use. Traditional management has asked experts to collect facts and bureaucrats to reach objective equitable decisions. However, water resources management is now moving from large structural projects (government designed and operated) to nonstructural programs (individuals making personal decisions on uses of water, floodplain land, electric power, outdoor recreation, and waste disposal practices within rules set by regulatory agencies). To make this work well, people need better information, and regulatory agencies need better ways to aggregate that information at larger scales and indicators that they can use to monitor for threats to the public interest.

The heritage of water management has been for academia to educate professionals, but we are entering a new era where uncertainty over the rules is at the heart of the perceived crisis. People are no longer willing to trust experts in shaping the "water environment," and academia must devise a new broader general education that covers issues and technology in water, wastes, and the environment to reach all citizens. Science has brought us into an information age. Monitoring, computing, and communications have produced vast new ability to make measurements and to disseminate facts. Information theory offers many new ways to organize and aggregate data to match the concerns of specific interest groups.

Now, academics in water resources need to enter this modern age. Water resources research is needed to make better applications of these tools. Water education is needed to support people when managing their water and energy, using flood prone land, and disposing of wastes.

The urgency of water issues is too great to proceed helter-skelter. We need an organizing philosophy. I find one in the position that Adam Smith took 225 years ago in presenting the market as the institution for coordinating buying and selling to make national economies grow. One condition was "perfect" information. In our present need to coordinate water and related land uses to achieve goals that are more broadly defined, the need for better information is, if anything, even more critical. People and societies who are better informed make better decisions. The goal of becoming able to provide better information to political leaders, agency officials, and citizens making water and land use decisions is both a great challenge and a specific target to use in the collection, accumulation, interpretation, and dissemination of data. It provides a focus for the education of both future professionals and educated people in the public at large.

SUSTAINABILITY

Using the buzzword of our day, a system for water resources management must be sustainable to succeed. It is a major challenge to preserve options in a dynamic world where changes are caused by anthropogenic activities, environmental evolution, and geologic processes. A management system that encounters periodic severe crises is less sustainable.

Perhaps, the greatest difficulty is in protecting future options as social preferences change. For example, it was popular from the 1930s to the 1960s to use a social discount rate lower than the market rate so that governmental agencies could build more and larger

projects so that the public would not forever by deprived of the option of having critical infrastructure that would surely be needed eventually. Now, the public preference has swung toward an environmental discount rate higher than the market rate to prevent large-scale construction from harming environmental values. I believe that planners need a protocol to apply different discount rates to flows of different kinds of economic, environmental, and social resources. This is but one example of the need to reconcile differences in what people want in a diverse and dynamic world, an issue at the heart of "value" research.

CHALLENGES TO SCIENCE

Water resources management has evolved through incremental refinements to its current point by using information on precipitation, stream flows, water demands, etc. largely based on a measurement technology that is more than 100 years old. Projects are strongly biased toward structural approaches, once-through water use, and water rights fixed through time. Now, scientific advances offer technologies that can be used to add much more information and provide much greater detail. We can plan nonstructural programs, repeated water reuse, and dynamic water rights. We can organize a system that responds to changing societal needs.

Let us consider the implications. At the planetary scale, people have summarized water supplies by stating the volume of the world's supply without noting that most water is inaccessible to would-be users because it is stored in polar ice, large lakes, or deep aquifers. At, the river basin scale as well, there is still great variability in access to water, and these can vary greatly in quality. Some users require a high quality water, and others are quite flexible. A contaminant that renders a given water source unsuitable for some users is not important to others who may have a different sensitivity. Modern technology permits water managers to classify water sources by locations, time periods, and chemical quality so that users can find suitable supplies and regulators can allocate the total supply in the larger public interest.

Analytic tools have changed as well. Stochastic methods, fractal mathematics, and dynamical systems offer valuable ideas to use to gain better understanding of how heterogeneous natural systems operate over the short and long run. Widespread access to computer technology enables effective graphic display of evolving risks. For example, computer simulations can be delivered by internet to portray movement of flood waves through communities with a detail that would let people see their houses on the screen.

CHALLENGES TO INSTITUTIONS

Additions to the infrastructure used for water resources management is shifting from building large facilities operated by prescribed rule curves to adjusting operations to become more flexible in meeting needs that vary by time and location. The trend from the structural to the nonstructural moves much of the cost burden from the public to the private sector. The public cost is shifting from facilities to regulation. Water management institutions need to keep pace with the infrastructure they manage.

CHALLENGES TO ACADEMIA

As the planning of facilities and operations shifts from serving a steady state to planning for continuing change where states are upgraded from one level to the next over many life cycles and as governments shift from being a builder to a facilitator and a regulator, academia must shift as well. We no longer only serve an elite of working professionals with highly technical information to use to protect the public interest. We must also serve the public at large with information that people with a general education can use personally. The implications for research and education are legion.

RECOMMENDATIONS FOR RESEARCH AND EDUCATION

The reality for water resources management is that the world has a fixed quantity of water to use to satisfy a widening diversity and deepening intensity of human and environmental needs. The academic community is the source of new science and of new technology to better organize and disseminate information. It is also the source of courses and literature that can inform people and make them comfortable with information resources. If we are to pursue research that can make a difference, we need to:

1. Be more daring. Incremental refinements to existing models will not achieve breakthroughs in better understanding of how, when, and where water flows, transports sediments and chemicals, accumulates and evolves chemically in aquifers, and is used or altered by biological processes. We need to think more creatively to gain deeper understanding of heterogeneity and diversity.

2. Think watersheds. Intense study at the small scale is not leading to reliable working policy for addressing watershed processes critical to water management.

3. Link disciplines. Increasing specialization detracts

from integrating ideas into sustainable programs.

4. Be sensitive to local conditions. We need to become able to tell anyone and everyone the situation where they are.

Educational programs need to support both water professionals and water users.

1. University programs are needed to train professionals who can integrate understanding from all three traditions noted above to support diverse public interests in gaining their goals.

2. K-12 programs and general-education college courses are needed to raise society to a higher level of understanding the consequences of land and water uses and waste disposal practices. The curricula need to provide basic understandings from the diversity of relevant academic traditions and making people comfortable with means for accessing the information that they want on science, policy, and local conditions.

SUMMARY and CONCLUSIONS

We have seen that water policy evolves incrementally over long periods and it subject to sudden change during political responses to crises. Presently, difficulty in reconciling human needs for land and water within the limits to what nature provides are on the verge of creating a water crisis. People want a way out.

Academia can respond with a science that brings a diversity of traditions together into better understanding of natural processes at the watershed scale and with ways to use the tools of the information age to support people making value judgments. We need institutions that can deliver information, provide oversight, and resolve conflicts. The information needs to be relevant to individuals, reliable, and local. The oversight needs to be relevant to the public interest and reliable at a larger scale. The conflict resolution needs to be equitable over the diversity of concerned people and interest groups, present and future. By leading the escape from incremental thinking, academia can make an important contribution to seeing society through its current dilemma.