THE WATER RESOURCES RESEARCH AGENDA: A VISION

Henry Vaux, Jr.

Former Chair, Water Science and Technology Board
University of California

INTRODUCTION

With the advent of the 21st Century, several groups have thought anew about the challenges of water resource management in the coming decades and about the role of science in addressing those challenges. Recently, the U.S. Army Corps of Engineers attempted to define and clarify the major water resource issues facing the country through a series of listening sessions (U.S. Army Corps of Engineers, undated). These sessions explored the role of science as a basis for the making of policy to maintain and enhance water quality (Hirsch, et al., 2001). A third report, prepared by the Water Science and Technology Board of the National Research Council, sets forth the comprehensive water resources research agenda to assist the nation in addressing the increasingly difficult water management problems that will confront the nation in the first decades of the 21st Century (National Research Council, 2001). This latter report, which is entitled *Envisioning the Agenda for Water Resources Research in the 21st Century,* is the subject of this article.

The water resources research agenda is the result of a series of discussions that the Water Science and Technology Board held over the last several years about the future of the nation's water resources and the research needed to support efforts to manage those resources in a sustainable fashion. This report was prepared by the Board itself rather than by a committee commissioned by the Board. It is unique because of the broad multidisciplinary perspective that the Board brought to this task. Environmental and civil engineering, hydrology, plant science, soil science, aquatic ecology limnology, public health, law and economics are among the disciplines represented on the Board.

The objectives of this report are four-fold:
(1) to draw attention to the urgency and complexity of water resource issues facing the United States in the 21st Century;
(2) to inform decision makers, researchers, and the public broadly about these issues and challenges;
(3) to identify needed knowledge and corresponding water resources research that should be emphasized immediately and over the long term; and
(4) to describe ways in which the setting of the water research agenda, the conduct of water research, and investments devoted to such research should be improved in the next decade or so.

While the term "crisis" does not appear in the body of the report, the Water Science and Technology Board believes that the U.S. will face significant challenges in the 21st Century in providing sufficient quantities of high quality water to its growing population. The concerns extend not just to the adequacy of existing supplies, but to the problems of sustainability and restoration of aquatic ecosystems, the viability of our current water resources research programs and the adequacy of our institutional and physical infrastructures. The Board identifies a number of trends to support the proposition that even as the effective management of water resources becomes more critically important, it will also become increasingly difficult.

Census Bureau projections suggest that the population of the U.S. may reach 390 million by the year 2050 (U.S. Census, 1999). Most of this growth is expected to settle in urban areas, thereby increasing sharply the demands for high quality domestic and industrial water. At the same time, the pressures to preserve and enhance aquatic ecosystems will continue to grow as the importance of ecosystem services, environmental stability and environmental amenities becomes more broadly recognized. In addition, there is some prospect that the Americas may be called upon to help feed a growing world population. Should this materialize there will be strong and growing demands for water to support agricultural production. All of these increases in demand will occur against a background in which existing and potential threats to water quality will require careful attention.

Simultaneously, the institutional arrangements that are in place for managing water resources are not well adapted to meet the challenges of the 21st Century. Nor is the water resource research enterprise, which is fragmented and focuses too frequently on short term and

operational problems to the exclusion of proactive and more far- reaching research.

The report is organized in four broad categories:

(1) Water Availability - water resources are discussed in terms of availability in order to accentuate the fact that water quality and water quantity are inextricably related. Discussion of water supplies too often masks this fact.
(2) Water Use - focuses on the gaps in knowledge of the determinants of water use and the possibilities for manipulating those determinants.
(3) Water Institutions - as noted earlier, many of our water institutions are outdated. Investment in research on institutional topics has been paltry compared with investment in other water research areas.
(4) Organizing for Research - the Board makes several suggestions for change in the way water resources research is organized and funded.

In the remainder of this article, the findings and recommendations in each of these categories are described.

WATER AVAILABILITY

The Need for Adequate Hydrologic Data

Existing programs for gathering and disseminating hydrologic data are not in good shape. Indeed, the last decade or so of the 20th Century witnessed a significant disinvestment in stream gauging and other hydrologic measurement activities. The Board urges that the research agenda of the 21st Century give priority attention to identifying the country's hydrologic measurement needs and to the development of a program that will glean and make available hydrologic data in an efficient manner. The Board also urges that emphasis be given to the development and distribution of data in near real time. This will facilitate improvements in the forecasting of weather, surface water discharges and water resource management operations. There is, in addition, a need to develop technically improved methods of measuring both surface and underground water flows as well as water quality. Here attention should be given to remote sensing as well as *in situ* techniques.

Development of Supply Enhancing Technologies

The search for additional quantities of new supplies can be enhanced by developing new technology and by reducing the costs of some existing technologies. Several categories of technology appear to hold considerable promise. Existing wastewater treatment technologies already make the costs of recycled water competitive in many of the arid and semi-arid regions of the country. Further reductions in the capital and operating costs of such technologies will make additional quantities of water available for reuse and will allow municipalities to meet prevailing water quality standards more inexpensively. However, a better understanding of public perceptions about the use of recycled water will be needed if wastewater recycling is to garner the public support necessary to allow it to occur on a significant scale.

The Board concluded that further development of desalting technology is likely to be justified under certain circumstances. Desalting technologies are already cost competitive for brackish source waters. Further development of membrane technologies and pretreatment regimes can probably make seawater desalting more affordable in regions with access to cheap energy. The problems associated with the disposal of brine from desalting facilities will also require additional research.

In regions where more storage is required, ground water storage may be promising because it avoids the problems of cost and environmental damage that are associated with surface water storage facilities. Aquifer storage systems will need to be developed with caution because water residence times in aquifers tend to be longer than in surface water storage systems. It will be important to identify possible environmental impacts and devise management schemes to avoid adverse environmental impacts. In addition, much practical research remains to be done on ground water recharge and storage. For example, we do have comprehensive knowledge to determine when recharge should be done by percolation or by direct injection.

Fundamental and Applied Studies of Water Quality

Threats to water quality will probably continue to intensify in the 21st Century as population grows and new technologies and chemicals are devised. The broad topics that require additional research within the water quality domain are already well known. What will be needed is a renewed and expanded commitment to pursue that research. Fate and transport studies will need to be continued and must embrace physical, chemical and microbial contaminants. Additional basic research will be needed to help develop better risk assessment and risk management strategies in the area of water quality. These include methods for prioritizing risks and assessing multiple sources of risk on a relative basis.

Greater attention will need to be given to the implications of the aging of the nation's water

infrastructure for water quality. The management of disinfection and disinfection byproducts will undoubtedly change and research will be needed to support this change by strengthening our understanding of microbial ecology as well as of the physical and chemical characteristics of distribution systems. The management of non-point source pollutants will be a continuing challenge. Efforts will be needed to improve practices used to identify and quantify non-point source pollutants; to develop models that can predict pollutant loadings from non-point sources; to identify and improve best management practices and to improve monitoring methods and control technologies.

Finally, more knowledge will be needed about the capacity of the environment to absorb and process contaminants. Research will be needed to identify the kinds of environments that are particularly susceptible to pollution as well as the resiliency of different environments to pollution episodes. Such studies should include efforts to characterize the susceptibility of organisms and ecosystems to acute and chronic contaminant exposure, recovery times of ecosystems following contaminant exposure, assessment of the effects of long term exposure to pollutants, and calculation of the of the residence times of different pollutants in different media.

Improving Hydrologic Forecasting and Prediction

Priority should be given to research that will enhance the capacity to forecast precipitation, evapotranspiration and streamflows across a range of time scales (days to seasons) and on a regional basis. The increase in the occurrence of extreme weather events such as droughts and floods is not well understood. Development of a comprehensive understanding of the causes of extreme weather events should result in improved forecasts of extreme weather and help in the devising of new and innovative policies for managing floods and droughts. Finally, much work will be needed to develop and deepen the scientific understanding of global climate change and its hydrologic impacts.

WATER USE

Understanding the Determinants of Consumptive Use

There is a need to characterize with some precision the factors that affect the demand for consumptive uses of water. Virtually nothing is known about the determinants of demand for commercial and public uses. The determinants of domestic use are generally known but it has been more than 30 years since the last comprehensive study of domestic use. A comprehensive study of domestic use would be helpful to water managers in thousands of communities across the nation. Industrial use appears to be highly responsive to pollution regulations but the precise nature of that response has not been characterized. The determinants of agricultural uses are incompletely known. The roles of temperature, humidity, crop type and uniformity of application are well understood for some crops in some regions but it is not possible to say that the determinants of agricultural water use are well understood for all or even most circumstances. A detailed understanding of the determinants of consumptive uses will permit those uses to be modeled. The models and the information used in the models will provide an essential base for the formulation of demand management policies.

The Importance and Scale of Agricultural Use

It will be particularly important to develop a comprehensive understanding of agricultural water use since that use accounts for 84 percent of consumptive use nationally and more than two-thirds of the withdrawals. Although agricultural water use is likely to shrink as a proportion of total consumptive use in the coming decades, it will remain the dominant consumptive use. New knowledge will be needed if irrigation is to be sustained and conducted in more environmentally benign ways. New techniques for managing salt balances, for minimizing the presence of agricultural chemicals in tail water and for the prevention of erosion will need to be found.

In some regions it will not be possible to sustain irrigated agriculture and conversion to dryland farming may be required if agriculture is to persist. There is a need to develop crop varieties that are specially adapted to dryland conditions and produce higher yields than would otherwise be expected. Similarly, the potential of biotechnology for improving crop water use should be explored comprehensively. It is not clear whether biotechnology can be used to accomplish fundamental changes in crop water use characteristics. The use of genetic engineering to generate deep rooting and increase the fraction of the plant devoted to grain and fruit may result in more efficient water use, obviate the need for agricultural chemicals, and optimize economic return for irrigation water. Research will also need to be devoted to identifying and understanding potential adverse effects associated with genetically engineered crops.

Understanding Environmental Uses of Water

Over the years, the Water Science and Technology Board has noted the need to understand aquatic ecosystems in a broad systems context. This is because intensive water development has altered aquatic

ecosystems as manifested by extinct and endangered species, loss of wetland and riparian areas and loss of biological productivity. Research will be needed to help determine the water requirements of aquatic and riparian ecosystems necessary to maintain certain environmental functions. In addition, a systematic understanding of the relationships between biologic, hydrologic and geologic factors will be necessary to undergird efforts to restore aquatic habitats.

In the past, terrestrial and aquatic ecosystems have been studied independently of each other. There is pressing need to develop a systematic understanding of the relationship between these ecosystems to support efforts to manage water on a watershed basis. Research is also needed on issues directly related to the protection of species diversity in aquatic habitats. Such efforts should include assessments of potential limiting factors and the means of managing those factors in optimal ways as well as research aimed at devising strategies for managing aquatic habitats for the purpose of preserving biodiversity and maintaining ecosystem health.

WATER INSTITUTIONS

During the 20th Century, research on water institutions dwindled in comparison with the work in other categories of water research. Yet, the design and creation of innovative water institutions will be key if water and environmental management practices are to be sound. The need for new and innovative institutions becomes clear when it is recognized that many of the current water management and governance institutions were devised in the 19th Century. The Board believes that the institutional issues on the research agenda are particularly urgent and recommends that efforts be made to invest relatively more in institutional research than has been the case in the past.

Laws and Legal Topics

Many existing water laws are not well suited or adapted to the likely circumstances of the 21st Century. For example, groundwater laws sometimes fail to promote the economical use of groundwater and to protect groundwater quality. Moreover, ground water laws are frequently not well integrated with statutes governing the use of surface waters. This leads to fractionated and inefficient water management. The development of improved legal principles and model statutes governing groundwater use to facilitate conjunctive use will be needed. In addition, research attention will be needed in helping to develop sounder legal bases for the management of trans-boundary waters.

New laws are needed to facilitate the management of water in instances where it has common pool and public good characteristics, to protect instream flows and ecological values adequately, and to clarify the status of Native American water rights as well as other federal reserved water rights. In addition, research is needed to help in the development of more flexible policies and legal frameworks that will, for example, permit adaptive management principles to be incorporated into new water management strategies.

Economic Institutions

Throughout the report the Board notes that the water situation in the 21st Century will be characterized by intensifying scarcity. Economic institutions are almost by definition adapted to the management of scarcity. This means that renewed and expanded research is needed to identify economic institutions that are well adapted to the management of common pool resources and public goods. Moreover, additional research focused on the estimation and management of third party impacts of water markets is also needed.

Priority should be given to developing improved methods for estimating the value of water in circumstances where it is not marketed or where market-generated prices fail to reflect the true value of water. Additional efforts will also be needed to help in the development of more efficient market and market-like arrangements for allocating water and for identifying the advantages and disadvantages of privatizing water supply and treatment services. Finally, research is needed to provide a better understanding of the role of prices, pricing structures and the price elasticity of demand in allocating and reallocating scarce water supplies.

Emerging Social Science Issues

The Board notes that other social science disciplines such as anthropology, geography, political science, psychology and sociology have not been constantly involved in water research even though the perspectives they bring are important. The importance of perceptions, the implications of different value structures and cultural norms for the management of water resources, and the role of politics and political institutions are all examples of topics to which the social science disciplines will need to contribute. In addition, there is a need for better understandings of existing experience with stakeholder input and stakeholder processes. Such understandings will be very helpful in designing stakeholder input processes, which are both efficient and honor the preferences of stakeholders.

Finally, and perhaps most importantly, there is need for additional research of all types that will inform policy-making processes. The Board believes and states that good policy begins with good science. It will also be helpful to engage in systematic *ex post* evaluations of past water policies. We have accumulated over 100 years of experience with water policies and too often this experience has not been subjected to any formal assessment to determine what has worked well and what has not.

ORGANIZING FOR WATER RESEARCH

In the last section of its report, the Board notes that the current water establishment is not well situated to develop and execute a coordinated and strategic national research agenda. It also notes that the real value of investment in water research appears to have decline over the last two decades. In seeking to characterize an effective means for identifying, prioritizing and executing the national water research agenda we have set forth a series of principles:

(1) The agenda should be set and prioritized by a broadly representative group of stakeholders.
(2) The agenda should be systematic, strategic and balanced among basic and problem-driven research and between research focused on short and long-term needs.
(3) There should be attention to reducing duplication and filling gaps.
(4) The research effort should be multidisciplinary and interdisciplinary.
(5) The research effort should be anticipatory and proactive and there should be public accountability.

The Board acknowledges that there are a variety of ways in which water research agenda-setting and execution could be organized; this organization should be developed through the policy making process by those better qualified to judge the most effective forms of organization. The Board urges the establishment of a National Water Research Board, patterned after the National Science Board, and composed of representative stakeholders from the public and private sectors and academia. This Board should be charged with establishing national water research priorities and overseeing the execution of the research that follows.

CONCLUSIONS

This report contains some 43 recommendations that can be usefully summarized into four key themes:

(1) The challenge of solving the nation's water problems will require a renewed national commitment requiring changes in the way research agendas and priorities are established and significant infusions of new federal funding;
(2) water quality and water quantity need to be thought of in an integrated fashion and research priorities in these areas should be developed in an integrated fashion;
(3) relatively more attention must be given to water related research in the social sciences and research focused on the development of innovative institutions than has been the case in the past; and
(4) research on environmental issues related to water will need to become a major part of the research agenda.

AUTHOR

Henry J. Vaux, Jr. is a professor of resource economics at the University of California, Riverside. He currently serves as Associate Vice President for the Agricultural and Natural Resource Programs for the University of California system. He previously served as Director of the University of California Water Resource Center. His principal research interests are the economics of water use and water quality. Prior to joining the University of California, he worked at the Office of Management and Budget and served on the staff of the National Water Commission. He received a Ph.D. in economics from the University of Michigan.

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