

Water Resources Research in the 21st Century¹

Henry Vaux, Jr.

University of California, Berkeley

In 2001, the Water Science and Technology Board of the National Research Council published a report entitled: *Envisioning the Agenda for Water Resources Research in the Twenty-First Century* (NRC 2001). The report was the result of a series of discussions held by the Board about the need for a cohesive national water resources research vision for the twenty-first century. That vision included research agenda setting, the coordination of research, and appropriate levels of public investment in water resources research. The Board developed a list of 43 high priority research topics which were cast broadly in recognition of the fact that the specific focus and emphases of resulting studies ought to reflect both the circumstances and the knowledge available at the time the research is undertaken. The Board arrayed these 43 topics in three broad categories: 1) water availability; 2) water use; and 3) water institutions. The categories were structured so as to be interrelated, with the notion of water availability emphasizing the fact that water quantity and water quality jointly determine water availability, while water use includes all of the factors that affect wants and demands for water. Water institutions were treated separately to highlight the importance of research on institutions and to acknowledge that institutional questions fall within the purview of a different set of disciplines than do questions of water availability and water use. The report also examined a range of issues related to how the nation should organize for water resources research (NRC 2001).

Congressional interest in the findings of this report developed soon after its release. The fiscal year 2002 Interior Appropriations Bill was based upon a Conference Committee report which concluded, in part:

The managers concur with the House direction to contract with the National Academy of Sciences to examine water resources research funded by all Federal agencies and by significant non-Federal organizations.

The specific charge given to the National Academy of Sciences included four specific tasks:

- Refine and enhance the findings of the *Envisioning* report
- Examine current and historical patterns of investment in water resources research and generally assess its adequacy
- Address the need to better coordinate the nation's water resources research enterprise
- Identify institutional options for the improved coordination, prioritization, and implementation of research in water resources

Following the usual processes and procedures employed by the U.S. National Academies, the National Research Council appointed a thirteen-person committee of water resource scholars and experts who brought a diversity of perspectives and disciplinary orientations to the task. The Committee met five times, heard testimony from representatives of state and federal officials charged with managing the nation's water resources, surveyed the current state of water resources research, and authored a report entitled *Confronting the Nation's Water Problems: the Role of Research* (NRC 2004).² The remainder of this article is devoted to an overview and summary of that report.

Why Another Water Research Initiative?

The history of federal support of water resources research shows a fluctuating pattern of response to scientific, political, and social movements. Early research was focused on describing the nation's water resources and illuminating the chemical, physical, and biological processes that characterized them. Some research consideration was given to the comprehensive development of the nation's waterways. Water quality problems, especially those linked to public health, were also the focus of early research efforts, which tended to be driven by scientific advances that led to an improved understanding of the causes of disease. Beginning in the 1930s, funding began to become available for research on the relationships between water and agriculture, the causes and cures of soil erosion, and all manner of engineering topics related to water resources.

In the aftermath of World War II, the report of Vannevar Bush, written at the behest President Franklin Roosevelt, concluded that the country would benefit if the kind of government-sponsored research that had been critical to the war effort was brought to bear on important problems of health and welfare. Bush recommended further that federal support be provided for both basic and applied scientific research. His report is widely thought to have triggered a significant expansion in all areas of federally-supported work in the post-World War II period. Although the immediate effect on water resources research was quite modest, recommendations from a Senate Select Committee on Water Resources, the National Academy of Sciences, and the Federal Council for Science and Technology ultimately led to enhanced funding for water resources research, beginning in the early 1960s.

During this time and the decades that followed, numerous water research agendas were produced, following on the earlier efforts of the Senate Select Committee. In 1966, a subcommittee of the federal Council for Science and Technology, called the Committee on Water Resources Research (COWRR), published a ten-year agenda for federal water research. In the early 70s, the thrust of the national water strategy changed from a focus on the physical development of water supplies to a focus on environmental issues related to the

development and management of water resources. Congressional directives related to the Clean Water Act and other environmental legislation of the time led to research focused on the support of regulatory activities to maintain and enhance the environment. The National Water Commission, which had been authorized by the Congress in the late 1960s, also produced a comprehensive water research agenda. Although some of these agendas were revised and updated, perhaps the most striking feature of them was the extent to which similar topics tended to appear and reappear in different agendas over time. Several conclusions emerge from this history. First, the reappearance of topics again and again suggests that the recommended research was not and is not being done. Topics recommended in the first post-World War II agendas still appear on modern agendas because they remain relevant and have not been attended to. A second conclusion that emerges from this history is based on the extensive fragmentation of the federal water resources research enterprise. There are no less than 17 federal agencies with interests in water resources and yet there is no structure in place to coordinate and integrate the agendas of different agencies and groups. The setting of the water research enterprise is highly decentralized, *ad hoc*, and lacks coordination of any kind. Why, in the face of this somewhat dismal record, does another foray into the general area of water resources research initiatives offer more prospect of success than those of the past?

The answer to this question is in three parts. First, past federally funded research has been effective in solving water problems and in supporting water-related regulatory activities. Problem solving research includes: the development of strategies to manage salinity in irrigation (ASCE 1990; NRC 1989); the facilitation of voluntary water transfers as a means of addressing water scarcity (NRC 1992); and the development of the science on which the forecast of El Ninos and other longer term climatological phenomena is based (NOAA 2002). Research that has effectively supported regulatory activity includes: investigations leading to the understanding of the causes of eutrophication; work leading to the characterization of the risks posed by methyl mercury in the environment; and work that identified correctly the causes of nitrogen loading in Chesapeake Bay thereby "...correcting' the

scientific bases on which regulations would ultimately be based” (Sims and Coale 2002).

Second, these examples help illustrate the purpose of a federal role in supporting such research. Much water resources research has the characteristic of a public good. That is, once the research is concluded the results are freely available to many or all, irrespective of whether recipients pay. Those who produce the public good (research) are not able to capture all of the returns from that research because the research itself is not patentable or licensable. This means that investment in water research is either absent or sub-optimal if left to the private sector. As the previous examples show, the benefits of research tend to be widespread and have resulted in an increase in the aggregate productivity of water both regionally and nationally.

Third, water and water problems are becoming more critical every day. In the coming decades no natural resource may prove to be more critical to human well-being and health than water. Yet, a future water crisis is unlikely to materialize as a monolithic catastrophe that threatens the health and/or economic welfare of large numbers of people. Rather, the emerging water crisis will be the sum of many water problems at regional and local scales. Problems include the need to preserve the quality of drinking water supplies, finding sufficient water to support both economic growth and the environment, finding ways to make responsive and effective water policies with a modern context, to maintain and enhance water quality, and to create water management systems that can be adapted to climate change. It is important to recognize that these water problems in their modern context are pervasive and not confined to the semi-arid West, as the interstate conflicts over new water supplies for the metropolitan Washington, D.C. and Atlanta areas attest.

Many of the growing number of water problems illustrate how the making of good decisions about water issues will require scientific understanding. Such scientific understanding can be gleaned only by continuing to invest in water resources research in ways that optimize the effectiveness and productivity of each research dollar. The growing complexity of water problems only reinforces the need for new scientific information upon which to base new and innovative solutions. Although the number, complexity and severity of water problems

is growing, investment in scientific research needed to better understand water problems and to devise appropriate ways of managing these problems has stagnated over the last four decades. Much of the current federal and state research agenda is focused on short-term problems of an operational nature and too little research is focused on the kind of fundamental, integrated, and longer term research that will be needed to successfully address current and emerging water problems.

Much of the research needed to solve tomorrow’s water problems should be initiated today. Basic and fundamental research done today provides the foundation for the applied research that will be needed a decade hence. The type and quantity of research needed are unlikely to be adequate if no action is taken at the federal level. In past years the devolution of responsibility for water research to the states has resulted in the neglect of long-term research, the further diffusion of research efforts and, as the states have testified (NRC 2004), inadequate financial investment in water resources research. These circumstances are explained largely by the fact that states and nongovernmental organizations have both limited incentives and limited financial resources to invest in water resources research. If a truly comprehensive, well integrated, and adequately financed research effort is to be undertaken, it will have to be undertaken by the federal government. While a vibrant and robust research program by itself will not be sufficient to guarantee that all current and emerging water problems can be solved in an efficient and timely fashion, the Committee concluded that the knowledge and insight gained from a comprehensive program of water resources research offers society its best hope for success in dealing with such problems.

The Research Agenda: A Case of Evolving Priorities

The Committee reviewed various water research agendas that had been prepared around the turn of the century and concluded that the 43 topic agenda which the Water Science and Technology Board set forth in the *Envisioning the Agenda for Water Resources Research in the 21st Century* (NRC 2001) was the best current statement of research needs. The Committee acknowledged, however, that

the list should be expected to change as circumstances and knowledge evolve. Indeed, an important feature of any revitalized federal program of water resources research will be regular review and revision of the entire portfolio of water resources research.

Additionally, the Committee noted that the review and revision of research priorities should be carried out with reference to an explicit set of criteria. The Committee offered the following criteria for updating the national research agenda:

1. **Is there a federal role in the specific research area?** A federal role is appropriate in those research areas where the benefits of research are widespread and do not accrue only to those who fund the research. It will also be important to consider whether the research in question can be addressed by institutions other than the federal government.
2. **What is the expected value of the research?** How important are the research results likely to be, either in terms of direct problem solving or in advancing fundamental knowledge of water resources.
3. **To what extent is the research of national significance?** National significance is greatest when research: 1) addresses issues of large scale concern; 2) addresses issues driven by federal legislation or mandates; and 3) results in benefits that are widespread.
4. **Does the research fill a gap in knowledge?** Research that fills knowledge gaps should be accorded higher priority than research that is duplicative.
5. **How well is the research area progressing?** The adequacy of efforts in a given research area can be evaluated according to: 1) current funding levels or trends in funding levels; 2) whether the issue is part of the agenda of one or more federal agencies; and 3) whether prior investments in this type of research have produced results.
6. **How does the research area complement the overall water research portfolio?** The overall research portfolio should be balanced among fundamental and

applied research, short-term and long-term research, agency-based contract and investigator driven research, and research that addresses both national and regional problems. It should also be balanced between the water availability, water use and water institutions categories set forth in the *Envisioning* report.

The Committee also set forth four themes that should guide and be evident in the conduct of future water resources research:

1. Research will need to be *interdisciplinary* in nature. The need for expertise from different disciplines to solve water problems has been widely recognized and there have been repeated calls for collaborative, interdisciplinary approaches to research (Cullen et al. 1999; Naiman and Turner 2000; Jackson et al. 2001).
2. Water research should be guided by a *broad systems approach* which acknowledges that the linkages among various components of the system are as important as the components themselves.
3. Water resources research should acknowledge and specifically account for *uncertainty*. Uncertainty is inherent to all research but it can and should be managed by describing the degree of uncertainty in research results thereby adjusting the expectations for use of data and models (Funtowicz and Ravetz 1990; Dovers et al. 2001).
4. The complexity of water resource problems and the changing contexts in which they occur means that *adaptability* will be important in designing research. That is, models and results that can be adapted to different locales and different sets of circumstances will need to be the rule rather than the exception.

These themes and criteria should be employed in periodic reviews and revisions of the nation's water research agenda. Periodic review and revision will help to ensure that the water research agenda is up-to-date and fully responsive to modern water problems. The use of the themes and criteria will ensure that the research agenda is balanced and

appropriately formulated and that research dollars are spent as efficiently and effectively as possible. Research priorities based on the four overarching themes are more likely to promote flexible, adaptive and timely responses to unique or unexpected problems than are research programs based on priorities that are developed solely to address the missions of the federal water management agencies.

Patterns of Investment in Water Resources Research

The Committee undertook a survey of water resources research funding in an effort to understand how the levels of investment and the mix of research had varied over time. A survey research instrument was designed with reference to a similar instrument used by the Federal Coordinating Committee on Science, Engineering and Technology (FCCSET) which conducted a water resources research appraisal annually between 1965 and 1975. The original FCCSET research categories were retained and one new category, Aquatic Ecosystem Management and Protection, was added. The eleven research categories, as modified, are listed in Table 1. The survey research instrument was sent to the 17 federal agencies with responsibilities for water research, three non-government organizations with substantial (more than \$3 million annually) programs of water research, and the four largest water resources research institutes located at the nation's land grant colleges (Table 2).

Agency representatives worked with the Committee in designing and pre-testing the survey instrument to ensure that the design was optimal.

Table 1. Modified FCCSET Categories.

1	Nature of Water
2	Water Cycle
3	Water Supply Augmentation and Conservation
4	Water Quantity Management and Control
5	Water Quality Management and Protection
6	Water Resources Planning and other Institutional Issues
7	Resources Data
8	Engineering Works
9	Manpower, Grants, and Facilities
10	Scientific and Technical Information
11	Aquatic Ecosystem Management and Protection

The survey elicited information from the agencies on total research expenditures for fiscal years 1999–2001 in each of the eleven categories. In addition, each of the respondent agencies was asked to discuss current and projected research activities; to indicate how they evaluated research performance; and to describe the mix of research in terms of the balance between fundamental and applied research, the mix of internal and external research, and the balance between short-term and long-term research. The results were subjected to a careful uncertainty analysis (reported in an appendix) which demonstrated that there was a high probability that the conclusions were correct.

As shown in Figure 1, the total level of federal investment in water resources research, when, adjusted for inflation, was about the same in the 1999–2001 period as in the middle 1970s. In constant, 2000 dollars, that level of investment would be \$700 million annually. The Committee noted that while funding levels in the FY 1999–2001 period were nearly identical to those in the early and middle 1970s, actual funding had declined from the earlier period inasmuch as the new category—aquatic ecosystems management—did not appear in the earlier survey. Moreover, the data show that total annual funding did not parallel the growth in economic and demographic factors such as population, gross domestic product, or budgetary outlays. This evidence is presented in Figure 2.

Five agencies—the National Science Foundation, the U.S. Geological Survey, the U.S. Department of Agriculture, the Environmental Protection Agency and the Department of Defense—accounted for about 87% of the water resources research funding

Table 2. Participating Agencies and Organizations.

Agriculture: ARS, CSREES, ERS, FS
Commerce: NOAA
Defense: Corps, ONR, SERDP/ESTCP
Energy
Health & Human Services: ATSDR, NCI, NIEHS
Interior: USGS, USBR
EPA, NASA, NSF
AWWARF
WERF
The Nature Conservancy
State Water Resources Research Institutes: NV, PA, TX, UT

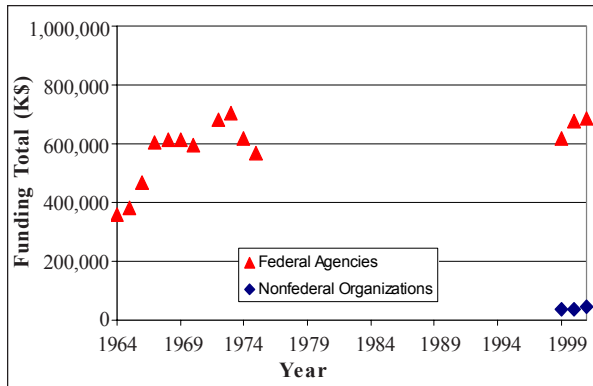


Figure 1. Total water resources research.

between 1999-2001 (Figure 3). The categorical breakdown, as shown in Figure 4, indicates that nearly three-quarters of the funds were invested in three categories: the water cycle, aquatic ecosystem management, and protection and water quality management and control. Perhaps more importantly, the categorical breakdown shows that the topical balance has changed since the 1965-1975 period in ways that make the present mix in the research portfolio inconsistent with current priorities. Specifically, the Committee found that the categories of: water demand/use, water law and other institutional topics, and water supply augmentation/conservation were significantly underfunded given current priorities.

The Committee concluded that while the total investment of \$700 million dollars might be adequate, the *ad hoc*, and independent nature of the processes now employed to establish agency research agendas and the lack of coordination means that the productivity and effectiveness of the research investment is less than it might be. It concluded, moreover, that 10% of the water research budget should be devoted to the underfunded topics in the areas of water use and water management institutions. Funding support for this research should come either from reallocation of the existing research budget or from a \$70 million augmentation. The Committee recommended further that of the \$70 million, \$50 million should be devoted to the water use category and \$20 million to the water institutions category.

Finally, the Committee noted that the lack of funding for the water use and institutions categories appeared to be at least partly the result of the fact

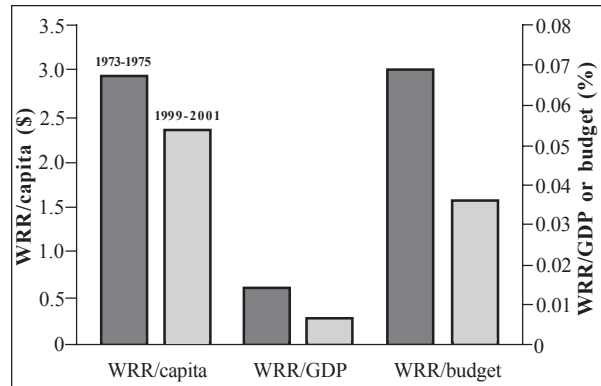


Figure 2. Comparison of funding in water resources research: mid-1970s to late 1990s.

that research in these areas did not clearly fall within the mission and domain of any of the 17 federal agencies with responsibilities for water research. Accordingly, a further recommendation urged that the \$70 million in funding for these categories be distributed through a national, peer reviewed, competitive grants program. The Committee also noted that the current research portfolio was out of balance with respect to the mix of basic and applied research and recommended that between one-third and one-half of the portfolio be devoted to basic or fundamental research.

Data Collection

Initially, the Committee construed its assignment to require a focus on research questions and issues related to the collection and management of water resources data were to be left to others. However, in the course of its deliberations, the Committee noted time and again a continuing pattern of disinvestment in water data gathering activities. More specifically, the Committee noted that key legacy monitoring of streamflow, groundwater, sediment transport, water quality and water use have been in substantial decline and in some cases nearly eliminated. The consequences of continuing the present policy of neglect associated with water resources monitoring will be very serious and will significantly constrain the nation's ability to carry out water resources research needed in the future. The Committee acknowledged that data collection does not have large political appeal but cautioned that the continued neglect of this activity would have large adverse consequences.

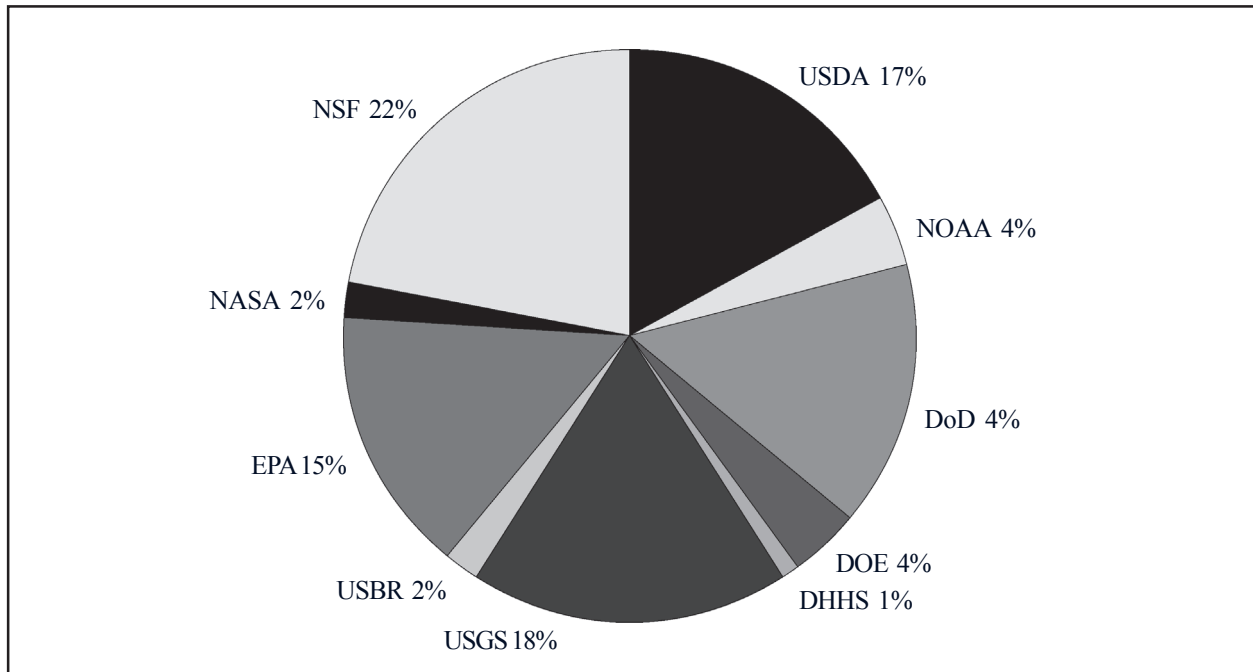


Figure 3. Agency breakdown for FY2000 funding.

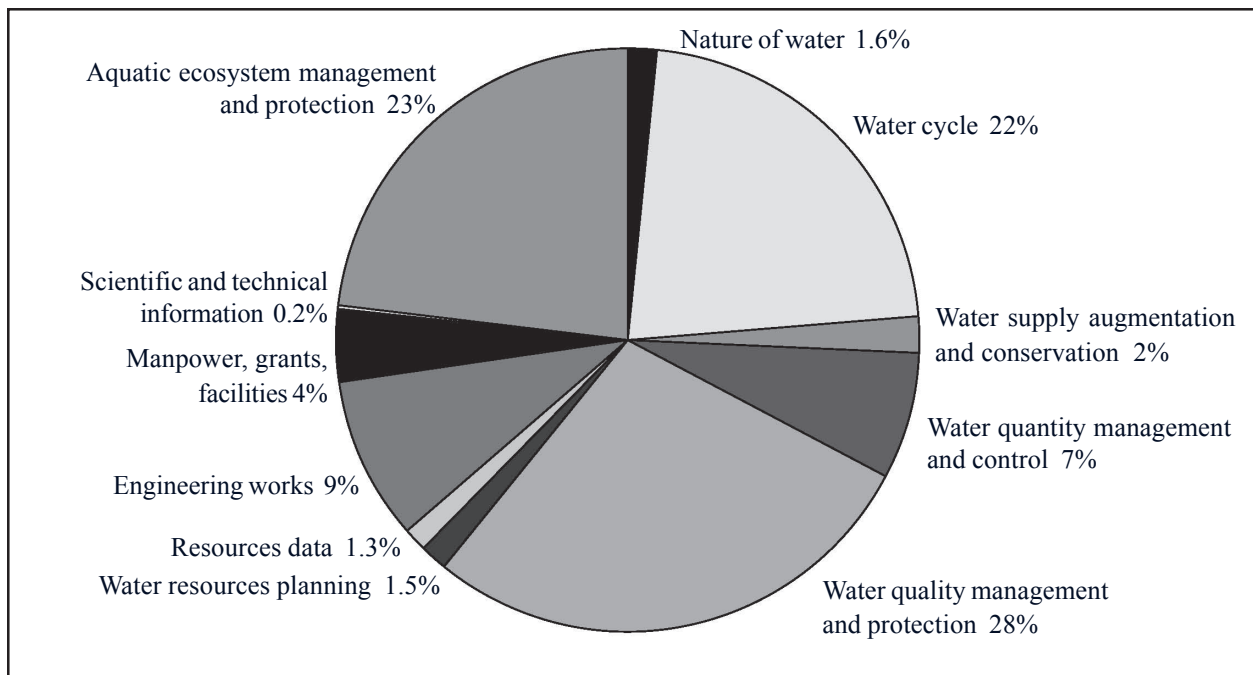


Figure 4. Category breakdown of FY2000 funding.

Organizing for a Coordinated Research Program

The many looming water crises across the United States and the current difficulties in addressing them suggest that the \$700 million spent annually on water

resources research is not sufficiently focused and is not effectively addressing national needs. The sum of individual federal water agency research priorities is not a truly comprehensive list of national water resources research needs. Water resources research across the federal enterprise has been largely

uncoordinated for at least three decades despite numerous *ad hoc* efforts to engage in interagency coordination. Given the competition for federal dollars generally and for federal research dollars specifically, the nation can no longer afford to allocate its water resources research dollars in a highly decentralized fashion in which preference is too frequently given to short-term, operational issues at the expense of the fundamental research and the more programmatically diverse portfolio needed to address both current and future water problems.

The Committee identified a substantial list of coordination actions that will be needed if the nation is to address its water problems in a cost-effective and meaningful way. There is a compelling need to conduct regular surveys of water resources research using input from federal agency representatives, much like the survey reported by the Committee. These surveys are essential if the magnitude and mix of investment in water resources research are to be understood and subject to revision as priorities and problems change. Similarly, it will be important to advise both Congress and executive offices such as the Office of Management and Budget (OMB) on the long-term national water resources research agenda every three to five years. Congress and OMB will also need advice from time to time on the adequacy of the mission driven research budgets of the federal agencies. Finally, Congress and OMB will need advice from time to time on the key priorities for a competitive grants program that will foster research on water institutions and water use as well as other types of research that is needed but does not fall within the purview of federal agency research programs. In addition, there will be a need to coordinate the entire set of research review processes and agenda-setting processes with the states, industry, and other stakeholders.

None of these coordination tasks are being done adequately, if at all. Virtually all of the current water research agenda setting activities are *ad hoc* and independent of each other. One result is that the water resources research program is less productive and effective than it might otherwise be. Another result is that the nation's water resources research program—if continued in its current mode—will almost surely fail to deliver the knowledge needed to address successfully the many new and complex water problems confronting the nation. The Committee

concluded that for these reasons a strong coordinating body is needed to guide and revise the national water research agenda and to oversee this research. The Committee concluded that to be effective and sustainable the coordinating body will need to draw upon a community of experts that is broader than those housed in the agencies themselves. Moreover, that broad community of expertise will need to be integrated into existing processes, to the extent feasible. Several options were considered for providing coordination among the multiple research and user communities and advising Congress and OMB on the key long-term priorities for the national water research agenda. Each of those options would increase the likelihood that at least some of the data collecting, information sharing, and national priority setting activities might be implemented. Three specific options were considered.

Option 1: Use Existing Arrangements. The National Science and Technology Council has empaneled a Subcommittee on Water Availability and Quality that is composed of representatives from all federal agencies with responsibilities for water resources. Currently, the Subcommittee appears to be functioning effectively in sharing information about water resource programs among the agency representatives. To date, the activities have not extended beyond information sharing. The charter of the Subcommittee calls for it to set national agendas for water resources research. Pursuit of this part of the charter is one way in which coordination could be achieved. This option would have the advantage of utilizing arrangements that are already in place, arrangements which include all of the pertinent federal agencies. Under this option the competitive grants program could be situated in the National Science Foundation.

Although there are significant advantages associated with this option, there are also significant shortcomings. The charter of the Subcommittee would have to be expanded and strengthened to provide incentives for the Subcommittee to look beyond the missions of the federal agencies. New funding would be required to allow the subcommittee to make a budget call and to support the staff needed to collect and analyze the data from the periodic surveys. In addition, it is not clear how the interests of non-federal stakeholders could be represented on the Subcommittee. Finally, the Subcommittee is little known outside of the National Science and

Technology Council and is probably not known at all in Congress.

Option 2: Independent Water Resources Research Board. A second option would be to empanel an independent National Water Research Board with broad representation from the federal agencies, states, and the entire range of non-governmental stakeholders. The composition of the Board would help to ensure that the entire range of research priorities would receive appropriate consideration, not just those of the federal agencies. The independence of the Board would allow it to articulate research needs beyond those associated with agency missions and ensure that appropriate emphasis is placed on the agendas for long-term research, in addition to those for mid- and short-term studies.

The weaknesses associated with this option stem from the independence of the Board. Agencies might ignore the findings and recommendations and could come to resent such a Board should their budgets be tapped to support it. It is also possible that OMB might prefer to work within the existing structure provided by the National Science and Technology Council. Finally, there would be guarantee that either OMB or the Congress would be inclined to take the advice of such a body.

Option 3: OMB-led Body. The third option is a melding of the first two and would entail the establishment of a formal water resources research body which would be comprised of senior level officials from federal agencies and would be led by a senior official from OMB. This OMB-led group could establish an Advisory Committee which would include a broad range of stakeholders and would provide advice to the OMB. The advantages of this model lie with the fact that the coordinating activity would be formally tied to the budget process. OMB is the only federal agency in a position to implement budget based coordination and crosscutting programmatic functions. It is legitimate to ask why OMB should perform this multiagency coordination function when there are other multiagency research programs throughout the government that are not similarly proposed for such coordinated activity. The answer rests with the fact that water resources research stands out as particularly in need of repair because of the sheer number of federal agencies involved, the critical importance of water to the economy, and the history of fragmentation in

research activities by agency mission rather than by broader national and regional research priorities.

A crucial strength of this approach lies with its connection to the budget process. This is also a weakness, however, as OMB may not have an interest in giving the senior level Committee free reign to devise an agenda because of the resulting costs associated with the support of such an agenda. The search for an unbiased development of a list of national water research priorities might not always be consistent with administration budget policies or policies governing federal programs of research as a whole. Although there is precedent for having OMB perform this type of program (in the general area of geosciences) there may be a general reluctance to go further with this particular type of organizational structure within OMB since it represents a substantial departure from the way in which OMB has traditionally operated.

The Committee concluded that it had no special expertise which would allow it to choose among these three coordination options. Rather, the decision should be left to federal level decision makers who are likely to choose the mechanism that meets perceived needs at acceptable levels of effort and funding. It is possible also that options not delineated here may ultimately be selected as superior, or some combination of these three options could prove attractive. While it is likely that federal agencies and others may continue to resist coordination efforts, the absence of such efforts will make it difficult, if not impossible, to develop a coherent strategy for investment in water resources research and to facilitate the development of the type of interdisciplinary, large scale research effort that will be needed to deal with future water problems.

Conclusions

The provision of adequate supplies of clean water serves not only basic and essential physiological needs. Clean water, in adequate quantities, is a matter of national security and it contributes significantly to the nation's economy as well as to the health of the environment. Thus, the provision of adequate water supplies of appropriate quality is one of the important strategic challenges the nation faces. The competition between and among all uses of water grows ever more intense and approaches gridlock

in many areas. Threats to water quality abound. The specter of climate change looms and threatens to change fundamentally the availability of water. If our water problems are to be addressed in an effective and timely way, new scientific information will need to be made available. A reinvigorated and integrated program of water resources research will be critical in the development of such information.

Approximately \$700 million is spent each year on water resources research. However, that research is not sufficiently focused and integrated to address national needs effectively. Current and anticipated problems in maintaining and enhancing the nation's water resources cannot be solved in the absence of a well thought-out, comprehensive national water research strategy. Federal agencies appear to be performing their mission-driven research satisfactorily. Yet, much of this work focuses on short-term problems which are frequently operational in nature. One consequence is the neglect of cross-cutting issues, longer-term research, and the basic research that will be needed to solve the water problems of the future. Many of the most pressing and expensive problems expected to confront the nation will require perspectives broader than those of water management agencies because they extend across the scope and authority of any single agencies. In addition, the current investment will need to be either augmented or reallocated to ensure that research on water demand and use and water institutions is funded at appropriate levels. Ten percent of the total federal investment in water research should be allocated to these categories.

Success in confronting the nation's myriad and mounting water problems requires that we get more from scarce water research dollars. In order to ensure that federal water research dollars are contributing as efficiently and effectively as possible to solving the nation's water problems both the legislative and executive branches of government will have to insist on the development of well-integrated and well coordinated program of water research whose agenda is national in nature and transcends more narrowly focused agency agendas. The problems of coordination and integration are unlikely to be solved without a concerted effort by leaders in Congress and the administration. These problems are solvable and failure to solve them now will sentence the nation to a costlier, more difficult future than need be the case.

Author Bio and Contact Information

HENRY VAUX, JR. is Professor in the Graduate School at the University of California, Berkeley, and Associate Vice President Emeritus of the University of California System. He previously served as Director of the University of California Water Resources Center. His academic field is the economics of water resources. Dr. Vaux is Chair of the Rosenberg International Forum on Water Policy and serves as President of the Board of Directors of the Sacramento, CA based Water Education Foundation. He has served on numerous committees of the National Research Council and was Chair of the Water Science and Technology Board of the National Research Council from 1997 to 2001. He is a National Associate of the National Academy of Sciences.

Mailing Address: Department of Agricultural and Resource Economics, 324 Giannini Hall, University of California, Berkeley, CA 94720; E-Mail: vaux@are.berkeley.edu.

References

- American Society of Civil Engineers (ASCE). 1990. Agricultural Salinity and Management. In *Water quality technical committee of the irrigation and drainage division of the American Society of Civil Engineers*, ed. K.K. Tanji. New York: ASCE.
- Cullen, P.W., R.H. Norris, V.H. Resh, T.B. Reynoldson, D.M. Roseberg and M.T. Barbour. 1999. Collaboration in scientific research: A critical need for freshwater ecology. *Freshwater Biology* 42: 131-142.
- Dovers, S.R., T. W. Norton, and J. W. Handmer. 2001. Ignorance, uncertainty and ecology: Key themes. In *Ecology, uncertainty and policy: Managing ecosystems for sustainability*, eds. J.W. Handmer, T.W. Norton and S.R. Dovers, 1-25. Harlow, United Kingdom: Prentice Hall.
- Funtowicz, S.O. and J. R. Ravetz. 1990. *Uncertainty and quality in science for policy*. Dordrecht, The Netherlands: Kluwer Academic Publishing.
- Jackson, R.B., S.R. Carpenter, C.N. Dahm, D.M. McNight, R.J. Naiman, S. Postel, and S.W. Running. 2001. Water in a changing world. *Ecological Applications* 11: 1027-1045.
- Naiman, R. J. and M.G. Turner. 2000. A future perspective on North America's freshwater ecosystems. *Ecological Applications* 10: 958-970.
- National Atmospheric and Oceanic Administration (NOAA). 2002. The economic implications of El Nino. *NOAA Magazine*. <http://www.noaanews.noaa.gov/magazine/stories/mag24.htm>.
- National Research Council. 1989. *Irrigation induced water quality problems*. Washington, D.C.: National Academy Press.
- National Research Council. 1992. *Water transfers in the west: Efficiency, equity and the environment*. Washington, D.C.: National Academy Press.
- National Research Council. 2001. *Envisioning the agenda for water resources research in the twenty-first century*. Washington, D.C.: National Academy Press.

- National Research Council. 2004. *Confronting the nation's water problems: The role of research*. Washington, D.C.: National Academy Press.
- Sims, J. T. and F.J. Coale. 2002. Solutions to nutrient management problems in the Chesapeake Bay Watershed, USA. In *Agriculture, Hydrology and Water Quality*, eds. P.M. Haygarth and S.C. Jarvis, 345-372. Wallingford, UK: CABI Publishing.

Notes

1. This paper is based on a presentation made to the Annual Meeting of the Universities Council on Water Resources on July 20, 2004 at Portland, OR.
2. As with all reports of the National Research Council the authorship was a joint effort of the entire committee. In the case of the present report, the analyses, findings and conclusions were developed and supported by consensus. Members of the committee were: Dr. J. David Allan, University of Michigan; Dr. James Crook, Water Reuse Consultant, Norwell, MA; Dr. Joan G. Ehrenfeld, Rutgers University; Dr. Konstantine Georgakakos, Hydrologic Research Center, San Diego, CA; Dr. Debra Knopman, the RAND Corporation, Alexandria, VA; Dr. George Hallberg, Cadmus Group, Inc.; Dr. Lawrence J. MacDonnell, Porzak, Browning and Bushong, Boulder, CO; Mr. Thomas K. MacVicar, MacVicar, Federico and Lamb, Inc., West Palm Beach, FL; Dr. Rebecca Parkin, The George Washington University Medical Center; Dr. Franklin W. Schwartz, The Ohio State University; Dr. Amy K. Zander, Clarkson University; and Dr. Henry Vaux, Jr., University of California, Berkeley (*Chair*). Dr. Laura Ehlers of the National Research Council provided professional staff support to the committee.