The role of science in solving the world's emerging water problems

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This article serves as an introduction to the Arthur M. Sackler Colloquium entitled *The Role of Science in Solving the Earth's Emerging Water Problems*. The Colloquium was held October 8–10, 2004, at the Arnold and Mabel Beckman Center of the National Academies of Sciences and Engineering in Irvine, CA. Sixteen speakers gave invited presentations in four sessions covering (*i*) water problems from a global perspective, (*ii*) water and the environment, (*iii*) new perspectives in water management, and (*iv*) the importance of water institutions.

Optimum management of global water resources presents one of the most crucial challenges of the 21st century. Global population will increase by three billion or more over the next 50–75 years, and the number of people living in urban areas will more than double. Most of the world's population growth will occur in developing countries where water is already critically short and many of the residents are impoverished. Even today, >1 billion people do not have access to safe and affordable drinking water and perhaps twice that many lack adequate sanitation services. In fact, inadequate drinking water quality is a leading cause of infant mortality worldwide.

Food production may soon be limited by water availability. Agricultural water use is not sustainable in many locales around the world for reasons that include soil salinization, ground water overdraft, and the overallocation of available surface water supplies. This situation raises questions about whether there are sufficient water resources to support the existing population on a long-term basis, to say nothing of the significantly larger population that will have to be fed in the remaining decades of this century.

Intensifying competition for water resources by agricultural, industrial, and domestic users has led to a sharp increase in stress on aquatic and wetland ecosystems. Moreover, the inadequacy of environmental water supplies in much of the world has been significantly exacerbated by declining trends in water quality. Many developed countries have addressed this problem by adopting laws to guarantee supplies for the environment, but such guarantees are contingent on having adequate water for urban needs and on the availability of sufficient quantities of food. No such guarantees can be provided in developing countries, which tend to neglect environmental needs and are unable to mount efforts to maintain and enhance water quality for financial reasons.

There seems to be little doubt that science and technology must play a vital role in devising the solutions that will be necessary to overcome the daunting problems arising from global water scarcity. This article summarizes the presentations of 16 internationally renowned water experts and the associated discussions that constituted the Arthur M. Sackler Colloquium entitled *The Role of Science in Solving the Earth's Emerging Water Problems.* The Colloquium was held on October 8–10, 2004, at the Arnold and Mabel Beckman Center of the National Academies of Sciences and Engineering in Irvine, CA. It attracted an audience of ≈100 that participated in wide-ranging discussions. The names of the water experts and the titles of their presentations are included on the NAS web site at www.nasonline.org/water. In addition, many of the presentations may be viewed online at the NAS web site.

In the next section of the article, present and future global water problems are characterized. Prospects for finding science-based solutions to these problems are discussed in the following section, and a third and concluding section offers some findings and recommendations about the role of science in addressing the world's water problems.

Global Water Problems: Present and Future

The single biggest water problem worldwide is scarcity. In much of the world, existing water supplies are insufficient to meet all of the urban, industrial, agricultural, and environmental demands. The primary condition determining whether a region has a water surplus or experiences water scarcity is whether precipitation exceeds potential evaporation. In regions where potential evaporation exceeds precipitation, there is minimal runoff available to be intercepted and stored for later use, leading to a critical dependence on the timing and amount of rainfall. The regions of greatest concern due to water scarcity are those of the global Savannah zone, which extends through much of Africa, parts of Southeast Asia, and the middle of South America. Many of the countries in Savannah zones have rapidly growing populations and insufficient wealth to permit the importation of food to feed their inhabitants. In the absence of substantial assistance from other countries, these nations may face widespread starvation in the future.

One manifestation of scarcity is attributable to the economic forces that influence different uses of water. The value of water in urban and industrial uses is typically far larger than its value in agriculture. Environmental uses, which tend to be undervalued by markets and quasimarkets, usually have significantly less value than urban uses. As the world population increases by several billion or more over the next 30 years, market forces will cause a significant reallocation of water resources from the agricultural and environmental sectors to the urban sector. This will result in intensifying stress on water-based ecosystems and on the world's food production capacity.

It is estimated that global water consumption will increase by ≈3,800 km^3/yr by 2025, and much of this water will have to be obtained from natural systems. This consumption increase will cause substantial additional depletion of river flows in many areas, with substantial environmental consequences. As a rough guideline, at least 30% of the average annual flow of a stream must re-

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main in place if the ecological health of the stream and related ecosystems is to be maintained. Even today, flows at or above this threshold level are not maintained in a significant number of rivers. Additional diversions of the magnitude necessary to meet increases in direct human use will result in the depletion of flows below the 30% threshold in many more rivers and will create adverse environmental consequences on a massive scale. Based on current trends in population and water-use patterns, it is estimated that both China and India will need all of their runoff to meet urban and agricultural needs within the next 20 years. It is not at all clear how water will be found to maintain the environmental amenities and services that derive from healthy aquatic ecosystems in these countries and other water-stressed areas around the world.

Projections of global water needs are worrisome enough when the water demands arising from future population and economic growth are compared with current estimates of developed and developable supplies. However, the reliability of current supplies is also in question. The fact is that there are trends and circumstances which will almost certainly reduce available supplies in the face of sharply escalating water demands world-wide. Ground water overdraft, a condition in which the rates of extraction from an aquifer exceed the rates of recharge by water percolating from above, occurs in almost every region of the world. China and India today are estimated to be feeding nearly 400 million people through irrigation supported only by the persistent overdrafting of aquifers, and they are not alone in this practice. Because aquifer capacity is finite, ground water overdraft is always self-terminating. In the absence of effective management, water tables are drawn down to the point where it is no longer economical to pump them, and extractions diminish to levels that balance recharge or even cease entirely because they are too costly. This economic exhaustion is the final outcome of persistent overdraft.

Historically, the solution to ground water overdraft has almost always been to develop supplemental supplies to substitute for the diminished extractions that are necessary to stabilize an aquifer and maintain it sustainably. Indeed, China plans large-scale water transfers from the south, where water is plentiful, to the north, where urban and agricultural demands are concentrated, in an effort to offset the projected consequences of continued ground water overdrafting. However, these transfers are planned only to alleviate scarcity in urban regions such as Beijing. Elsewhere in China, there is insufficient water either locally or remotely to offset overdraft. One dramatic example is in the North China Plain, where 70% of the water needed to support 400 million people comes from ground water. Overdraft is very substantial in this region, and economic exhaustion of the aquifer will occur within two decades unless something is done to reduce extractions. This situation reflects a broader global trend in which supplemental water supplies to offset ground water overdraft will be difficult, if not impossible, to find. Overdraft is also the cause of many serious ancillary problems such as seawater intrusion and land subsidence, which threaten the integrity of ground water resources in different locales around the world. In the absence of effective ground water management at the basin or regional level, problems will worsen to the point where the threat of catastrophe may be realized. However, effective ground water management institutions have only been used sparingly in the past, and it remains to be seen whether institutions can be devised that are capable of addressing the most serious issues in ground water management in an effective manner.

Climate change and associated global warming are also likely to affect the availability of water in the future. Although existing climate models are only an approximate tool for estimating future change, there is a growing consensus among researchers that precipitation will increase at higher latitudes and decrease in the subtropics as warming occurs. As mean temperature increases, the volume of snowpack will decrease at higher elevations and snowmelt will occur earlier than in the past, causing an earlier release of water and greater losses. Because one-third of global water supplies are obtained from snowmelt, any change in the timing of releases will have serious repercussions for management. The problem will be especially serious in Europe, which draws 80% of its freshwater from snowpack.

Despite the uncertainty associated with the results of climatic forecasting models, simulations made by using different assumptions have led to a consensus on several qualitative characteristics of the impact of climate change on global water resources. There is almost unanimous agreement that precipitation will become more variable and will create amplified variations in runoff and streamflow. Associated with this increased variability will be an increase in the frequency of extreme events such as floods and droughts. As a result, water planning in the future will have to focus more on extreme events and managing runoff and streamflow that is highly variable over time.

Future water supplies are also threatened by declines in water quality caused by pollution. Wherever agriculture becomes modernized, dramatic increases occur in nitrate- and pesticide-loading of nearby surface and ground waters. In certain soils, enhanced drainage from agricultural operations can leach toxic metals from the subsurface to surface and ground waters. In areas where adequate sanitation services are absent, growing populations inevitably lead to increased levels of pathogens in water supplies. Decades of land disposal or accidental release of untreated toxic waste have created a serious ground water contamination problem in many areas, and much of the waste still lies in the soil. Ground water contamination is extremely expensive to remediate, and it is unlikely that developing countries will have the resources in the future to support significant remediation efforts.

Soil salinization will continue to be a problem that plagues irrigated agriculture, particularly in arid and semiarid climates. Salt buildup in shallow soil can significantly decrease crop yields and in extreme cases render the soil unfit for farming. Ironically, the best way to avoid salinization is to apply water at a rate substantially in excess of crop water needs to avoid buildup of salt in the crop root zone. Unfortunately, this practice increases the likelihood that agricultural chemicals will reach the underlying ground water. Salinity will become increasingly difficult to manage as water supplies become scarcer, which will constrain the ability of arid and semiarid countries (and regions) to feed their growing populations.

The picture that emerges from extrapolating current trends in global water use provides ample cause for concern, if not alarm. Even as population and economic growth lead to sharp increases in demand for new water supplies, unsustainable water management and regional scarcity make it highly unlikely that additional water supplies will be available to meet new demands. The effect of water shortages on food production will rise dramatically in the next two decades as many countries, including India and possibly China, lose the capacity to produce the food needed for their populations. The presence of persistent and pervasive ground water overdraft, the specter of climate change, and the salinization of soils in arid and semiarid areas will exacerbate the problem. The growing dependence of developing countries on food imports could easily reach crisis proportions in this century.

The result will inevitably be an escalation of water conflicts among upstream and downstream riparians (and countries) and among different water-using sectors. There will be growing stresses on the environment. The associated economic hardship and likely political unrest may be very difficult to manage.

The Prospects for Science-Based Solutions

The science on which solutions to present and future global water problems must be based does not fall within the purview of a single discipline but rather is truly multidisciplinary and inherently interdisciplinary. It embodies the fundamental physical and biological sciences as well as applications of those sciences and substantial contributions from the engineering sciences, hydrology, climatology, and geology. A host of institutional, policy, and management issues must be addressed by fundamental and applied social sciences, which have been largely neglected in recent decades. Significant scientific information is already available, but much more will be needed in the near future through technological advances, improvements in climate modeling and forecasting, and developments in ecosystem and sustainability science. New and innovative contributions will be needed from all of the social sciences. These contributions will be critical for understanding water-use behavior and for devising effective institutions to manage water in times of intensifying scarcity.

Advances in Technology. One of the defining differences between the developed and developing countries in the world today is the provision of access to safe drinking water. Worldwide, >1 billion people have no alternative but to drink contaminated water. The result is an ≈50 million deaths annually and an incidence of a host of waterborne diseases that are rarely seen in the developed world. Cholera, for example, will kill half of all infected people if left untreated. Even the more advanced drinking water treatment technologies, such as chlorination, fail to provide complete protection against some pathogens such as cryptosporidium. Effective water and wastewater treatment technologies are expensive, and the necessity of tailoring them to site-specific circumstances increases the cost even more. For the poorest countries of the world, the high cost means that these technologies are not viable. Wastewater treatment services and potable water supply in the developing world are constrained both by inadequate infrastructure and the acute scarcity of water itself. The most common infrastructure failure is inadequate pressurization to prevent contamination during transport and storage. The need to protect the environment while managing very limited resources is becoming increasingly urgent in water-short countries. Substantial cooperation and support from developed countries will be needed to deal with both problems.

By contrast, the developed world is about to benefit from a revolution in membrane technology. The latest generation of membrane filters will accommodate large flow rates and offer improved cleaning effectiveness. The result is that larger volumes of water can be treated less expensively than in the past. Desalination technology is advancing rapidly, and seawater can now be reclaimed with a single pass through a reverse osmosis membrane. Although seawater conversion remains too expensive for general application, the cost of desalting brackish waters is now well within reach of many locales in the developed world. Similarly, membrane bioreactors have greatly increased the efficiency with which solids can be separated from fluids during activated sludge treatment processes. This means that bioreactors can be coupled with reverse osmosis membranes to increase the efficiency and effectiveness of the treatment process. Problems remain with membrane degradation and fouling, and additional research is needed to develop membranes that filter certain toxicants such as boron. To date, advances in wastewater-treatment processes have been impressive, but even greater efficiencies can be achieved if water demand is separated into different use categories so that treatment and reclamation can be used selectively to create the appropriate water quality for different uses.

The time-honored means for dealing with temporal variability in precipitation and runoff has been the construction of water storage and transport facilities. Storage allows water to be captured in wet times and places and retained for use in dry times and places. One measure of water security is expressed by the amount of storage per capita, and the resulting figure varies dramatically from country to country. Many developing nations have little or no infrastructure for enhancing storage. Thus, for example, storage is as little as 11 m^3 per person in the poorest parts of Africa, whereas the contrasting figure for North America is 6,000 m^3. The World Bank is attempting to address this deficiency through financial aid for the construction of dams, where appropriate. More recently, such aid has extended to the development of aquifer storage and recovery systems that are less disruptive to the environment and indigenous populations.

Significant investments in the creation of infrastructure may be economically infeasible for developing countries. In these circumstances, small-scale, decentralized technologies become very important. There are a number of so-called "soft path" technologies that focus on increasing the overall productivity of water at the basin level rather than on the development of new supplies. The general approach is to create community-managed, low-cost water supply and wastewater treatment technologies and small-scale technologies for irrigated agriculture. Examples include manually operated treadle pumps and inexpensive diesel pumps, both of which are in growing use. Sanitation services can be provided through latrines or septic sewer systems as well as education on basic hygienic practices. These local solutions can have a significant positive effect on the quantity of food that can be produced with a fixed volume of water. China, for example, has tripled its water-use efficiency while decreasing overall water use through a variety of both local and large-scale technologies.

Further science-based technology development will be essential to solving the world's water problems. Improvements in rainwater harvesting and microirrigation technology are two examples. The development of more salt-resistant and drought-resistant crops may be particularly important. There are a number of avenues through which wastewater reuse can be further developed, although ample attention must be paid to potential health risks. Research focused on reducing conflicts between agricultural and environmental uses will also be important. One measure that could be particularly helpful entails the use of ecosystem services in agriculture. An example would be the use of natural wetlands for rice cultivation.

Science for Managing Water for Agricultural and Environmental Purposes. Agriculture is by far the largest consumer of water, accounting for 80% of water consumption worldwide and even more in the United States. It has been thoroughly documented that irrigated agriculture is far more productive than rain-fed agriculture. Moreover, there is also evidence to show that the lack of water for agriculture is an important determinant of rural poverty and malnutrition. Other things being equal, a logical response to the anticipated increase in population and economic growth would be to expand irrigated agriculture. Yet, because of the pressures for more urban supplies and because of existing unsustainable practices in agriculture such as ground water overdraft and water supply contamination, it seems clear that acquiring additional water for agriculture will place enormous strains on aquatic ecosystems. As noted previously, ecosystem health cannot be maintained below some critical level of water supply. Thus, one of the "devil's choices" embedded in the intensifying scarcity would entail the bearing of the large costs associated with losses in environmental stability and sustainability as part of the price paid for making more water available to agriculture.

The clear solution to this dilemma lies with making irrigated agriculture a more efficient user of water. There are many possible means for reducing agricultural water demand by increasing the economic productivity of water. Central to strategies for increasing productivity will be the pairing of the most appropriate and efficient crops with given sites and climates. Thus, for example, rice will rarely be an appropriate crop to grow in the desert. Additionally, improvements in on-farm management of agricultural water, both through utilization of advanced irrigation technology and improved irrigation scheduling, offer the prospect of significant increases in productivity. In addition, moisture-stressing crops at strategic points in the life cycle or annual cycle offers the possibility of high-quality yields with minimal reductions in quantity. In short, the prospects for improving agricultural water management are large and entail both the use of existing scientific information and the pursuit of new information through research.

The motivation for improving the productivity of water in agricultural uses is partly to do a better job of managing scarcity and partly to ensure some (minimal) level of water for environmental uses. Environmental uses of water provide environmental amenities and environmental services that include air and water purification, production of useful biomass, provision of domestic water supply, power production and transportation, and environmental stability. These services are not always obvious because of problems in measuring them both directly and in terms of the value they provide. Methods do exist for evaluating overall ecosystem importance as a function of the extent to which there has been human interference with the ecosystem. These methods permit the identification of optimum levels of human interference.

One approach entails the assignment of a baseline importance to an ecosystem, which corresponds to its natural state, and then examining the changes that accrue in the provision of the ecosystem services cited above as a consequence of different types of human influence. An overall value measure can be obtained as the sum of weighted services appropriately adjusted for the extent to human influence. Analyses of this sort focused on different ecosystems have revealed some important trends. Typically, there is little decline in ecosystem value due to human interference up to some threshold value after which the value of services decreases precipitously. Services driven by biological processes are the most complex in their response to human influence, and more research will be needed to define response thresholds for biologically dominated systems.

There have been a number of important scientific advances in both terrestrial and aquatic ecology in the past decade or so. Ground and surface water are now regarded as a single management unit, characterized by many interactions and interdependence. The extent to which ecosystem health depends on ground water and the ground–surface water system had not previously been well understood. Modern management paradigms include humans as part of any ecosystem and incorporate ecosystem services into assessments that identify optimum management strategies. Much current research is devoted to identifying biogeochemical hot spots showing high reaction rates at broader scales of space and time by using them in quantitative models. Their activity is often enhanced at terrestrial–aquatic interfaces. Ecosystem functions are significantly influenced by climate change, by anthropogenic mobilization of key chemical constituents, by growth in human populations, and by invasive species. All of these factors will grow in importance in the present century, and their impact on terrestrial and aquatic ecosystems will need to be the focus of large and continuing research efforts.

Water development and wildlife preservation are inherently incommensurate, and there has been continuous conflict in the United States over the proper balance among the two. Laws aimed at protecting endangered species and water pollution control laws often produce conflicting priorities in water management. Water development (for human uses) is estimated to stress one-third of all species listed as threatened or endangered under the provision of the United States Endangered Species Act. Specific water management activities such as diversions of streamflow and flow disruptions are estimated to affect one-quarter of all species. Such conflicts are likely to incur with increasing frequency around the world as aquatic and terrestrial ecosystems are subject to increasing levels of stress.

Science can contribute to the resolution of conflicts, such as those between water development and species preservation, by elucidating the role of hydrologic processes in the behavior of the environmental and social systems in conflict, by defining the pivotal role that physical integrity of the hydrologic system plays in optimum management, and by providing an effective perspective for decision-making through de-emphasis of commodity-based approaches and emphasis on holistic concepts and processes. An integrated and balanced perspective will be critical to the success of integrated, basin-wide water-management strategies.

Climate and Climate Change. Climate modeling is an evolving science, and varying degrees of reliability characterize the forecasts of future change that are derived from climate models. As noted above, the most reliable predictions are for continued warming in the present century causing less snowpack and earlier runoff. The prognosis that there will be greater variability in precipitation leading to more floods and droughts is also highly reliable, and it is predicted with some confidence that rainfall will increase at higher latitudes and decline in the subtropical regions. However, accurate estimates of changes in the amount of precipitation in different regions and in different locales within regions are more difficult to forecast. In addition, modeling has not advanced to the level where the effects of the El Niño Southern Oscillation can be assessed. The science of climate change forecasting is evolving and should become more reliable with further research.

New developments in hydrologic modeling will also be important. The response of aquifers to changes in snowmelt and runoff patterns cannot be assessed with precision, although it is known that recharge is higher from snowmelt than from rainfall-generated runoff. Much remains to be learned about large-scale hydrologic processes and about the interrelationships between hydrologic and climatological processes. Advances in the physical sciences that underlie and explain the behavior of water resources will be critically important in the future.

Developing Management Institutions and Policies. The era in which most growing demands for water could be addressed by developing water supplies through large-scale infrastructure like dams in canals appears to be over or nearly over. The main consequence of this change is that the greatest potential for improving global water security is through better management of water resources. Unfortunately, the current institutional arrangements for managing water exhibit glaring deficiencies. Many existing institutions were created in times and eras when the problems of developing and managing water resources were very different from what they are today. Thus, for example, a number of the institutions in the arid and semiarid western United States were devised at a time when water was treated as an important instrument of settlement. Other deficiencies that water institutions tend to embody include a focus on narrow interests; artificial divisions between the management of water quality and the management of water quantity; multiple and fragmented management jurisdictions across fundamental hydrologic units such as basins and watersheds; and an absence of institutions that are designed to deal with the fundamental problems of water scarcity.

There are a number of encouraging trends that have appeared in newly devised institutions for managing water. Chief among these trends is a centralization of rules and standards accompanied by a decentralization of the authority to administer these rules and standards. This reorganization permits standards and rules to be uniform but allows local stakeholders to administer them in ways that fit local conditions and circumstances. For example, the European Water Framework Directive has created uniform standards for water policy within the European Union and has shifted the focus of management strategies to the river basin. Economic analyses are used to guide water-use decision-making, and extensive programs of public and stakeholder involvement have developed.

The California Bay-Delta Authority has for the first time incorporated environmental concerns in water management through the concept of place-based ecological resources, and is developing a systems approach to water allocation and regulation. Adaptive management, which relies on extensive monitoring followed by adaptive adjustments, has become a crucial management tool, and environmental restoration has been acknowledged as an important water management goal.

Water markets play an increasingly significant role in the developed world in allocating water on a regional basis. There are several examples in which government has used markets or market-like arrangements to resolve vexing problems of allocation. Nongovernmental organizations (NGO) have grown in importance and are responsible for much of the institutional change that is occurring in the water resources sector today. Markets and NGOs will play an important role in the future challenges of adapting to water scarcity.

Virtually all of the undeveloped water supplies around the world are found in international river basins and aquifers. There are some 263 drainage basins that transcend nations, and 60% of all river flows are found in those basins. These basins supply 40% of the world's population. Institutions for managing international river basins are neither robust nor well developed. The absence of treaties, enforceable legal decisions, or voluntary agreements about the allocation of waters in international basins creates an enormous potential for conflict. That potential will only grow as scarcity intensifies. Much remains to be done by way of legal research and the development of innovative ideas and institutions to govern these commonly held resources.

In addition, much remains to be learned about the role of human behavior in water use. Additional information is needed on issues such as determinants of levels of water use, the role of culture, different systems of incentives, effective organization of stakeholders, and stakeholder input. Institutional research, as it relates to water resources, has unfortunately been negligible in the past decade or two at a time when new and innovative institutions will surely be part of the solution to the world's emerging water problems. Some of the social science disciplines such as anthropology, psychology, sociology, and geography that should be involved have not been systematically engaged or incorporated into interdisciplinary investigations. Efforts will need to be made to encourage contributions from these disciplines both in the development of new institutions and to inform public water policy making.

Conclusions

There is little question that science must play a critical role in forming a successful solution to the world's emerging water problems. In the broadest sense, there are two distinct ways in which science needs to be used. First, there is significant existing scientific information that could be helpful in solving contemporary and anticipated problems, but it is not being used. The scientific underpinnings that justify the use of holistic, integrated ways of managing the water resources of a basin are strong and well known. Yet, many of the world's water resources continue to be managed in a fragmented way that (*i*) creates conflict between upstream and downstream riparians and between the various water-using sectors; (*ii*) ignores the essential interrelatedness of ground and surface waters; (*iii*) ignores the crucial connections between water quality and water quantity; (*iv*) encourages ground water overdraft although persistent overdraft is known to be unsustainable; (*v*) promotes short-sighted and wasteful agricultural water-use practices; and (*vi*) ignores the substantial benefits that flow from well managed and maintained ecosystems.

The task for scientists and policy analysts alike is to do a better job of explaining, communicating, and educating water managers, decision makers, and members of the public. Only through effective programs of communication and outreach will existing science be used to its fullest potential in the development of comprehensive strategies for addressing the many water problems that confront the world. The importance of effective outreach and communication extends beyond the challenge of fashioning new and innovative solutions to the water problems of today and for the foreseeable future. These problems are daunting, and existing science will not be sufficient to solve them. Yet, the new scientific advances that will be necessary for managing the intensifying water scarcity and other emerging global water problems will also have to be extended and communicated so that it can form the basis of new technologies, management strategies, and policies. Failure to do a better job of extending and communicating science and educating could lead to a world overwhelmed by water problems even though the scientific information needed to solve those problems might be in existence.

To be sure, new research and the new scientific information resulting from it will be needed. Water will become scarcer and scarcer as populations grow and as the developing world seeks new levels of economic growth. The fundamental scientific understanding of hydrologic processes and the climatological processes that influence them must grow apace. At the same time, we must improve our understanding of the basic biological systems and processes that influence the availability of water and are, in turn, influenced by that availability. New developments in science and its applications will also need to extend to the social sciences so that human behavior with respect to water resources is better understood and improved institutions for governing and managing water can be developed. New science must be focused not just on filling the gaps in knowledge but also on correcting many of the misunderstandings about the fundamental nature and behavior of water. In addition, a new science of sustainability will be needed if the prospects for managing and solving the world's emerging water problems are to be bright.

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