Ecological Applications, 10(4), 2000, pp. 941–948

ENTERING AN ERA OF WATER SCARCITY: THE CHALLENGES AHEAD

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Abstract. Fresh water is a renewable resource, but it is also finite. Around the world, there are now numerous signs that human water use exceeds sustainable levels. Groundwater depletion, low or nonexistent river flows, and worsening pollution levels are among the more obvious indicators of water stress. In many areas, extracting more water for human uses jeopardizes the health of vital aquatic ecosystems. Satisfying the increased demands for food, water, and material goods of a growing global population while at the same time protecting the ecological services provided by natural water ecosystems requires new approaches to using and managing fresh water. In this article, I propose a global effort (1) to ensure that freshwater ecosystems receive the quantity, quality, and timing of flows needed for them to perform their ecological functions and (2) to work toward a goal of doubling water productivity. Meeting these challenges will require policies that promote rather than discourage water efficiency, as well as new partnerships that cross disciplinary and professional boundaries.

Key words: biodiversity; dams; ecosystems; fresh water; irrigated agriculture; resource conflicts; water productivity.

Introduction

A growing scarcity of fresh water relative to human demands is now evident in many parts of the world. Two of water's most fundamental functions—its role as a prerequisite for life, on the one hand, and its use as a commodity or economic resource on the other—are increasingly in conflict. In many areas, extracting more fresh water for agriculture, industry, or cities now places at risk the health of aquatic ecosystems and the life those ecosystems support (Covich 1993, Postel and Carpenter 1997). With the world population projected to increase by an additional two billion (2×10^9) people by the year 2030 (United Nations 1998), finding ways to satisfy humanity's water demands while at the same time protecting the life-support functions of freshwater systems now ranks among the most critical and difficult challenges of the 21st century. It is a challenge that spans science, technology, policy, and politics, and is one that demands new partnerships that cross disciplinary and professional boundaries. In this paper, I discuss the dimensions of the water-scarcity challenges that lie ahead and propose some goals and directions for addressing them.

Dimensions of the Challenge

The global hydrological cycle annually makes available several times more fresh water than is needed to sustain the current world population of about six billion ($\sim 6 \times 10^9$) people. Because this water is not distributed evenly in time or space, however, much of it is not accessible for human use. Half of the estimated 40 700 km^3 of annual runoff (which equates with net precipitation on land) runs rapidly off the land in floods. An additional one-fifth of annual runoff is geographically too remote to be an economically viable source of supply for farms, cities, or industries for the foreseeable future. This leaves $\sim$31% of annual runoff as accessible for controlled human use, a figure that increases only as newly constructed dams capture and store additional floodwater. However, even optimistic projections of dam construction over the next 30 years suggest an increase in accessible runoff of no more than 10%, while population during this period is projected to grow by some 30–35% (Postel et al. 1996).

Postel et al. (1996) estimate that humans already appropriate half of this accessible runoff, either directly in the form of withdrawals for agriculture, cities, and industries, or indirectly in the form of pollution dilution and other instream uses. Even with optimistic assumptions about dam construction to increase supplies coupled with modest assumptions about the growth in human demands, we estimate that human appropriation of accessible runoff could climb to 70% by the year 2025. Such a degree of human dominance of fresh water would severely degrade aquatic ecosystem services, decimate fish populations, and drive additional beneficial species to extinction. Assessments show that these trends are well under way (Covich 1993, Naiman et al. 1995, Pringle 2000).

There is also widespread physical evidence that human activities have already reached or exceeded re-

Manuscript received 25 January 1999; revised 28 April 1999; accepted 15 September 1999. For reprints of this Invited Feature, see footnote 1, p. 939.

newable water limits in many regions. The clearest indicator of unsustainable use is chronic overpumping of groundwater, a practice now widespread in many important food-producing regions and large urban areas (Postel 1996). Groundwater withdrawals exceed recharge levels in much of China's north plain, an important grain production area; the U.S. Great Plains and California's Central Valley; parts of the Middle East and north Africa; the valley of Mexico; and parts of southeast Asia (Postel 1999). Six of India's most important agricultural states are overexploiting groundwater to meet current irrigation demands. Their collective water deficit totals an estimated 100×10^9 m^3/yr (National Environmental Engineering Research Institute, *unpublished manuscript*), a volume of water that exceeds the average annual flow of the Nile River.

Another sign of excessive water use is that many major rivers now run dry during all or part of the dry season, when irrigation water is most needed. These include the Ganges in South Asia, the Amu Dar'ya and Syr Dar'ya in Central Asia, the Nile in Africa, and the Colorado in the American Southwest (Postel 1996). China's Yellow River has run dry in its lower reaches every year this decade, with the dry section often stretching 600 km, from Henan Province to the river's mouth. In 1997, the river ran dry for two-thirds of the year, a record 226 d, up from 133 d in 1996 and 122 d in 1995. China's ''mother river'' and the cradle of Chinese civilization, the Yellow supplies water to 140 million people and 7.4×10^6 ha of irrigated cropland (Postel 1999).

With many aquifers and river systems being overtapped to meet current water demands, stresses on freshwater systems will worsen markedly as population and consumption levels increase. Three major dimensions of the water-scarcity challenge stand out: (1) maintaining food security in the face of water constraints on agriculture, (2) preventing a downward spiral in the health of the aquatic environment, and (3) averting political instability in international river basins. I discuss each of these briefly below.

Water and food security

Food production is a very water-intensive activity. It takes on the order of 1000 Mg (1000 metric tons) of water in the form of soil moisture to grow 1 Mg (1 metric ton) of grain (Doorenbos and Kassam 1979). Irrigated agriculture accounts for two-thirds of all the water removed from rivers, lakes, and aquifers for human activities (Shiklomanov 1996). Approximately 40% of the world's food comes from the 17% of the world's cropland that is irrigated, and that dependence on irrigated land is expected to increase in the future because of limited opportunities to expand rainfed crop production. Growing the food needed to feed the global population in 2025 could require an additional 500 km^3 of irrigation water, a volume roughly equivalent to the annual flow of 6 Nile Rivers or 28 Colorado Rivers (Shiklomanov 1996). An even larger volume of additional water will need to be extracted from natural water systems if that water is delivered and applied to farms inefficiently. In light of the water-use trends just presented, it will be difficult to supply this much additional irrigation water on a sustainable and ecologically sound basis.

As urban water demands increase, cities are beginning to pull water away from agriculture. By 2025, nearly five billion (5×10^9) people are expected to live in cities, about twice as many as in 1995. If those projections hold, the urban population will represent 61% of the global population, up from 46% in 1996 (United Nations 1997). Rosegrant and Ringler (1998) project that annual water demands by households and industries in developing countries will increase by 590×10^9 m^3 between 1995 and 2020, and that the share of water going to these activities will more than double, from 13% of total water use to 27%. Almost certainly, a portion of these greater urban and industrial demands will be met by transfers of water out of agriculture. As Rosegrant and Ringler (1998) note, the manner in which this farm-to-city reallocation of water is managed ''could determine the world's ability to feed itself.''

To date, global food models have largely ignored water constraints, leading to an overly optimistic picture of future food supplies. By 2025, the number of people in the developing world living in countries categorized as water-stressed—those with $<$1700 m^3 of renewable water per capita—is projected to increase more than six-fold, from $\sim$470 million to 3 billion. With few exceptions, water-stressed countries are net food importers because they do not have sufficient water supplies to satisfy all of their water needs (Postel 1998). The vast majority of water-stressed populations in 2025 will be in sub-Saharan Africa and South Asia. Whether sufficient exportable food surpluses will be available at a price that poor food-importing countries can afford is an important and under-attended question.

Health of freshwater ecosystems

Global water demand has roughly tripled since mid-century. To meet that rising demand, engineers have constructed large dams and river diversions and drilled groundwater wells at an unprecedented pace and scale. Since 1950, the number of large dams—those at least 15 m high—has increased from 5000 to 40 000 (McCully 1996). Thousands of kilometers of canals have been built to divert and transport river water both within and between river basins. But while society built these dams to meet the legitimate goals of water supply, flood control, and hydroelectric generation, water engineering has failed in large measure to protect the fundamental ecological functions of rivers and freshwater ecosystems. Many of these ecosystem services go unvalued in the marketplace, but are estimated to be worth in the trillions of dollars on an annual basis (Postel and Carpenter 1997).

Dams, dikes, levees, and other hydraulic infrastructure are primary destroyers of aquatic habitat and disruptors of ecological functions, both downstream and upstream (Covich 1993, Collier et al. 1996, Pringle 1997). This infrastructure alters a river's seasonal flow patterns, water temperature, dissolved oxygen levels, nutrient and sediment transport, as well as its interconnections with the land, including its floodplain and delta. In what Covich (1993) has called a ''cascade of biotic effects,'' these changes in turn impact plant and animal communities and their interrelationships. If dams and diversions sever a river's connection with the sea, highly productive coastal ecosystems can suffer, as has occurred where the Ganges River enters the Bay of Bengal, where the Colorado River enters the Sea of Cortez, where the Yellow River enters the Bo Hai, where the Chao Phraya enters the Gulf of Thailand, and where the Nile enters the Mediterranean, to name a few cases (Postel 1996).

Modern society is thus faced with a monumental design problem. There are hundreds of billions of dollars of hydraulic infrastructure in place that is literally killing the aquatic world. Globally, the World Conservation Union estimates that one out of every three fish species is to some degree at risk of extinction, compared with one out of every four mammals, one out of every five reptiles, and one out of every nine birds (Baillie and Groombridge 1996). Similarly, in the United States, the Nature Conservancy finds that water-based life is proportionately at greater risk than land-based life. The organization reports that 67% of freshwater mussels are at risk, along with 51% of crayfish, 40% of amphibians, and 37% of freshwater fish (Stein and Flack 1997). The primary reason for the imperilment of these species is the destruction and degradation of their habitats.

Perhaps no place better illustrates the consequences of undervaluing ecosystem services than the Aral Sea basin in Central Asia. Four decades ago, Soviet central planners calculated that using central Asian rivers for the irrigation of cotton would generate greater economic value than letting the majority of their flow empty into the Aral Sea, which was then the planet's fourth largest lake (Micklin 1991*a*). Irrigated area in the region expanded greatly during the ensuing decades, and now totals 7.9×10^6 ha. Prior to 1960, the Amu Dar'ya and Syr Dar'ya released 55×10^9 m^3/yr. of water into the Aral. As river diversions for irrigation increased, however, this flow diminished. Between 1981 and 1990, the rivers' combined flow into the sea dropped to an average of 7×10^9 m^3 per year, 13% of the pre-1960 inflow. The Aral has lost half of its surface area and three-fourths of its volume (Micklin 1992), and continues to shrink.

The still-unfolding chain of ecological destruction ranks the Aral Sea's demise as one of the planet's greatest environmental tragedies. All 24 native fish species have disappeared (Stone 1999), and the fish catch, which totaled 44 000 Mg/yr (44000 metric tons/yr) in the 1950s and supported some 60 000 jobs, has dropped to zero (Postel 1996). Abandoned fishing villages dot the sea's former coastline. Each year, winds pick up on the order of 10^8 Mg (10^8 metric tons) of a toxic dust-salt mixture from the dry sea bed and dump them on the surrounding farmland, harming or killing crops. The low river flows have concentrated salts and toxic chemicals, making water supplies hazardous to drink and contributing to high rates of many diseases. The population of Muynak, a former fishing town, has dropped from 40 000 several decades ago to just 12 000 today. The 28 000 people who have fled are ''ecological refugees'' in the truest sense (Micklin 1991*b*, Postel 1996).

Both the Amu Dar'ya and Syr Dar'ya deltas have been severely degraded by the diminished river flow. Micklin (1992) reports that the tugay forests that are vital habitat for the region's animal life have been decimated. Wetlands have shrunk by 85%, which, combined with high levels of agricultural chemical pollution, has greatly reduced waterfowl populations. In the Syr Dar'ya delta, the number of nesting bird species has fallen from an estimated 173 to 38.

The Aral Sea tragedy provides the most striking example of the interconnections between the health of an ecosystem and that of the economy, community, and people dependent on that ecosystem. But there are many other examples as well. As dams, diversions, and other water infrastructure continue to alter river systems and diminish freshwater ecosystem services, the costs and risks of ignoring downstream and upstream impacts are rising.

Regional instabilities and conflicts

The third major dimension of the water-scarcity challenge is preventing competition for water from leading to regional tensions and conflicts. Approximately 260 rivers flow through two or more countries (Wolf 1998). Many countries depend on rivers flowing into their territory from other nations for a substantial portion of their water. In the vast majority of these river basins, there is no treaty among all the parties setting out how the river water is to be shared. In the absence of such treaties, tensions are almost certain to rise as populations grow and water demands increase. In five of the principal hot spots of water dispute—the Aral Sea region, the Ganges, the Jordan, the Nile, and the Tigris–Euphrates—the total population of the nations comprising each basin is projected to climb between 32% and 71% by the year 2025 (Population Reference Bureau 1999).

The U.S. intelligence community is gradually taking notice of the threats to regional stability that water scarcity poses. The U.S. Department of State has set up regional ''environmental hubs'' in parts of the world where it sees the potential for environmental degradation and resource scarcity to lead to political tensions. Four of the six hubs have water as a principal concern: Amman, Jordan in the Jordan basin; Kathmandu, Nepal in the upper Ganges basin; Tashkent, Uzbekistan in the Aral Sea basin; and Addis Ababa, Ethiopia in the Nile basin (Marcus 1997). The challenge in each case is to turn what appears to be a zero-sum game, in which one party's gain is another's loss, into win–win situations, in which all parties are made better off. The search for creative solutions can be greatly aided by the work of hydrologists, ecologists, water engineers, and others who can help identify a full range of options, and help anticipate their ecological consequences.

Two Proposed Goals

Meeting the water challenges of the coming decades will require a global effort (1) to ensure that freshwater ecosystems receive the quantity, quality, and timing of flows needed for them to perform their ecological functions and (2) to double water productivity; that is, to get twice as much service, satisfaction, and benefit out of each unit of water extracted from rivers, streams, lakes, and aquifers. In the absence of concerted movement toward these goals, the health of the aquatic environment will deteriorate markedly and a large portion of basic human needs for food, safe drinking water, and a healthy environment will go unmet.

Reserving water for ecosystems

Covich (1993), Gleick et al. (1995), Naiman et al. (1995) and others have argued for the need to provide natural systems with enough water of sufficient quality to sustain their habitat and other ecological functions. To date, I am aware of only one country, South Africa, that has adopted this goal as a matter of national policy. Among the many constitutional, legal, and policy reforms undertaken by South Africa's post-apartheid democratic government has been an overhaul of water laws and policies. These include a strong environmental priority for water management: ''The quantity, quality, and reliability of water required to maintain the ecological functions on which humans depend should be reserved so that the human use of water does not individually or cumulatively compromise the long term sustainability of aquatic and associated ecosystems'' (SADWAF 1996). It remains to be seen how effectively this principle is implemented.

In Australia's largest river basin, the Murray–Darling, the basin states have agreed to allocate 25% of the river's natural flow to maintaining the system's ecological health. As in South Africa, however, the hard work of actually accomplishing this objective remains to be done. In 1997, the Murray–Darling Basin Commission recommended capping allocations to major cities and towns at projected year-2000 levels of water use, and suggested that cities meet any demands above this level by purchasing water from irrigators (Anonymous 1997*a*).

In the United States, a number of initiatives are under way to return water now allocated for human uses back to the natural environment in order to restore and protect ecological functions. In late 1992, the U.S. Congress passed legislation that overhauls the operation of the large federally operated Central Valley Project in California in order to restore habitat and ecological health to the Sacramento–San Joaquin river system. Among other objectives, the law sets a goal of restoring the natural production of salmon and other anadromous fish to twice their average levels over the preceding 25 years (Gray 1994). Efforts are also under way to limit the volume of fresh water that can be diverted from the San Francisco Bay delta–estuary, a highly productive aquatic ecosystem that is home to >120 species of fish. In addition, a 1994 California Supreme Court decision mandated that Los Angeles reduce its withdrawals of water from tributaries feeding Mono Lake, which had lost half its volume over several decades because of the city's diversions. The court based its ruling on a broader interpretation of the public trust doctrine, which is emerging as a potentially powerful legal tool for restoration and protection of important natural ecosystems (Postel 1996).

Dam construction and operation, both in the United States and abroad, are now coming under closer scrutiny. A growing number of dams have been slated for removal in the United States because officials have judged their environmental damages to outweigh their current benefits to society. Among them are Edwards Dam on Maine's Kennebec River and the Elwha and Glines Canyon dams in Washington state. The U.S. Army Corps of Engineers is now studying the idea of breaching four dams on the Lower Snake River in the Pacific Northwest in order to restore salmon and steelhead populations (DeSena 1997, Anonymous 1997*b*). Upon signing the landmark agreement clearing the way for the removal of Edwards Dam, Secretary of Interior Bruce Babbitt said there is now ''a challenge to dam owners and operators to defend themselves—to demonstrate by hard facts, not by sentiment or myth, that the continued operation of a dam is in the public interest, economically and environmentally.'' (U.S. Department of Interior 1998). Internationally, an independent World Commission on Dams has been established to evaluate ''the development effectiveness'' of large dams and to assess ''if and how they can contribute to sustainable development'' (Dorcey 1997).

Proposals have also been issued to operate dams in a manner that restores or protects some of the ecological functions of a river's natural flow pattern. Typically this involves managing dams so as to partially mimic pre-dam patterns of runoff in order to maintain critical habitat and benefit native species. For example, after the U.S. Fish and Wildlife Service invoked the federal Endangered Species Act to protect critical habitat for endangered chubs, suckers, and squawfish, officials began dictating that operation of Flaming Gorge Dam on the Green River in Utah be driven not just by irrigation, flood control, and hydroelectric power needs, but in a way that would re-create natural habitat (Collier et al. 1996). Poff et al. (1997) have described the importance of five critical components of natural river flow regimes in determining ecological functions, and note that ''just as rivers have been incrementally modified, they can be incrementally restored, with resulting improvements to many physical and biological processes.''

Doubling water productivity

Opportunities to protect and restore natural freshwater systems will be limited without a concerted effort to reduce human demands for water. Given projected demographic trends and the already serious state of decline of many freshwater ecosystems, I maintain that society will need to approximately double water productivity over the next three decades. In this usage, water productivity is a broader concept than water use efficiency. It refers to the output, service, satisfaction, or benefit derived from each unit of water removed from natural water sources.

Because irrigation accounts for two-thirds of global water extractions worldwide, raising water productivity in agriculture is the linchpin of any strategy to double water productivity globally. Technologies and methods now exist to go a long way toward achieving this goal. Drip irrigation, for example, has the potential to at least double crop yield per unit water in many applications, including irrigation of most vegetables, cotton, sugarcane, and orchard and vineyard crops. A collection of research results from various Indian research institutes indicates typical water use reductions with drip irrigation of 30–60% and typical yield increases of 20–50% for a variety of crops, including cotton, sugarcane, grapes, tomatoes, and bananas (Indian National Committee 1994, Sivanappan 1994). Together, the greater water application efficiency and higher yields produce a doubling or tripling of water productivity. Although few technologies have the combined water-saving and yield-enhancing potential of drip irrigation, many other technologies and methods can produce substantial improvements in efficiency and thus water productivity (Postel 1999).

A shift toward more water-efficient diets can play an important part as well. Calories derived from animal products require 4–16 times more water to produce than those derived from vegetable products (Cohen 1995). Overall, the typical American diet requires twice as much water to produce as nutritious but less meat-intensive diets common in developing countries and some Asian and European countries (UNFAO 1996). By eating lower on the food chain or selecting less water-intensive forms of animal protein, consumers could get twice as much nutritional benefit out of each liter of water consumed in food production. Stated differently, the same volume of water could feed two people instead of one, leaving more water in rivers and streams to help restore fisheries, wetlands, and natural ecosystem services (Postel 1999).

Substantial potential exists in industries and municipalities to move toward greater water productivity as well. Installing water-efficient plumbing fixtures in homes and commercial buildings, establishing native landscapes rather than water-consumptive lawns, recycling process and cooling waters in manufacturing plants, and reusing municipal wastewater for irrigation are just a few of the potential measures for raising water productivity (Vickers, *in press*). In most cases, however, water pricing and other policies and institutions fail to encourage efficient water practices, delaying the transition to a more water-efficient economy.

A multiple-benefits approach to water management

Meeting the water challenges of the 21st century is going to require new ways of thinking about, using, and managing water. Reconciling the growing tension between instream water needs and extractive water needs will require new and creative approaches. Long the purview of engineers, water planning and management increasingly requires the input of many different professions and many different stakeholders. It is no longer sufficient for water planners to project future demands and then construct new projects to meet those demands. The rising costs—economic, ecological, social, and political—of many large water projects requires a new approach, one that builds on the idea that water can be managed to provide multiple benefits simultaneously or sequentially, which, in turn, offers opportunities for defusing tensions between competing water uses and users. Rather than irrigators, environmentalists, fishing interests, and other water users each battling for a bigger slice of the water pie, they may be able to achieve their separate goals jointly and cooperatively by getting multiple benefits out of the same water.

In the Colorado River delta in northern Mexico, for example, there is a 20 000-ha wetland that resembles what the delta must have looked like prior to the construction of large dams and diversions in the Colorado River basin. The treaties that divide the Colorado's flow among seven U.S. states and Mexico allocate more water to the eight parties than the river actually carries in an average year. Virtually no flow remains to sustain the delta ecosystem that American naturalist Aldo Leopold once called ''a milk and honey wilderness'' and a land of ''a hundred green lagoons'' (Leopold 1949).

Today, most of the delta is a desiccated landscape of salt flats, mud flats, dry sand, and scattered murky pools. The Ciénaga de Santa Clara, however, stands out as a vital wetland remnant. It is a major stopover point for migratory birds along the Pacific flyway, and may be home to the largest remaining populations of endangered Yuma Clapper Rails (*Rallus longirostris yumanensis*) and desert pupfish (*Cyprinodon macularis*) (Glenn et al. 1992, 1996).

The Ciénaga de Santa Clara wetlands are the unplanned consequence of an agricultural drainage canal that extends from an irrigation district in Arizona to the southern portion of the Colorado delta. It was built as a temporary solution to the water quality problems resulting from the discharge of the district's salty drainage into the river just before the river crossed the border into Mexico. Although poor in quality, the irrigation drainage has created and sustains one of the largest desert wetlands in the American southwest and has helped save at least two species from extinction (Postel et al. 1998). By supporting the Ciénaga, the irrigation district's water is generating dual benefits: it is growing crops and it is creating wildlife habitat. California's tragic experience with selenium-laced drainage entering the Kesterson wetlands is a reminder that this kind of arrangement needs to be carefully planned and monitored (Harris 1991, Dunning 1993). Executed properly, however, the reuse of irrigation water to expand wetland habitat is a way of increasing water productivity; getting more value out of each unit of water removed from natural water systems.

Flood-recession farming, a common practice in the Senegal, Niger, and Lake Chad basins of SubSaharan Africa, provides another example of the multiple benefits made possible from a whole-systems approach to raising water productivity. As the phrase implies, flood-recession cropping involves planting crops after a river's seasonal flood recedes. The moisture stored in the floodplain soils then supports the crops through the growing season. Judged by grain yields alone, flood-based agriculture appears considerably less productive than modern intensive irrigated agriculture. But when other productive elements of flood-recession systems are included, this productivity equation shifts (Scudder 1991, Horowitz and Salem-Murdock 1993).

A case in point is the Manantali Dam on Mali's Bafing River, a tributary of the Senegal River. Constructed during the 1970s, the dam is supposed to be operated to expand irrigation, generate hydropower, and extend barge transportation. By eliminating the river's seasonal floods, however, the planned operation of the dam would destroy a highly productive flood-based system that valley dwellers depend on for their livelihoods. In a creative example of ecologically based systems thinking, an international and interdisciplinary research team demonstrated that by using the dam to release an ''artificial'' flood rather than eliminating the flood altogether, the primary goals of the dam could be met without destroying the flood-dependent production systems downstream. They also showed that when all of the flood-based system's benefits were taken into account, including crop production, fisheries, and use of the floodplain by livestock, this system was actually more productive than the irrigation option (Horowitz and Salem-Murdock 1993). Researchers are now exploring the potential of this approach for river basins in northeastern Nigeria, the Tana basin in Kenya, and the Mekong in Southeast Asia (Horowitz 1994).

Summary and Conclusions

Satisfying humanity's water demands while simultaneously protecting the ecological support functions of freshwater systems will be one of the most difficult and important challenges of the 21st century. Water scarcity has spread rapidly to many parts of the world as population and consumption levels have increased against a fixed supply of renewable fresh water. Meeting the challenges water scarcity poses to food production, ecosystem health, and political and social stability will require new approaches to using and managing water. Greater efforts will be needed to reserve water for the maintenance of ecological functions and, where necessary, to return water to natural systems to restore those functions. Concerted efforts will also be needed to slow the growth in human demands for water. I have urged the adoption of a goal of doubling water productivity: getting twice as much benefit out of each unit of water extracted from natural water systems.

Creative new ways of obtaining both commodity and ecosystem benefits from the same volume of water will also be needed. Developing and implementing these options will require new partnerships and alliances that draw upon the expertise of professionals from many disciplines including biology, ecology, engineering, hydrology, economics, anthropology, and demography. It will also require a willingness of professionals to cross not only disciplinary boundaries but professional boundaries; for academics to join with practitioners, for example, and for both of these groups to interact with policy makers.

Water management practices that protect natural capital rather than depleting it will be critical to the survival and sustainability of agricultural and economic activities. In the spirit of the new social contract for science called for by Lubchenco (1998), institutional reward mechanisms to encourage synergistic collaborations among scientists, practitioners, water users, and policy makers could greatly help advance the cause of ecologically sound and sustainable water use and management.

Acknowledgments

I thank the Pew Fellows Program in Conservation and the Environment for the financial support to undertake this research. Portions of this article are adapted from my book

Pillar of Sand (Postel 1999), the research and writing of which were supported by the Pew Fellows Program and the Worldwatch Institute. I also thank the Ecological Society of America and the American Society of Limnology and Oceanography for the invitation to deliver a plenary address at their joint meeting in St. Louis in June 1998, which led to the invitation to prepare this article. Finally, thanks to Stephen Carpenter, Robert Naiman, and Catherine Pringle for reviewing the manuscript.

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