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# America's Water Supply: Status and Prospects for the Future

by
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**W**ater is critical for the health of both humans and ecological systems and an important element in many of our recreational and economic activities. Neither plants nor animals can survive long without it, and water is used in virtually everything we make and do. It is the most widely used resource by industry; it is used both directly and indirectly to produce energy; it provides the basis for much of our outdoor recreation; it is an important part of our transportation network; it serves as a vehicle for disposing of wastes; and it provides important cultural and amenity values. The quality of life, as well as life itself, depends on an adequate supply of freshwater.

Water covers almost 70 percent of the surface of the globe and is the Earth's most abundant resource. About 97 percent of the water is in the oceans and is too salty for drinking, growing crops, or most other human uses. Almost all of the freshwater is held in the ice caps of Antarctica and Greenland or in deep underground aquifers where, for most practical purposes, it is inaccessible for human use. Only about 0.3 percent of the earth's freshwater, less than 100,000 cubic kilometers or 81 trillion *acre-feet* (the unit of water needed to cover one acre to a depth of one foot, which is about 326,000 gallons), is found in rivers and lakes. These surface waters together with accessible groundwater resources comprise the usable supply (Table 1).

Water is also one of the Earth's most renewable resources. Globally, the total quantity of water is essentially constant and unaffected by human activities. Driven by energy from the Sun, water constantly circulates from the seas, lakes, and streams (through evaporation) or the plants (through transpiration) to the atmosphere and back to earth (through precipitation). The evaporative process removes salts and other impurities that may be picked up either naturally or as a result of human use, making it possible to use and reuse water virtually indefinitely.

The United States is relatively well endowed with water. Annual precipitation averages nearly 30 inches or 4,200 billion gallons per day (bgd) throughout the conterminous forty-eight states (Figs. 2 and 3). Two-thirds of the precipitation is quickly evaporated and transpired back to the atmosphere; the remaining one-third flows into the nation's lakes, rivers, groundwater reservoirs, and eventually to the ocean (Figure 1). These flows provide a potential renewable supply of 1,400 bgd, which is nearly fifteen times current daily consumptive use -- the quantity of water withdrawn from but not returned to a usable water source. Moreover, much larger quantities of freshwater are stored in the nation's surface and groundwater reservoirs. Reservoirs behind dams can store about 280,000 billion gallons (about 860 million acre- feet), even larger quantities are stored in lakes, and water stored in *aquifers* (subterranean bodies of unconsolidated materials such as sand, gravel, and soil that are saturated with water and sufficiently permeable to produce water in useful quantities) within 2,500 feet of the earth's surface is at least 100 times the reservoir capacity. These stocks are equivalent to more than fifty years renewable supply.

Despite the apparent global and national abundance and the renewability of the resource, water adequacy has emerged as one of the nation's primary resource issues. For many of the developing countries of the world the problem is a critical one. In this country concerns about the availability of freshwater to meet the demands of a growing and increasingly affluent population while sustaining a healthy natural environment are based on several factors: (1) uncertainties as to the availability of supplies stemming from the vicissitudes of the hydrologic cycle and the threat that a greenhouse warming might alter the cycle; (2) the high costs of developing additional surface-water supplies; (3) the vulnerability of the resource and the problems of restoring and protecting valued surface and groundwater resources; (4) the importance of reliable supplies of high-quality water for human and environmental health and economic development; and (5) the shortcomings of our institutions for allocating scarce supplies in response to changing supply and demand conditions.

## UNCERTAINTY OF SUPPLY

Timing, location, and reliability are important dimensions of the potential value of supplies. Because of the spatial and temporal variations in the distribution of water, national and long-term annual averages of precipitation and runoff are poor indicators, for practical purposes, of available supplies and potential problems. Precipitation generally declines as one moves from east to west in the United States (Figure 2). Average annual precipitation ranges from less than 1 inch in some desert areas in the Southwest to more than 60 inches in parts of the Southeast.

Underlying these regional averages are large seasonal and annual variations that can result in droughts and floods. In the absence of flow regulation and storage, the ratio of the maximum to minimum streamflow within a year may exceed 500 to 1. Natural climatic variability results in interannual fluctuations. The ratio of very high annual flows (amounts exceeded in five percent of the years) to very low (exceeded in 95 percent of the years) is 2.9 for the conterminous United States; the ratio for the nation's arid and semiarid regions is significantly higher. But almost any region lacking adequate storage is likely to encounter both periods when supplies are relatively plentiful or even excessive as well as periods of shortages.

Water resource issues tend to be local or regional in nature: abundant supplies in one area are of no help to water-deficit areas unless there are facilities to transport supplies among regions. Water flows naturally within hydrologic basins and can be moved between basins where transfer facilities have been constructed. But water is too expensive relative to its marginal value to transport long distances out of these existing channels in response to climate- induced changes in supply or demand. Thus, large seasonal, annual, interannual, and regional variations in precipitation and runoff pose major challenges for planners and down-to-earth risks for water users and occupants of the flood plains.

Human efforts to alter the hydrologic cycle date back to ancient times. Primitive societies tried to bring rain through prayer, rain dances, human and animal sacrifices, and other rituals. *Cloud seeding* (dropping silver iodide crystals or dry ice into selected clouds to stimulate ice crystal formation and induce precipitation) represents today a more recent and more scientific, but still uncertain, attempt to influence rainfall. Although it is questionable whether any of these intentional efforts have succeeded in significantly modifying the rainfall, human activities are inadvertently altering the climate. Changes in land use and land cover can affect atmospheric circulation and the movement of moisture locally. Evaporation from neighboring states, which depends on land use, can be the source of as much as one-third of the precipitation of inland areas. The anthropogenic increase in the atmospheric concentration of carbon dioxide and other greenhouse gases is expected to increase the average global surface temperature. Such a change would also affect precipitation patterns, evapotranspiration rates, the timing and magnitude of runoff, and the frequency and intensity of storms as well as the demand for water. But the magnitude and even the nature of these impacts on the supply and demand for water in specific regions are largely unknown.

## RISING COSTS OF DEVELOPING NEW SUPPLIES

The United States has invested large sums of private and public money to adapt to the vicissitudes of the hydrologic cycle. A vast infrastructure of dams, reservoirs, canals, pumps, and levees has been constructed over the years to collect, control, and contain surplus flows and to distribute water on demand during low as well as high flow periods. As a result, most water users take for granted that virtually unlimited quantities of freshwater will be available at the turn of a tap. Moreover, the nation's water use patterns have come to reflect a disregard for the limits of natural hydrological conditions; the highest levels of use and the lowest prices are often found in the more arid areas of the country. But, as droughts and floods frequently remind us, water often is not where we want it, when we want it.

### *Dams and reservoirs - the traditional approach to increased supplies*

More than 75,000 dams and reservoirs with a storage capacity of about 860 million acre-feet help convert the United States' naturally varying water resources into more reliable and controlled supplies. Even though currently developed storage represents only about 70 percent of the potential reservoir capacity, dam construction has slowed to a trickle in recent years. Moreover, future increases in assured water supplies for municipal, industrial, and irrigation use through the addition of surface reservoir capacity are likely to be modest for several reasons.

First, sedimentation is reducing existing reservoir capacity each year by about 1.5 million acre-feet (maf). Second, sizable investments are required to rehabilitate, maintain, and in some cases, remove dams. A 1992 national dam inventory classified almost a third of all dams in the United States as hazardous: more than 10,000 dams as having a high hazard potential and another 13,500 with a significant hazard potential. The consequences of a dam failure can be catastrophic. In 1972, 125 people died and more than 3,000 were left homeless when Beaver Creek Dam in West Virginia failed. In 1977, 14 were killed and more than $1 billion in damages resulted from the failure of Teton Dam in Idaho, and 39 were killed when Kelly Barnes Dam in Georgia failed.

Third, the best sites for storing water are the first to be developed within a river basin. Consequently, subsequent increases in storage generally require an ever larger investment. A study of decadal changes in reservoir storage capacity per unit volume of dam for the 100 largest dams in the United States suggests that sharply diminishing returns are already the case: the average reservoir capacity produced per cubic yard of dam declined 35-fold between the 1920s and 1960s.

Fourth, there are diminishing returns in the "safe yield" produced by successive increases in reservoir capacity within a river basin. At some point the increase in evaporation losses due to increased reservoir surface area can more than offset any gains in safe yield associated with additional surface storage. A study of U.S. river basins suggests that safe yield reaches a maximum when the ratio of storage to average annual renewable supply is in the range of 1.6 to 4.6. By this criterion the point of negative returns may have already been reached in three major basins -- the Lower Colorado, the Upper Colorado, and the Rio Grande, where the ratios of storage to average renewable supply are now within this range.

The fifth, and perhaps most important, reason for the inevitability of rising water costs is that the remaining opportunities for adding storage are now far more restricted by environmental concerns: the environmental costs of storing and diverting water increase as the number of free-flowing streams declines and as society attaches more value to water left in a stream. To the extent that water projects control flooding and capture water that otherwise would be lost to human use as a result of evaporation or runoff to the oceans or other unusable sinks, such facilities increase usable freshwater supplies. However, as water development expands and the resource becomes increasingly scarce (that is, when using water for one use adversely affects its availability for other uses), construction of another dam and reservoir on a river may add little, if anything, to the overall supply. Rather, the project may only provide a means of allocating supplies among alternative uses, usually from instream uses such as fish and wildlife habitat and recreation to withdrawal uses such as irrigation or domestic supplies. Examples are found in basins where the flows are already highly controlled and intensively used, such as the Colorado River Basin. The value of the water that is taken from instream uses (such as hydroelectric power generation and habitat for fish and wildlife) when more water is withdrawn becomes an important factor in the economic costs (both financial and environmental) of augmenting a region's effective supply of water for domestic, industrial, or agricultural use.

Public resistance to the high financial and environmental costs associated with the traditional means of augmenting water supplies has forced suppliers to consider a number of alternative approaches to increasing reliable supplies such as recycling wastewater, desalination, and more exotic schemes.

## *Recycling*

The technology now exists to upgrade wastewater to meet standards for domestic use, and wastewater recycling is certain to become an increasingly important source of new water in the coming decades in many areas. Although public resistance is still a barrier to the use of reclaimed water for drinking, recycling for other uses is more and more common. California, the leading consumer of recycled water in the United States, uses about 325,000 acre-feet of recycled water annually for industrial cooling, groundwater recharge, barriers against salt-water intrusion, and irrigating landscapes, parks, golf courses, and certain crops.

The economics of recycling are driven in large part by the environmental and health regulations that dictate how communities collect and treat waste water. It costs about \$430-\$490 to recycle an acre-foot of water, which is several times what most cities paid to develop existing supplies. About three-fourths of the cost of recycling wastewater is incurred meeting federal requirements that effluent discharged into waterways undergo certain minimal treatment. The marginal costs of the additional purification needed to make the water suitable for unrestricted agricultural use and of storing and conveying the upgraded water to the user are only about \$125 per acre-foot, which is competitive with alternative sources of new supplies in many areas.

## *Desalination*

Almost unlimited quantities of sea water are available to coastal areas, and brackish waters containing salt levels too high for most uses are available in many aquifers and inland seas. The cost of desalination depends on the quantity of salts removed. It is less expensive if the process starts with brackish water -- with salt concentrations well below the 35,000 parts per million characteristic of sea water -- and if the finished water is not treated to meet drinking water standards. Technological advances have reduced desalting costs as much as 50 percent during the last three decades, and future improvements may have the potential of still further reductions. Still, desalination of sea water today costs about \$1,800 an acre-foot, and is energy-intensive, making it a supply of last resort. Brackish water, on the other hand, might be upgraded to drinking-water for less than half this cost.

### *Other potential sources of supply*

Weather modification through cloud seeding, though controversial, is still seen by some as a promising, low-cost way to increase water supplies in arid and semiarid areas. While the impact of seeding on precipitation remains difficult to measure, winter *orographic* clouds (formed by encounters with elevated features such as mountain ranges) have been seeded in areas of the western United States for nearly half a century, increasing seasonal precipitation in some areas, by some reports, by about 10 percent. Recent research suggests that other seeding materials might condense precipitation from clouds of higher temperatures and thus in other seasons.

Proponents argue that in areas with favorable conditions cloud seeding can supplement water supplies for about $10 an acre-foot. But even if the technology is improved and the economics are favorable, the potential impact on water supplies is likely to be small and geographically limited. Moreover, legal barriers may restrict its use. Towns receiving more snow might object to higher snow- removal costs; downstream residents might suffer increased spring flooding; and downwind communities might feel that they are being deprived of precipitation that otherwise would have fallen on them.

Vegetation management, such as removing *phreatophytes* (high-water-use plants that thrive along streams, such as trees of the willow family) or managing forests for increased water yields, could increase water supplies in some areas. The financial costs of vegetation management may be competitive with other supply augmentation alternatives, but environmental concerns may limit its use: phreatophyte removal is likely to have adverse effects on wildlife habitat, and managing forests for increased water yields may conflict with commercial timber production and recreational opportunities.

Growing water scarcity in the arid and semiarid West has fostered a number of bold proposals to utilize the enormous quantities of water stored in polar ice (Table 1) or to divert northern rivers in the largely uninhabited areas of Canada and Alaska. However, the technical, economic, legal, and environmental obstacles to transporting and using icebergs to supplement water supplies in an area such as southern California currently appear insurmountable. The enormous financial and environmental costs of proposals such as the North American Water and Power Alliance that would transport 110 million acre-feet of water annually (about eight times the average annual flow of the Colorado River) from Alaska and northern Canada to the western United States and northern Mexico have relegated them to the realm of science fiction for the foreseeable future.

## VULNERABILITY OF THE RESOURCE

Aquifers, which contain much of the country's usable water, are classified as confined or unconfined. Confined aquifers are overlain by impermeable materials and receive little or no recharge. The natural movement of water into and out of these aquifers is so slow that they can be treated as a stock resource that can be depleted through pumping. Unconfined aquifers, on the other hand, are more active and integral parts of the hydrologic cycle: continually recharged by the percolation of precipitation, snow melt, or water from overlying streams, canals, and reservoirs. Discharges from unconfined aquifers are the source of about 30 percent of the nation's streamflow. Recharge and discharge rates vary with seasonal and annual changes in precipitation and runoff as well as with pumping. In the long term and under natural conditions, water lost through discharge is balanced by ongoing recharge.

Pumping disrupts the equilibrium between recharge and discharge; groundwater levels decline when water is initially withdrawn. If the rate of pumping is not excessive, a new equilibrium is established (at a lowered water table) in which pumping is balanced by changes in the natural rates of discharge and recharge. Depletion can continue for decades, as it has in the portions of the Ogallala aquifer that lie under the southern High Plains and in the San Joaquin Valley of California. Eventually, however, if natural flows do not adjust first, higher costs due to increased pumping lifts and lower well yields act to reduce the rate of pumping. Higher pumping costs have already resulted in several million acres being taken out of irrigation in the High Plains. The San Joaquin Valley likely would have had a similar experience were it not for the federal Central Valley Project that provides the region with millions of acre-feet of water annually from the Sacramento and Trinity basins in northern California. In 1980, groundwater, which provides about half of our drinking water and is the source of nearly one-fourth of all freshwater withdrawals, was being depleted from six western and midwestern river basins at a rate of 20.4 million acre-feet per year. In 1983 groundwater levels declined under more than 14 million irrigated acres in eleven states in amounts ranging from 6 inches to over five feet.

Pumping from aquifers near a coastline reduces the natural discharge of freshwater toward the sea, causing saline water to shift inland and toward the surface. Saltwater will continue to intrude into the aquifer under these conditions as long as pumping exceeds the flow of freshwater to the sea. Saltwater intrusion threatens important drinking water supplies in a number of coastal areas including Long Island; Cape Cod; seven New Jersey counties; and the Florida cities of Miami, Tampa, and Jacksonville.

Water quality is an important dimension of water supply. Water is rarely pure. All ground and surface water contains minerals dissolved from soil and rock, and precipitation may contain impurities picked up in the atmosphere. The natural concentrations of contaminants in the nation's rivers, lakes, and aquifers are generally acceptable for most human uses. Anthropogenic factors, however, contribute a wide variety of substances that have reduced and in some cases destroyed the utility of specific water supplies. Despite the major progress that has been made in recent decades in reducing municipal and industrial point sources of pollution, about one-third of the assessed rivers, lakes, and estuaries in 1990 were judged to be capable of only partially supporting their designated uses.

Only a small fraction of the nation's groundwater resources is known to be contaminated such that they fail to meet drinking water standards. Communities that rely on groundwater for drinking are subject to federal monitoring requirements. In most other areas, however, groundwater monitoring is infrequent or nonexistent. Effective monitoring is expensive, and there are millions of potential sources of groundwater contamination. For example, roughly 20 million on-site domestic waste disposal systems in the country contain nitrates, phosphates, pathogens, inorganic contaminants, or other toxins that could leak into neighboring groundwater supplies. There are 1.5 million underground tanks that store hazardous substances or petroleum products: many of them are not protected from corrosion, and a good many have been in service beyond their expected 15 to 20 year lifetime. Other potential sources of groundwater contamination include landfills, abandoned waste sites, oil and gas brine pits, and the chemicals applied to most of the 325 to 375 million acres typically planted to crops each year.

## IMPORTANCE OF THE RESOURCE

Water uses are separated into *instream* uses and those that involve *withdrawing* the resource from a surface or groundwater source. The former include the production of hydropower, recreation, and the provision of fish and wildlife habitat. Water is withdrawn for a variety of purposes ranging from drinking, the removal of wastes from homes and factories, irrigation of crops and golf courses, and snow making. Withdrawal uses are rarely fully consumptive; on average more than 70 percent of the water withdrawn is eventually returned to a stream or groundwater source where it can be used again. However, when water is withdrawn and subsequently returned, it affects, often adversely, the quality, location, or timing of the water available for other withdrawal or instream uses.

Freshwater withdrawals for all purposes averaged more than 1,300 gallons per person, per day in 1990 (Table 2); consumptive use averaged about 380 gallons. Per capita withdrawals peaked in 1975, and total withdrawals peaked in 1980. The recent decline in offstream water use is due in part to efforts to restore some of the instream values that were sacrificed in providing for the ten-fold increase in withdrawals between 1900 and 1980.

Irrigation and thermoelectric cooling accounted for 80 percent of all withdrawals in 1990. In the seventeen western states, irrigation alone accounted for five of every six gallons of water consumptively used. About 100 gallons per person per day was for domestic uses such as drinking, bathing, washing clothes and dishes, toilets, and food preparation as well as outdoor uses such as watering lawns and gardens and washing cars. Drinking and cooking represent only a small fraction of domestic water use, but in the absence of dual supply systems, all domestic supplies must meet drinking water standards.

The importance of freshwater to society is not easily measured and is commonly overlooked when it is readily available. But, as Benjamin Franklin suggested, we know the value of water when the well runs dry. A striking illustration of the importance of water is provided by the plight of the many millions of people around the world who lack ready access to clean water. The differences between developed and developing countries are many, but few have greater impact on human welfare than the availability of safe drinking water and adequate sanitation. In contrast to the situation in the United States where these basic services are taken for granted by virtually everyone, 1.3 billion people in the developing world (almost 1/4 of all who live on the Earth) lack access to safe drinking water supplies and 1.8 billion are without decent sanitation facilities. Water-related diseases and illnesses exact devastating impacts on mortality and morbidity; prospects for economic development are also decreased by the diminished health of the labor force and the countless hours spent transporting water for drinking and other domestic uses from distant and often contaminated sources.

We do not need to look abroad for examples of the costs associated with inadequate water supplies. Microorganisms in municipal drinking water supplies have led to several outbreaks of water- borne disease in the United States. *Crytosporidium* in Milwaukee's water supply resulted in some 400,000 serious illnesses and 50 deaths in the spring of 1993. Just before Christmas 1983, contaminated drinking water in Luzerne County, Pennsylvania caused an outbreak of *giardiasis* -- a common diarrheal disease -- that left 6,000 people ill and forced 75,000 others to obtain more expensive alternative sources of drinking water. Recent droughts in the western and southeastern regions of the United States have resulted in sizable economic and environmental losses. Even in the absence of drought, tens of millions of dollars worth of potential hydropower production was sacrificed in the Colorado, Columbia, Missouri, and Sacramento river basins when water was allocated for the preservation of fish and wildlife.

## INSTITUTIONAL SHORTCOMINGS

The opportunities as well as the incentives to use, abuse, conserve, or protect water supplies are the result of many fragmented local, state, and federal water institutions. These institutions determine how tradeoffs among alternative water uses are made and whether high- quality water is likely to be available for drinking, new development opportunities, water-based recreation, or fish and wildlife habitat. Water adequacy would be less of a concern were these institutions more effectively interlinked and more capable of efficiently protecting the quality of drinking supplies and valued aquatic ecosystems and of allocating scarce supplies to higher value uses in response to changing supply and demand conditions.

High rates of water withdrawals are a legacy of past laws and policies that historically favored offstream over instream uses. During the first two-thirds of this century water policy was dominated by the view that it is wasteful to leave resources unused that are capable of producing crops, power, or other products. Water was free for the taking, and most users enjoyed virtually unlimited supplies at low cost during all but the most extreme droughts. But the environmental costs of ignoring the impacts on instream flows were high; thousands of miles of once free-flowing streams were lost and the quality of many streams and lakes deteriorated such that they were unusable for most purposes. The engineering and diversion of the nation's rivers contributed to the sharp decline in the nation's wetlands, which store floodwater, control erosion, provide fish and wildlife habitat, improve water quality, and furnish recreational opportunities.

During the last quarter century, the policy focus has shifted almost 180o toward protecting remaining flows and recovering some of the environmental and recreational benefits that were sacrificed in the drive to provide homes, factories, and farms with inexpensive water. This shift is evident in a number of legislative acts. The Wild and Scenic Rivers Act of 1968 precludes development activities that might significantly alter an area's natural amenities on thousands of miles of rivers and streams. The National Environmental Policy Act of 1970 requires all federal agencies to give full consideration to environmental effects in planning their programs. The Federal Water Pollution Control Amendments of 1972 (commonly known as the Clean Water Act) together with the Safe Drinking Water Act of 1974 and other legislation regulating the use and cleanup of toxic materials have made water quality rather than water supply the driving force behind the nation's water-related investments. The expenditure of more than $500 billion on water pollution control since 1972 has produced major improvements in the quality of U.S. surface water resources in the face of increasing population and economic pressures.

The Endangered Species Act (ESA) of 1973 has come to dominate water management and investment decisions in the Pacific Northwest. Since 1982 the Northwest Power Planning Council has supervised the expenditure of more than $1.7 billion for measures to rebuild salmon stocks. Despite these costly efforts, three stocks of salmon that spawn in the Snake River are listed as threatened or endangered, petitions have been filed for listing several other stocks, and as many as eighty-five salmon stocks throughout the Columbia River basin are so weakened that they could be granted protection under the ESA.

The ESA could have a similar impact on water management in California where the Delta smelt, whose prime habitat is the Sacramento-San Joaquin Delta, has been granted protection. Protecting the habitat of the smelt or other Delta species that are under consideration for protection would limit the ability to export water from the Delta to the millions of people in central and southern California who depend on its supply for domestic, industrial, and agricultural uses. The ESA has been invoked to alter water investment and management decisions in other areas, including putting a hold on the $590 million Animas-La Plata project in the Colorado River Basin.

The Electric Consumers Protection Act of 1986 (ECPA), which requires the Federal Energy Regulatory Commission to give power and non-power benefits equal consideration in its licensing and relicensing decisions, has made hydropower relicensing another battleground in the struggle over alternative water uses. The United States has more than 2,300 hydroelectric power plants with a total capacity of 73,500 megawatts; annual production in 1993 of 265 billion kilowatt hours accounted for about 9% of U.S. electrical power generation. Most of these plants operate under federal licenses that were issued as many as fifty years ago, when fewer questions were raised about the effects of hydropower on fish and wildlife habitat. As the licenses expire, the utilities are faced with a complex, costly, and time-consuming relicensing process under ECPA that is likely to require a detailed environmental assessment of a plant's impacts on fish and wildlife habitat, water quality, recreation, land use, local communities, and cultural resources. If a new license is eventually granted, it is apt to be encumbered with restrictions that diminish the value of the plant's power output.

## CONCLUDING THOUGHTS

There is justifiable cause for concern over the adequacy of our water supplies. We have limited control over the resource, most opportunities for increasing supplies are financially and environmentally costly, and current uses are depleting or contaminating some valued supplies. While demands for the many services provided by water are growing, institutions have been slow to adapt to the challenges of growing scarcity, supply vulnerability, and rising instream values.

On the other hand, there is reason for optimism as to the long-term adequacy of water supplies. Although the costs of freshwater are likely to rise in the future, we are in a position today to influence the magnitude and even the nature of those costs. Critical determinants of future water costs will be the efficiency with which existing supplies are managed, how supplies are allocated among competing uses, and the effectiveness and costs of efforts to protect aquatic environments and drinking water quality.

As the competition for water increases, all users within a hydrologic unit or watershed become increasingly interdependent; each water use can affect the quantity or quality available to all the others. Moreover, ground and surface water supplies are often naturally connected such that what is done to one affects the other. Today the interdependencies among water users and the interchangeability of supplies are all too often ignored in management decisions because natural hydrologic regions are split into multiple political and administrative units; water supply facilities are under separate ownership; and ground and surface waters are subject to quite different laws. Integrated management of existing supplies and infrastructure, ideally at the river basin level (Figure 4) but also within smaller watersheds, is a cost-effective means of increasing reliable water supplies and resolving water conflicts in many regions.

With demand growing faster than supply in many areas, we need to provide appropriate incentives to conserve and protect the resource, and opportunities to allocate supplies efficiently among competing uses. When water is under priced and its allocation is restricted by law and tradition, the inevitable results are inefficient water use, lost development opportunities, interruptions in service, and higher costs for new water users. On the other hand, when the real costs are borne by users of the resource and there are opportunities to transfer water voluntarily among alternative uses, then the resource is used more efficiently, there are increased incentives to develop and adopt water-conserving technologies, the highest-value uses are assured of an adequate supply, and society derives greater net benefits from its scarce supplies. Efficient, voluntary water transfers must include provisions to incorporate third-party effects into trade decisions (since parties other than the buyer and seller are likely to be impacted by a water transfer), without imposing high transactions costs. The nature and magnitude of future water costs will depend importantly on our success in developing such market institutions.

The provision of instream benefits such as fish and wildlife habitat, water-based recreation, and the amenities of natural waterways pose special problems because they are not marketed. Moreover, while the adoption of water-conserving technologies can slow or even reverse the growth in demand for domestic, industrial, and agricultural water, technology is not likely to offer suitable substitutes for instream uses such as fish and wildlife habitat, water- based recreation, and the amenities of natural waterways. Another challenge for improving water management and allocation decisions is to develop procedures that expeditiously strike an appropriate balance among environmental, social, and developmental values. In some instances, environmental values continue to be slighted by institutions rooted in a bygone era when water left in a stream was assumed to have no value. In other cases, environmental values are introduced preemptively through legislation such as the Endangered Species Act or through long and costly judicial or administrative proceedings. The public interest is likely to be better served if instream uses are considered within a basin-wide context rather than on a project by project basis.

The United States has made impressive gains over the last two decades in restoring and protecting its water resources. But resistance is growing to the enormous investments that continue to be made in treating industrial and municipal wastes because of high costs and diminishing returns. More cost-effective approaches to water-quality goals are needed. These might include effluent fees that provide incentives to develop and adopt least-cost technologies, and tradable permits to pollute that establish an allowable quantity of pollution in a watershed and provide incentives to meet this level at the lowest cost. Non-point-source pollutants such as runoff from farms, urban areas, and construction sites and seepage from landfills and septic systems are now the principal sources of pollutants reaching the nation's waters. Since these pollutants lack specific points of discharge where they can be collected and treated, watershed management with particular emphasis on the use of *riparian* (riverside) lands must be employed to achieve significant further improvements in the quality of the nation's waters.

Concerns regarding the safety of drinking water are still growing in spite of the billions of dollars that are spent annually monitoring and treating supplies. Legislative reforms are needed that would (1) allow local communities to target their resources to the most pressing problems; (2) provide the Environmental Protection Agency more flexibility to focus on the contaminants that pose the greatest health risks; and (3) give greater emphasis to protecting drinking water supplies from contamination in the first place.

In summary, with improved basin-wide management of supplies, institutions that enable water to be transferred efficiently and expeditiously among uses in response to changing supply and demand conditions, and cost-effective approaches to protecting aquatic ecosystems and drinking water supplies, reliable supplies of freshwater will be available at readily affordable prices for the foreseeable future.

## FOR FURTHER READING

*Water In Crisis: A Guide to the World's Fresh Water Resources* by Peter H. Gleick, Oxford University Press, New York, 1993.

"Water Resources: Increasing Demand and Scarce Supply," by K. D. Frederick in

*America's Renewable Resources: Historical Trends and Current Challenges*, K. D. Frederick and R. A. Sedjo, editors. Resources for the Future, Washington, D.C., 1991.

U.S. Geological Survey *National Water Summary* (various years 1983-1991), Water-Supply Paper series (U.S. Government Printing Office, Washington, D.C.).

Reviewers

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