Water | 5

Status

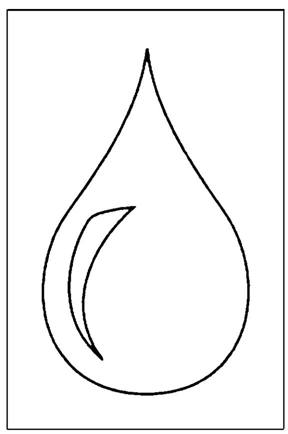
- Competition for high-quality water is increasing due to population grow@ concerns for the environment, and assertion of new water rights.
- Significant water-quality problems; urban water infrastructure aging; ground water overdraft is a problem in some areas.

Climate Change Problem

- **Changes** in water availability could add stress to already strewed systems.
- Changes in the frequency, duration, or intensity of floods and droughts could occur.

What Is Most Vulnerable?

- **Parts of the Nation already experiencing considerable stress (e.g., many parts of the Southwest and South Florida).**
- **Areas where competition for water is expected to increase.**
- **The central part of the United States, which many scientists expect to become hotter and drier.**



Impediments

- Rigid and inefficient institutions.
- **Fragmented and uncoordinated management.**
- **Traditional engineering solutions less acceptable economically and environmentally.**

Types of Responses

- Promote contingency planning for floods and droughts.
- Improve supply management (e.g., by improve coordination, using ground and surface water conjunctively, improving reservoir and reservoir-system management).
- Facilitate water marketing and other transfers.
- Promote use of new analytical tools.
- Improve demand management (e.g., pricing reform and conservation).
- Augment supplies (e.g., by adding reservoirs and building desalination plants).

OVERVIEW

Fresh water is an integral element of all the systems discussed in this two-volume report. Its abundance, location, and seasonal distribution axe closely linked to climate, and this link has had much to do with where cities have flourished, how agriculture has developed, and what flora and fauna inhabit a region. The potential for climate change to affect, first, the current status of the Nation's water resources and, second, those systems that depend on water, is of considerable long-term importance. Exactly how climate change will affect water resources, especially regionally, is still unknown. Although it is unlikely that the droughts, floods, and hurricanes that have been so much a part of the news in the past few years can be linked to a changing climate, they illustrate the kind of extreme events that climate change may make more common in the future.

Climate change, then, is an additional factor to consider in water resource planning. A variety of other factors is clearly straining the Nation's water resources and leading to increased competition among a wide variety of different uses and users of water. Human needs for water are increasingly in conflict with the needs of natural ecosystems. The stress is particularly obvious in the West, where a high percentage of available supplies has already been developed in some areas, but examples of conflict among uses for scarce, high-quality water occur throughout the country.

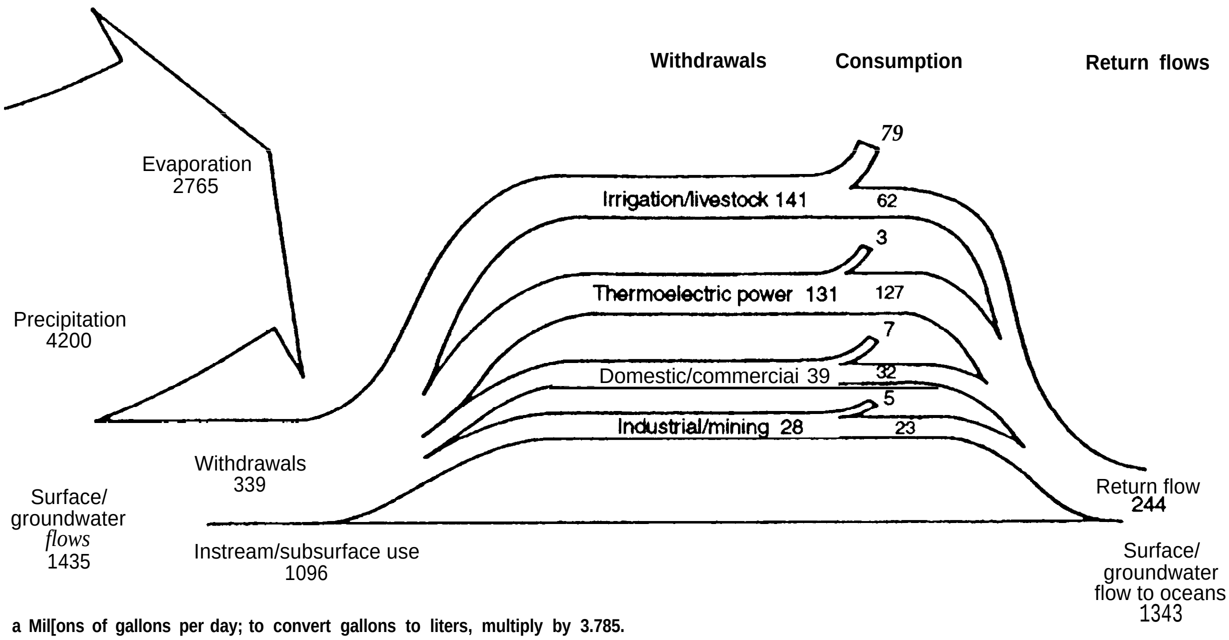
The Nation faces a considerable challenge in adapting its water resource systems to these numerous current and potential stresses. Among other things,

- Traditional engineering solutions for developing additional supplies have become less acceptable.
- Many institutions are ill-designed to cope with scarcity in water resources.
- Few incentives exist to conserve water.
- Responsibilities among Federal agencies often overlap or conflict.
- Coordination between levels of government can be inadequate.
- Flood- and drought-related costs amount to hundreds of millions of dollars each year and continue to increase.

Major changes are occurring in the way water resource problems are addressed. The management of existing resources is taking on increasing importance as the potential for developing new supplies declines. Similarly, reallocating water through markets from lower- to higher-valued uses is becoming more common. Promising practices beginning to be used include conservation, pricing reform, resenvoir-system management, marketing and transfers, conjunctive management of ground and surface water, wastewater reclamation, and river basin planning. These practices promote greater flexibility and/or efficiency in water resource management which will help enable water resource systems to cope with uncertainty and adapt to any climate change. Necessary improvements in the management of water resources do not, however, come easily: proposed changes often create losers as well as winners, so many politically sensitive debates can be expected.

Stresses on water resources are most acute and visible during extreme events such as floods and droughts. The Nation's approaches to dealing with such events have generally proven to be unsatisfactory and expensive. Policies that improve the ability to cope flexibly and efficiently with floods and droughts would be valuable now and would help prepare the Nation for a less-certain future. It is difficult to know whether the recent 6 years of drought in the western United States are a rare but possible outcome of natural climate variability, an early indication of climate change, or a return to the average climate after a long, particularly wet spell. Longer climate records are needed to distinguish among these various possibilities. Regardless of the cause of recent droughts, improving plarnning for and management of extreme events should be a high priority for the Federal Government.

Figure %1—Water Withdrawals and Consumption In the Coterminous United States, 1985[a]



a Mil[ons of gallons per day; to convert gallons to liters, multiply by 3.785.

SOURCE: Adapted from W. Solley, R. Pierce, and H. Perlman, Estimated Use *of Water the United* States *in1990,* **USGS Survey Circular 1081**

dependent on water (e.g., fishing and sailing) or enhanced by it (e.g., camping),[4] and the demand for water-related recreation is growing (79). Substantial amounts of water are used for cooling fossil fuel and nuclear power plants. Finally, water dilutes and/or helps carry away pollution that either intentionally or unintentionally reaches the Nation's rivers, lakes, and estuaries.

Throughout the country, stress on water supplies is increasing, and many of the uses for water are being (or could eventually be) affected in one or more regions. The increasing stress is especially obvious in arid and semiarid parts of the country where water is not abundant, but is also apparent in many nonarid areas as well. Population growth in some areas has stimulated increased demand for water and has been ultimately responsible for many water-quality problems, groundwater overdraft, and saltwater intrusion into some freshwater aquifers.

Additionally, groups whose water rights were not previously represented or asserted are beginning to compete for water with traditional users. In particular, as more water is diverted from streams for human purposes, concern has grown about the need to reserve water for environmental purposes. Several States now recognize rights to *instream flow* (i.e., rights to retain water in the stream channel) or have minimum-flow requirements to protect fish and wildlife, and water left in streams is no longer considered wasted. Similarly, entities such as American Indian tribes, whose water rights have been inadequately recognized in the past, are beginning to claim their rights. In many cases, unused Indian water rights are senior to the rights of those who now divert the water. The new competitors, plus a growing population, will all draw from the same basically fixed supply of water.

Many of the Nation's water institutions (e.g., doctrines, laws, administrative procedures, and compacts), first established when water use was low, are proving unable to cope with increasing competition amid greater relative scarcity. In particular, many existing institutions lack the flexibility required to ease adjustment to changing circumstances. Finally, much of the Nation's water infrastructure is aging. High leakage rates, for example, are common in urban water systems, and many of the country's reservoirs need reconditioning.

Climate change cannot yet be counted among the reasons water resource systems are under stress. Moreover, demographic and technological changes are likely to have a greater effect on water management in the near term than climate change. However, climate change does have the potential to seriously affect some water supplies, further stressing already stressed water resource systems.

POSSIBLE EFFECTS OF A WARMER CLIMATE ON WATER RESOURCE SYSTEMS

The hydrological cycle, depicted in figure 2-12, traces the cycling of water in the oceans, atmosphere, land and vegetation, and ice caps and glaciers. Exchanges of water among these elements occur through precipitation, evapotranspiration, and stream and groundwater flow. The hydrological cycle has an important role in the global climate system and both affects climate and is affected by it (8).

Most scientists agree that global warming will intensify the hydrological cycle (31). The increase in global average temperatures anticipated for a doubling of greenhouse gases[5] could increase average global precipitation from 7 to 15 percent and evapotranspiration between 5 and 10 percent (62). Increases in temperature, precipitation, and evapotranspiration would, in turn, affect stream runoff and soil moisture, both very important to human and natural systems. Average global runoff would be expected to increase, but general circulation models (GCMS) do not relia-

[4] The figure is a combined one for fresh and salt water.

[5] Most scientists accept 1.5d4.5'C (2.7 and 8.2 °F) as the range for an "effective CO_2 doubling" (32); see chapter 2 for more discussion.

bly predict how much (62). Certain models predict that precipitation will increase in some regions, whereas others suggest it will decrease (48). The range (and therefore the uncertainty) in the models' predictions of soil moisture and runoff is even greater than it is for precipitation (34).

Most important to water resource planners is how global warming will affect key variables regionally. A variety of factors, including local effects of mountains, coastlines, lakes, vegetation boundaries, and heterogeneous soil, is important in determining regional climate. Currently, GCMS cannot resolve factors this small because the grid they use-blocks of 155 to 620 square miles-is too large (80).

Climate modelers generally agree that a first likely consequence of climate change is that precipitation will increase at high latitudes and decrease at low to middle latitudes (where the water-holding capacity of the atmosphere will be largest (18)). Thus, in the midcontinent areas, especially in summer, evapotranspiration could exceed precipitation, and soil moisture and runoff would decrease. The potential for more-intense or longer-lasting droughts would, therefore, increase (58).

A second likely consequence is changes in the type and timing of runoff. Snowmelt is an important source of runoff in most mountainous areas. Warmer temperatures in such areas would cause a larger proportion of winter precipitation that now falls as snow to fall as rain. Thus, the proportion of winter precipitation stored in mountain snowpacks would decrease. Winter runoff would increase, and spring runoff would subsequently decrease. During times when flooding could be a problem, a seasonal shift of this sort could have a significant impact on water supplies because to maintain adequate storage capacity in reservoirs, early runoff would probably have to be released (40). Many Western States (e.g., California and Colorado) depend on the late spring snowmelt as a major source of water. Runoff filling reservoirs early in the spring means that less stored water would be available during summer, when demand is highest. The California Department of Water Resources has estimated, for example, that if average temperatures warm by 3 'C (5.4 oF), winter snowmelt runoff would increase, but the average April-July runoff would be reduced by about 30 percent.[6]

Sea level rise, a third likely consequence of global warming, could have effects on water supplies in some coastal areas. Higher sea level would cause a slight increase in saltwater intrusion of freshwater coastal aquifers, would create problems for levees protecting low-lying land, would increase the adverse consequences of storm surges, and might affect some freshwater intakes. (Effects of sea level rise on coastal structures and wetlands are discussed in detail in ch. 4 and in vol. 2, ch. 4.)

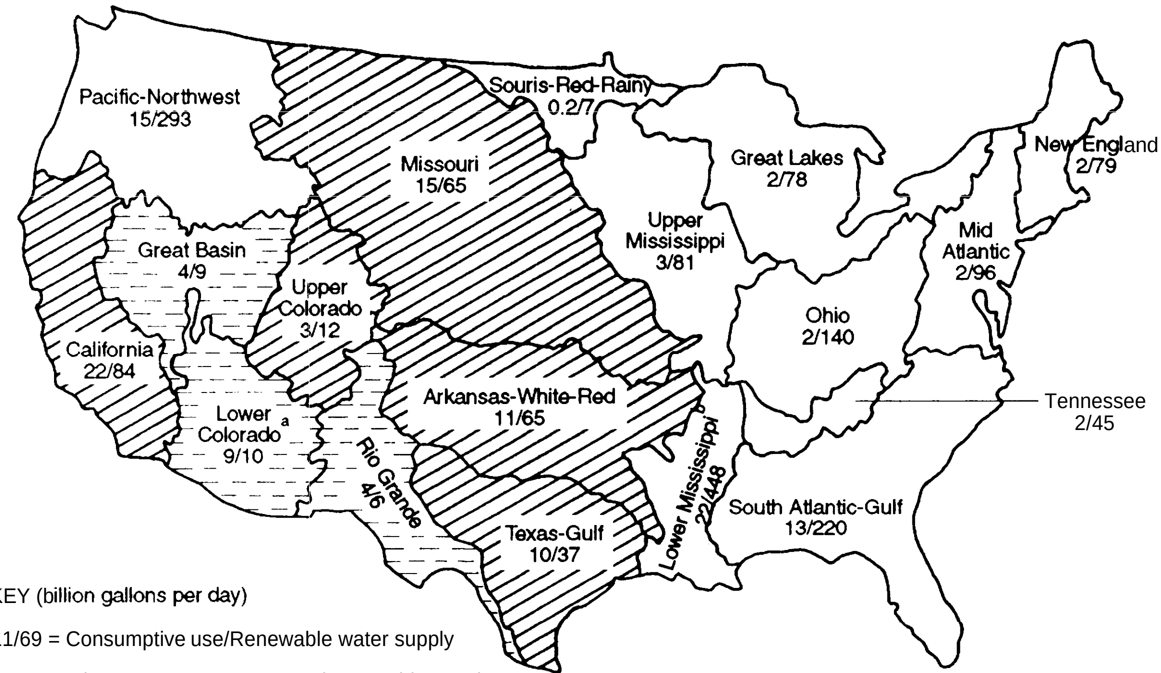
CURRENT AND POTENTIAL STRESSES ON WATER RESOURCE SYSTEMS

Introduction

Although scientists are not yet certain about the magnitude, direction, or timing of the regional impacts of global climate change, much can be said about current stresses on water resource systems. Climate change could, exacerbate the adverse effects of these stresses in some regions and alleviate them in others. However, areas that are already approaching limits for developing new water supplies or are under stress for other reasons should be particularly concerned about the possibility that climate change may further stress water resource systems and reduce the capability to adjust. Appendix A catalogs the major water resource problems for each of the 50 States.

[6] M. Roos, Chief Hydrologist, California Department of Water Resources, personal communication 1992.

Figure 5-2—Average Consumptive Use and Renewable Water Supply by Water Resource Region



KEY (billion gallons per day)

11/69 = Consumptive use/Renewable water supply

Consumptive use as a percentage of renewable supply

o-1o 10-40 B4O-1OO

a Represents entire Colorado River Basin.
b Represnts entire Mississippi River Basin.

NOTE: To convert gallons to liters, multiply by 3.785.

SOURCE: W. Solley, U.S. Geological Survey, 1993,

Growing Population, Increasing Competition

Water is a renewable resource, but long-run average supplies are essentially fixed as long as climate fluctuates within a known range. The U.S. population, however, is steadily increasing. By 2010, the United States is projected to add about 35 million people to its 1993 population of roughly 256 million people. Total U.S. population is projected to grow about 7 percent over this decade, but the populations in the 10 fastest-growing States[7] will increase by 14 to 23 percent. Nine of these States are in the South and West, yet developed water-supply systems in many are already overburdened. Current demand for water relative to annual supply in all western river basins (except the usually well-watered Pacific Northwest) is 10 to 50 times higher than it is in the eastern half of the country, and some western basins have few undeveloped sources left (26). Figure 5-2 illustrates average consumptive use relative to renewable water supply in each of the water resource regions of the conterminous states.

Large western cities, like Los Angeles and San Diego, must import water from sources hundreds

[7] In order of decreasing projected growth rate, these arc Arizona, Nevada, New Mexico, Florida, Georgia, Alaska, Hawaii, New Hampshire, C& ifornia, and Texas (78).

of miles away. As a result of population growth, atisfying the demand of such cities is becoming more challenging, especially during drought. Despite considerable water-storage capacity in California, for example, many cities find it necessary to implement emergency-rationing procedures. Other fast-growing western cities-Las Vegas, Reno, Denver, El Paso, San Antonio, for e x a m p l ~e having problems ensuring adequate water supplies for the future. In the Southeast, population growth is becoming a problem for water-supply planners in Atlanta and in some cities in Florida.

The challenge for growing cities is to develop or acquire new sources of water and use the water they have more efficiently. Many opportunities exist for using water more efficiently, and some cities and States are addressing water-supply-related problems in creative ways (see the section Adapting Water Resource Systems to Climate and Other Changes, later in this chapter). However, a general and growing complication is that demands for water for use in cities can and increasingly do conflict with established or previously neglected demands for water for other purposes, including irrigation, fish and wildlife sustenance, ecosystem conservation, recreation, navigation, and power generation. Areas that become hotter and drier as a result of climate change would likely see competition among uses increase (see box 5-A).

Poor Water Quality

People also stress water systems when they permit pollutants to enter surface Water and subsurface groundwater.[8] Pollution can diminish supplies available for human consumption (sup plies that in some cases are already stressed by population growth) and can adversely affect fish and wildlife that depend on clean water. Surface waters may be contaminated by siltation, nutrients, salts, organic matter, and hazardous materials (94). Despite high-priority Federal and State efforts, many supplies of surface and groundwater are currently polluted.

Box 5-B describes water-quality problems affecting the Rio Grande. This river presents a particularly challenging set of problems because it flows through an arid region where water is much in demand and because it forms a 1,200-mile boundary between two sovereign countries, the United States and Mexico, that must work together to ensure the river's health.

During drought, when stream flows and lake levels are low, water temperatures are higher and pollutants are more concentrated (33). Low stream flows in estuarine areas also enable salt water to move further upstream, in some cases affecting freshwater supplies. For example, in 1988, drought-related salt intrusion into the Mississippi River Delta affected petroleum refineries at New Orleans, and fresh water had to be barged into operate boilers and to cool machinery (57). Rivers that normally carry high salinity loads, such as the Colorado, can be dramatically affected by decreased runoff. These problems would be exacerbated in parts of the country that become drier as a result of climate change.

Higher surface-water temperatures can be a problem for fish that depend on cold water for spawning, such as Chinook salmon. When optimal temperatures for salmon incubation are exceeded by only a few degrees, increases in mortality can be expected (l). In California's Sacramento River System, for example, a problem exists during dry years when reservoir levels are lower and water discharged from them is warmer than normal (35). A few newer dams have temperature-control outlets that allow water to be released from various depths, but retrofitting dams that do not have such controls is very expensive. Global warming may make it impossible to preserve some cold-water fish without providing artificial temperature controls at large dams that lack these controls (35). Conversely, some warm-

[8] Groundwater constitutes about 36 percent of municipal drinking-water supplies.

Box 5-A-Climate Change, Water Resources, and Limits to Growth?

Many cities of the Southwest-Las Vegas, Tucson, and Phoenix, for example—have beautiful green golf courses positioned like islands amidst seemingly endless expanses of parched desert. Although less likely now, it is still possible to see fountains shooting water, much of which evaporates, high into the airon scorching summer days. These are just two of the more obvious extravagant practices that people who have relocated from the well-watered eastern parts of the country brought with them as they settled the arid and semiarid parts of the American Southwest. Growing cotton and other water-intensive crops in such areas is another.

Many people are drawn to the Southwest by generally mild climates and outstanding recreational opportunities and by the new, dynamic potential for economic development. High growth rates have been typical, and the three U.S. States with the highest projected growth rates, Arizona, Nevada, and New Mexico, are all arid Western States. California much of which is arid, is now the most populous of the 50 States (78).

That continued growth and development of water-stressed areas of the United States is desirable is rarely questioned. Until recently, except perhaps for a few small settlements in out-of-the-way places, water has not been a limiting factor in western development. Where additional water has been needed to enable further growth, water managers have been able to find it-but now usually at increasingly long distances from where it is used or at greater depth in subsurface aquifers. Los Angeles, for example, imports significant portions of its water from sources hundreds of miles away-northern California, the Owens Valley, and the Colorado River. Without this additional water, Southern California would not be able to sustain the dramatic growth that has occurred there (at least given current usage patterns). San Diego, Las Vegas, Reno, Denver, El Paso, Phoenix, and many other cities, large and small, face similar challenges in acquiring enough water to sustain growth or in using what water they now have more efficiently.

Western author Wallace Stegner noted that aridity imposes limits on human settlement that can be ignored only at one's peril (68). So far, the impressive water infrastructure developed in the West during the past 100 years has enabled society to meet its water demand and push back these limits. Growth could be difficult to sustain without major and difficult adjustments. Explicit growth-control policies have been limited and generally very unpopular. Water issues, especially in the West, are usually framed in terms of how to accommodate urban growth and not how to adjust to limitations imposed by a harsh environment (70).[1] Nevertheless, it maybe prudent at least to consider the possibility that future severe water shortages in arid parts of the country will require strong and explicit growth-limiting policies in addition to implementation of other adaptive measures. Federal constitutional doctrines designed to promote the free flow of goods and people across State lines and the core principle of public utility law-that water providers have a duty to serve market demand (70)-imply that growth maybe difficult to restrict legally. Nevertheless, at some point in a possibly drier future, some industries and individuals may begin basing their decision to move to arid areas (or to stay in them) in part on the cost and availability of water. Such an occurrence would mark a fundamental shift in development and demographic patterns.

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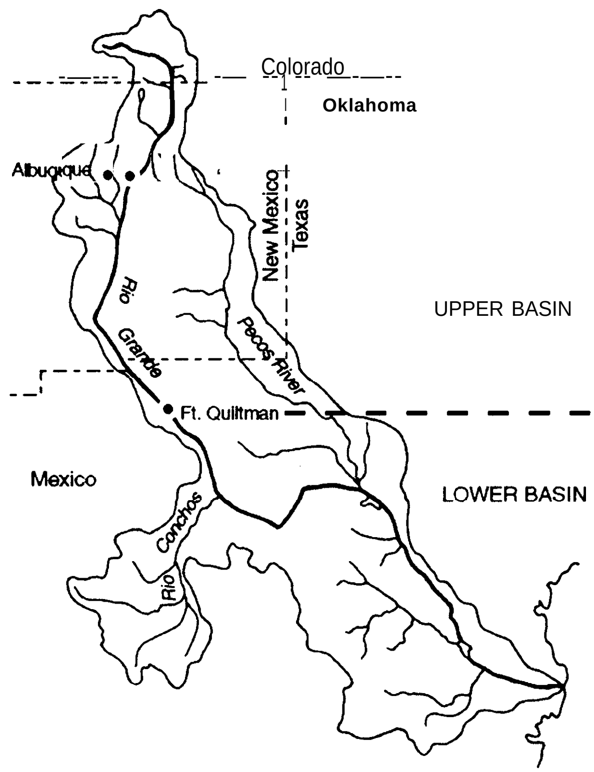
[1] A few policies do recognize limitations. Arizona, for example, requires developers to show that they have a 100-year water supply before they are allowed to build. Such policies, however, generally have not fundamentally called into question the desirability of continued growth. The Arizona policy has also had some unwanted side effects because it has encouraged cities to take extraordinary action to find water for continued long-term growth. As a result, the practice of "water farming" has developed. Some rural areas are being dewatered, and economic development in these areas has consequently been stifled.

Box 5-B-Water Quality, Climate Change, and the Rio Grande

The Rio Grande Basin



SOURCE: W. Stone, M. Minnis, and E. Trotter (eds.), *The Rio Grands Basin: Global Climate Change Scenarios, New Mexico* Water Resources Research Institute Report No. M24, June 1991.

Poor water quality is a problem in many parts of the country. However, in an arid region such as southwest Texas, where water is relatively scarce, water-quality problems can contribute significantly to water-supply problems. This water quality/water quantity connection is especially important in the lower Rio Grande Basin, where population growth, municipal and industrial expansion, and an increase in irrigation have dramatically increased the demand for water while negatively affecting water quality. Managing the water resources of the Rio Grande is especially difficult given the river's bi-national status.

The Rio Grande forms the border between Texas and Mexico for some 1,200 miles (1 ,935 kilometers)[1] and is one the most important rivers in North America. It originates in Colorado as a pristine alpine stream, but as it makes its way south and east to the Gulf of Mexico, it becomes a river under stress. Intensive municipal and industrial activities along its banks have resulted in tens of millions of gallons of sewage yearly entering the river. Agricultural runoff degrades water quality by contributing significant amounts of fertilizers and pesticides to the river. And natural discharges of highly saline groundwater contribute to salinity problems. In addition, a very high 72 percent of the renewable water supply of the basin is now consumed. This percentage is surpassed only in the Colorado River Basin and is dramatically greater than the single-digit percent of renewable supply consumed in most basins in the eastern United States. If current trends continue, consumption of water in the basin is likely to increase.

Climate change could exacerbate current water conflicts. Many western rivers, including the Rio Grande, would experience a significant reduction in dependable stream flow if average temperature increases. This effect would seriously threaten irrigated agriculture, industrial development, and drinking-water supplies in the region. Even if climate change leads to a decrease in agriculture in the lower Rio Grande Basin, industrial and municipal development, spurred by the North American Frw Trade Agreement (NAFTA), mght continue to place significant demands on the river in a warmer climate. The combined effects of climate change and more-direct human-caused stresses would pose a considerable adaptation challenge.

The Rio Grande's drainage basin is separated into northern and southern regions encompassing a total of 182,215 square miles of arid to semiarid land in southern Colorado, New Mexico, Texas, and Mexico. Some 2.7 million people live in the basin and depend on its water. Precipitation ranges from 10 inches (25 cm) per year in the western part of the basin to up to 24 inches (60 cm) per year along the Gulf Coast, but annual evaporation exceeds

1 To convert miles to kilometers, multiply by 1.609.

(Continued on next page)

Box 5-B–Water Quality, Climate Change, and the Rio Grande-(Continued)

precipitation in much of the region. Many parts of the area rely on ground water to supplement scarce surface water supplies, and groundwater overdraft is a problem in parts of the region. Concern about droughts and flooding has led to the construction of dams and levees, so the once highly variable flow of the river is now moderated. Stored surface water is the principle source of supply in the western part of the basin, but the lower part of the basin depends almost entirely on surface water due to the poor quality of ground water in the area.

Historically, the Rio Grande Basin has supported a predominantly agrarian economy. Many of the crops grown in the valley are very water-intensive, including cotton, rice, and sugar cane. To northerners, the region is known as the "winter garden" because it supplies the country with voluminous amounts of citrus fruits and vegetables during winter months (see ch. 6). The Rio Grande is almost completely diverted at Juarez/El Paso to support irrigated agriculture in the southern part of the basin. (Return flows and more southerly tributaries supply water to the river below this point.)

Low flows and surface-water shortages have become a problem in the basin, as have increases in salinity in groundwater. To date, farmers have been more concerned with water shortages than with increasing salinity. Salt buildup in the soil, however, is certain to affect future production and may force abandonment of some agricultural lands. Runoff laden with pesticides, fertilizers, and sediment reaches the river and further impedes water quality. Moreover, reduced flows mean that less water is available to dilute pollutants, so their concentration in the river increases during low-flow periods.

Municipal and industrial demands on the river are growing dramatically, driven by the region's burgeoning population growth. A significant increase in growth is occurring in the so-called "colonias" that have been established along the border. These communities, which are home to many hundreds of thousands of people, generally lack sewage systems, wastewater treatment plants, and potable water. Wastewater in some cases is discharged directly into irrigation canals, which ultimately supply water for some crops. This lack of infrastructure, including overflowing and inadequately lined waste dumps, has resulted in a high incidence of infectious diseases (e.g., hepatitis and cholera), contamination of groundwater, and clogging of storm-water systems. Industrial operations exacerbate these problems by discharging wastewater directly into the river. As a result, water quality is so low in the eastern part of the basin that only 1 percent of the water is fit for agricultural or municipal use. All of these impacts have severely degraded water quality in the river, and, given the limited supply, could present serious water-allocation problems in the future. Changes in management practices will ultimately be required on both sides of the border.

The international boundary created by the Rio Grande separates much more than land mass: it represents the often dramatic division of first and third world nations. The socioeconomic differences that exist between the two countries are deeply rooted. Some of the poorest U.S. counties with some of the fastest-growing populations are along this border. These communities generally experience depressed economies, poverty-level incomes, short life expectancy, low levels of education, and high population mobility. Much of the economy is based on providing food for other parts of the United States. Economic conditions in Mexico are even worse. Such conditions make the development of sound water-management policies and the development and enforcement of regulations to sustain human and ecosystem health much more difficult.

Wildlife and migratory bird populations also rely on the river, but maintaining stream flow for environmental purposes is not always possible because of competing demands for the water, and it will likely become even more difficult in the future.

Conservation, recycling, shifting to dryland farming, changing water pricing, and establishing water-master programs for the basin are among the approaches that could be used to address present and future water-quality and -quantity problems. Focusing on improving water quality may be one way of assisting adaptation to climate change that would be especially appropriate in the arid Rio Grande Basin.

SOURCES: This box is drawn largely from J. Schmandt and G, Ward, *Texas and Global Warming: Water Supply and Demand in Four Hydrological Regions* (The University of Texas at Austin: The Lyndon Baines Johnson School of Public Affairs, 1991); W. Stone, M. Minnis, and E. Trotter (ads.), *The Rio Grande Basin: Global Climate Change Scenarios,* New Mexico Water Resources Research Institute Report No. M24, June 1991.

water fish populations are likely to benefit from temperature rises associated with global warming as their thermal habitat expands (52).

The contamination of groundwater is a particularly troublesome problem; once an underground aquifer becomes contaminated, its value is impaired or lost for a long time. Fertilizers and pesticides, effluent from various manufacturing processes, leakage from underground storage tanks, and oil spills can all find their way into groundwater. The extent of groundwater pollution in the United States is not known precisely, but some groundwater contamination occurs in every State, and the Environmental Protection Agency (EPA) has identified close to 1,000 hazardous-waste sites that have contributed to groundwater contamination (10). The Northeast has groundwater problems associated with industrial waste, petroleum products, and landfill leachate, and many farming States have problems arising from agricultural practices.

Groundwater can also be contaminated by saltwater intrusion-particularly in coastal States. In some cases, intense groundwater pumping has allowed salt water to intrude into coastal aquifers. For example, Orange County, California, now injects treated, recycled surface water into its coastal aquifer to keep salt water from intruding. Miami has spent millions trying to repel saltwater intrusion. Sea level rise will enable salt water to penetrate somewhat further into coastal aquifers (80).

Many water-quality problems will be addressed in 1993 and 1994, when Congress considers reauthorizing the Clean Water Act (P.L. 92-500). The Water Pollution Prevention and Control Act of 1993 (S. 1114) was introduced in June 1993 and will likely serve as the main vehicle for considering changes in the Nation's water-pollution laws. Box 5-C describes some key issues being considered.

Environmental Water Allocation

The value of water for environmental uses (e.g., for preserving aquatic species and habitat) has typically been neglected in developing water resources for consumptive purposes (16). In the early part of the 20th century, water was often considered wasted if it was allowed to remain in a stream and not put to some "beneficial' use. Diverting water from a stream was not especially a problem for instream requirements as long as enough water was available. However, the effect of diversions on instream environmental uses has increased as more and more water has been developed for consumption. Over the past 20 years, popular awareness of the environment and the desire to protect it have increased. Thus, an important new competitor for water (or at least one with increasing clout) is the environment: water used for protection of wetlands, fisheries, and endangered species or for preservation of the wild and scenic status of a river cannot be simultaneously available for offstream, consumptive uses like irrigation and domestic supply.

The potential for conflict between instream and other uses of water is high. California's Central Valley farmers, for example, vigorously (but unsuccessfully) opposed a provision of the recently enacted Central Valley Project (CVP) Improvement Act (P.L. 102-575) that requires 800,000 acre-feet (af)[9] of project water to be reallocated or set aside for fish, wildlife, and habitat restoration. Similarly, South Florida's demands for water for the environment (e.g., for restoring the Everglades) are in growing competition with water for humans (see box l-D). Notably, the Endangered Species Act (P.L. 93-205) has become a powerful preservation tool in recent years, and many water resource managers are concerned that vigorous enforcement of this act to protect water-dependent species will in-

[9] One acre-foot (af) equals 325,851 gallons of water (43,560 cubic feet, or 1,234 cubic meters), the amount of water it takes to cover 1 acre to a depth of 1 foot. It is enough water to sustain two average households for a year, To convert from acre-feet to cubic meters, multiply by 1,234!

Box 5-C-Reauthorizing the Clean Water Act

The Clean Water Act (CWA; P.L. 92-500), formally known as the Federal Water Pollution control Act of 1972, is the Nation's foremost piece of water-quality legislation. The ambitious goai of the original act was to restore polluted waters throughout the Nation to a "fishable, swimmable status" by 1983, to eliminate discharges of pollutants into navigable waters, and to prohibit the discharge of toxic pollutants in toxic amounts. Two major strategies for achieving these goals included establishment of a Federal grant program to heip local areas build sewage treatment plants and a requirement that all municipal sewage and industrial wastewater be treated before it is discharged into waterways (1 1). The comprehensive act specifies technology-based effluent limitations and standards, receiving-water-quality standards, and a discharge permit system.

The Nation has made considerable progress in cleaning up polluted waters since 1972. Some $540 billion has been spent on water-pollution control (36). Currently, more than 37 billion gallons (140 billion liters)[1] of wastewater are treated daily, and about 15,500 wastewater treatment facilities and dose to 20,000 collection systems operate in the United States. Eighty-nine percent of waste treatment facilities now provide secondary or advanced treatment (11).2 As a result, Conventional pollutants such as bacteria and oxygendernanding materials have diminished. Nevertheless, and despite major amendments to the CWA in 1977, 1981, and 1987, some significant water-quality problems remain. Sedimentation, nutrient enrichment, runoff from farmlands, and toxic contamination of bottom sediments are proving to be more persistentprobiems(11).

The Clean Water Act will likely be reauthorized again during the 103d Congress inan attempt to address these continuing problems. S. 1114, the Baucus-Chafee Water Pollution Prevention and control Act, has emerged as the primary legislative vehicle for revising water-quality iaw. The bill revisits such key issues as watershed planning, control of non-point-source pollution and of toxic discharges, and funding for municipal wastewater treatment facilities.

Watershed planning—S. 1114 encourages states to adopt watershed-pianning programs. A watershed generally is defined as a region that lies between two ridges of high iand and drains into a river, river system, or other body of water. Watershed planning refers to efforts to identify water-quality problems unique to a particular watershed, pinpoint the sources of those problems, and devise a strategy for addressing them. This approach recognizes that local solutions to local problems may often be preferable to a single national solution. Voluntary watershed-pianning programs would be encouraged through a series of financial and other incentives.

Non-point-source pollution—Non-point-source (NPS) pollution accounts for half the Nation's remaining water-qualit y problems (11). S. 1114 would place stronger emphasis on mitigation and alteration in management practices to reduce the volume of polluted runoff. Mitigating NPS pollution is difficult, however, because it involves changing the land-use practices of private landowners. Runoff from agricultural lands containing, for example, nitrogen and phosphorus fertilizers, contributes a sizable percentage of nutrients and sediment to ground and surface water, but urban areas, failed septic systems, silviculture activities, cattle feedlots, and suburban development are sources of NPS pollution as well (81). S. 11 14 directs States to submit revised NPS management programs—containing specific program elements—to EPA within 30 months after the act is reauthorized.

Funding for municipal sewage treatment—The Environmental Protection Agency's (EPA's) most recent estimate of sewage-treatment requirements suggests that over $100 billion will be needed during the course of the next 20 years for State and local governments to meet the goals and mandates of the Clean Water Act (1 1). The State Revolving Loan Fund established by the CWA substantially assists communities and municipalities in

[1] To convert from gallons to liters, multiply by 3.785.

2 Secondary treatment typically means that 85 percent of solid and organic matter Is removed; advanced treatment removes more than 95 percent of pollutants and Is required when seoondary treatment is Insufficient to proteot a receiving stream and meet a State's water-quality standards.

their efforts improve water quality, but appropriations for this program are set to expire in 1994.S.1114 expands funding for wastewater treatment programs. Funds would be available for improving aging infrastructure, controlling non-point-source **pollution, managing** estuaries, addressing combined sewer overflows and storm-water problems, and managing animal waste.

Regulation of **toxics—EPA** currently regulates only about one-fifth of the industrial plants that dump toxic substances into rivers and lakes. Non-point sources of toxic pollutants, such as pesticides from agricultural fields **and various** contaminants in urban storm-water runoff, are **currently** unregulated (36). Toxic pollutants may have adverse effects on human and aquatic health and may remain in the ecosystem for long periods. S. 1114 calls for EPA to identify at least 20 toxic pollutants that would have to be controlled by industry through intensive pollution-prevention strategies. The bill also **calls for not less than 80 percent** of **the volume of** each pollutant listed to be reduced within 7 years and provides for the public to petition EPA to add pollutants to its list.

Wetland protection-Wetlands play a key role in preserving water quality, but the extent and nature of the authority provided by the CWAfor wetland protection promises to be a contentious issue in CWA reauthorization. The current version of S. 1114 does not address wetland protection, but an additional section on **wetlands** is expected to be included in the final reauthorization. The Federal Government has struggled over the past few years to reach a workable compromise with property owners, industry groups, environmentalists, and others on how and to what extent wetlands should be protected. Major wetland issues likely to be addressed in the reauthorization include clarifying the regulatory process and responsibilities of Federal agencies; clarifying the process through which States can take control of permitting; paying attention to opportunities for wetland restoration through mitigation banking; and considering whether Alaska, which has large amounts of **wetlands,** should receive special treatment. (See vol. 2, **ch.** 4, for a **complete** discussion of wetland issues.)

The reauthorization of the Clean Water Act comes at a critical time. The understanding of ecological processes and of the effects of human influence on ecosystems is growing. However, stresses on ecosystems are also growing. Additional data gathering and monitoring are needed to close remaining information gaps. **Legislative** efforts must attempt to balance human needs and ecological health.

creasingly impinge on development and use of water supplies.

Although the benefits of maintaining minimum **instream** flows are increasingly recognized and are gaining legal protection in a growing number of States (75), the rights to a significant amount of stream flow in the West have already been established. In Western States, rights to divert water are acquired under the prior-appropriation doctrine (i.e., first in time, **first** in **right)(see** box 5-D), and many rivers are either completely appropriated by those who got there first (senior rights holders) or are close to being so. A few are even overappropriated. The rights to water for **instream** uses, where protected at all, are usually very junior. This means that water for fish and wildlife has the lowest priority, and the need for it is satisfied only after the demands of senior rights holders are met. During a drought, junior and unprotected rights are most at risk, so fish and wildlife may suffer more than they would if **instream** water rights were better protected.

Clearly, growing competition between consumptive and environmental uses for water would be exacerbated in areas of the country that become drier as a result of climate change. If available supplies diminish and/or demand increases, existing developed supplies will have to be used more efficiently to satisfy both consumptive and environmental uses. Protecting adequate **instream** flows to attain multiple water-use goals, which is not easy now, could become much more difficult in the future.

Uncertain Reserved Water Rights

Rights pertaining to water for the environment are not the only "new" rights being asserted that may conflict with established uses of water.

Box 5-D-Major Doctrines for Surface Water and Groundwater

Surface Water

Riparian doctrine-Authorization to use water in a stream or other water body is based on ownership of the adjacent land. Each landowner may make reasonable use of water in the stream but must not interfere with its reasonable use by other riparian landowners. The riparian doctrine prevails in the 31 humid States east of the 100th meridian.

Prior appropriation **doctrine—Users** who demonstrate earlier use of water from a particular source acquire rights over all later users of water from the same source. When shortages occur, those first in time to divert and apply the water to beneficial use have priority. New diversions, or changes in the point of diversion or place or purpose of use, must not cause harm to existing appropriators. The prior appropriation doctrine prevails in the 19 Western States.

Groundwater

Absolute **ownership—Groundwater** belongs to the overlying landowner, with no restrictions on use and no liability for causing harm to other existing users. Texas is the sole absolute-ownership state.

Reasonable use **doctrine—Groundwater** rights are incident to land ownership. However, owners of overlying land are entitled to use groundwater only to the extent that uses are reasonable and do not interfere with other users. Most Eastern States and California subscribe to this doctrine.

Appropriation-permit systern-Groundwater rights are determined by the rule of priority, which provides that prior uses of groundwater have the best legal rights. States administer permit systems to determine the extent to which new groundwater uses will be allowed to interfere with existing uses. Most Western States employ this doctrine.

SOURCES: U.S. Army Corps of Engineers, *Volume III, Summary of Water Rights—State Laws and Administrative Procedures*, report prepared for U.S. Army, Institute for Water Resources, by Apogee Research, Inc., June 1992; and U.S. Geological Survey, *National Water Summary 1988-89—Hydrologic Events and Floods and Droughts*, Water-Supply Paper 2375 (Washington, DC: U.S. Government Printing office, 1991).

Indian reservations, National Forests, and National Parks are *reserved* lands-that is, they have been reserved or set aside from public-domain lands and, as such, carry with them authority for Federal reserved water rights (see also vol. 2, ch. 5). These rights have priority over State appropriative water rights acquired at a later date. In the case of Indian reservations, they have specifically been recognized in the Supreme Court's 1908 *Winters* decision (65), and ensuing court cases have extended the reservation doctrine to other lands.

Significantly, many Indian claims have not yet been exercised or quantified, although Indians assert large claims to both surface water and groundwater throughout the West. Because reserved rights are often senior once they are quantified, junior, non-Indian water users may have to forgo water uses in times of shortage (93). In some cases, water for settlement purposes has been purchased by the Federal Government from other water users. However, the potential for conflict between Indian and non-Indian water users is clear and could grow in areas that become drier as a result of climate change. Similarly, Federal reserved rights in National Forests and Parks have the potential for leading to disputes between States and the Federal Government if supplies decrease. Wilderness areas within Bureau of Land Management lands do not now have reserved water rights, and this has been a source of contention in most wilderness legislation before Congress.

A still-unresolved issue is whether Indians will be allowed and will choose to transfer some or all of their water off-reservation. If so, flexibility

Figure 5-3-U.S. Groundwater Overdraft

NOTE: To convert gallons to liters, multiply by 3.785.
SOURCE: H. Ingram, Udall Center for Studies in Public Policy, University of Arizona, 1993.

and economic efficiency might be enhanced, and some wealth would be transferred from non-Indians to Indians (70). The exercise of Federal reserved water rights for National Parks and Forests has proved controversial, but it is one means of providing water for such nonmarket uses as maintenance of fish and wildlife habitat (92).

Groundwater Overdraft

Groundwater overdraft is the removal of subsurface water at a rate faster than its natural recharge rate. When groundwater is pumped faster than this rate over long periods of lime, it is in effect being mined and, therefore, is nonrenewable. Overdraft is a problem in several parts of the country (fig. 5-3). It is common in the Ogallala Aquifer, for example, which is the principal source of water for farming on the Texas High Plains (see box 6-G), and to a lesser degree, in some sections of the aquifer that underlie other Plains States. Overdraft leads to successively higher water costs because pumping expenses increase as the water table is drawn down. Higher costs, in turn, can lead to adoption of innovative water-saving strategies, dryland farming, or reduced planted area. Groundwater overdraft also occurs in the southern half of California's Central Wiley, much of Florida, and parts of other States. Some regions are trying innovative plans to restore or conserve groundwater supplies (e.g., Arizona with its Phoenix-area groundwater replenishment plan).

Climate change will Meet groundwater. In some locations, it could increase recharge, but it could also lead to increased groundwater pumping in areas where surface-water supplies diminish. Mining groundwater may sometimes make economic sense (as, for example, can mining coal) but, where feasible, it should be viewed only as a temporary adaptation to climate change. To the degree that groundwater is mined, flexibility to respond to future dry spells and droughts is reduced. Overdraft may also lead to land subsidence. Temporarily increasing groundwater pumping, however, can be an effective short-term response to drought-whether it occurs under current climate conditions or during a future warmer climate.

Outmoded Institutions

Most laws and institutions guiding the allocation and use of water were established when water was essentially free and supply greatly surpassed demand. These provisions served their regions reasonably well when most new demands could be met by developing new supplies. However, new development is no longer either easy or inexpensive, and in some areas, it is practically impossible. Institutions and laws must increasingly deal with shortages and competing legitimate demands for water, many of which represent new tasks for which they were not originally designed (15). Subject to changing competitive demands and societal interests, some institutions are too rigid and inefficient to allow adequate responses to real or apparent water scarcity. Also, little has been done to educate the public about water issues, and as a result, professional knowledge of the value and scarcity of water has not been adequately disseminated.

Examples of innovative institutions are not rare, however, and institutional change is occurring. Congress, for example, passed the Central Wiley Project (CVP) Improvement Act in 1992, which explicitly recognizes the importance of instream uses for water in California's Central Valley and the need to balance competing demands for water. The Act includes provisions to: 1) guarantee that much more water will remain in streams for fish or be directed to wildlife refuges, 2) remove institutional obstacles that limit beneficial water transfers and discourage conservation, 3) raise the price of Water sold to farmers, 4) establish a fish and wildlife restoration fund (to be financed by fees on CVP water and power sales and on water transfers), and 5) place limits on the renewal of irrigation and municipal water contracts. In coming years, this law may serve as a model for similar changes in other parts of the West. Arizona's Ground-Water Management Act, with its goal of safe yield in the State's important groundwater basins, is another innovative, if imperfect, institutional change.

Nevertheless, rigid and inefficient institutions are common. Such institutions can add to the stress already on water resources by making adjustments to new situations more difficult. When water rights are unclear, for example, as they continue to be in parts of the West, reallocation of water is difficult. Agreements abound that were negotiated when either information was inadequate or future circumstances concerning supply and demand could not be foreseen. These agreements constrain the responses that water resource managers can make to short- and long-term problems, and they are often difficult to change.

For example, much water is supplied to Southern California by the Metropolitan Water District (MWD). By statute, MWD member agencies are entitled to water in proportion to their percent contribution to MWD tax revenues. Los Angeles currently contributes about 27 percent but now uses only 5 percent of its allotment because its other sources are usually adequate. San Diego, however, takes up the slack and currently uses about 30 percent of MWD supplies, although it is entitled to only 12 percent. If Los Angeles' supplies shrink during a drought, the city would be entitled to claim its MWD allotment, and San Diego, which receives about 90 percent of its water from MWD, would have to cut back (91). As San Diego grows, the potential for significant water shortages could create a critical problem during drought.

Similarly, the structure of the Colorado River Compact and related laws governing the Colorado River System make it impossible to operate this system as efficiently as possible. Problems are already apparent, given aridity, growing and shifting populations, and the fact that the Compact, negotiated in 1922 after a few unusually wet decades, allocates more water among the seven basin States than the average annual flow (26). The Colorado could be operated more efficiently (and San Diego might have an additional source of water) if, for example, interstate water transfers were legitimized. A stumbling block is that States that have water allocations through the Compact legislation and individual contractors jealously guard their existing entitlements and believe any changes in the current institutional structure could dilute their water-use rights (70).

Current stresses on water resource systems are already motivating changes in laws and institutions. The potential for climate change adds another, if currently secondary, reason to make those changes. Given the uncertain impacts of climate change on water resources, however, institutions that are flexible (i.e., those that could facilitate adaptation in a variety of different climates) and that foster an *efficient allocation* of water would be most responsive to changes caused by global warming (47). As institutions change, *equity in* water resource allocation could be promoted by providing more opportunities for the public to become involved in decisionmaking bodies. Such involvement could stimulate healthy debate about the values at stake in water resource decisions.

In many cases, promoting flexibility, efficiency, and equity will require more coordination and cooperation among the large number of Federal, State, and local water resource organizations. (Table 5-1 shows how complex the Federal water structure alone is.) River basins and watersheds are rarely managed in an integrated fashion, for example, and there are clearly opportunities for some significant increases in yield by more-efficient joint management of existing reservoir systems (63, 64). Similarly, water-quantity laws and water-quality laws are seldom coordinated. Surface water and groundwater are often managed separately. The respective responsibilities of Federal and State agencies are sometimes unclear, and Federal Government agencies that have water responsibilities do not always cooperate with one another.

■ Aging Urban Water Infrastructure

The current poor condition of much of the Nation's urban water infrastructure (e.g., pipes, valves, pumping stations, and storm-water drains) could affect both safety and water-supply efficiency in the future. Also, urban infrastructure needs are likely to compete for funding with other water-development needs.

In the Northeast and Midwest, deterioration of old systems is especially a problem. In 1977, for example, the Boston distribution system, due both to leaks and nonfunctioning meters, could not account for 50 percent of the water it had distributed (89). Although the American Water Works Association recommends a 67-year cycle of replacement, many of Boston's water mains are over 100 years old. More recently, the Association found an average leakage rate of about 10 percent in a study of 931 U.S. utilities.[10] Although eliminating leakage entirely is probably not practical, opportunities exist in this area for improving the efficiency of water-supply systems.

The inability of some urban storm-water drainage and treatment facilities to handle possible increases in flood discharges is a source of concern. The need for additional facilities is growing as urban areas grow. Expenditures for new construction, maintenance, and rehabilitation do not appear to be meeting current needs, and the potential for sea level rise and urbanization of undeveloped land will likely increase needs in the future. Many communities will have to invest more in storm-water drainage or face increased property damages from flooding. In-

10 Unpublished observations, 19%?. The leakage rate in this study included water escaping from leaks and breaks, and failed meters.

Table 5-I—Federal Offices Involved in Water Resource Planning, Development, or Management

Legislative offices (U.S. Congress)
- Senate Committee on Agriculture, Nutrition and Forestry
- Senate Committee on Appropriations
- Senate Committee on Commerce, Science and Transportation
- Senate Committee on Energy and Natural Resources
- Senate Committee on Environment and Public Works
- Senate Select Committee on Indian Affairs
- House Committee on Agriculture
- House Committee on Appropriations
- House Committee on Energy and Commerce
- House Committee on Interior and Insular Affairs
- House Committee on Merchant Marine and Fisheries
- House Committee on Public Works and Transportation
- House Committee on Science, Space and Technology
- General Accounting Office
- Library of Congress
- Office of Technology Assessment

Executive off ices
- Executive Office of the President
  - Office of Environmental Policy
  - Office of Science and Technology Policy
- Department of Agriculture
  - Agricultural Research Service
  - Agricultural Stabilization and Conservation Service
  - Cooperative State Research Service
  - Economic Research Service
  - Extension Service
  - Farmers Home Administration
  - Forest Service
  - Soil Conservation Service
- Department of the Army
  - Army Corps of Engineers
- Department of Commerce
  - Economic Development Administration
  - National Bureau of Standards
  - National Marine Fisheries Service
  - National Ocean Service
  - Nationa Weather Service
- Department of Energy
  - Assistant Secretary for Conservation and Renewable Energy
  - Federal Energy Regulatory Commission
  - Federal Power Administrations
- Department of Health and Human Services
  - Agency for Toxic Substances and Disease Registry
  - National Center for Toxicological Research
  - National institute of Environmental Health Sciences
- Department of Housing and Urban Development
  - Assistant Secretary for Community Planning and Development
- Department of the Interior
  - Bureau of Indian Affairs
  - Bureau of Land Management
  - Bureau of Mines
  - Bureau of Reclamation
  - Fish and Wildlife Service
  - Geological Survey
  - Minerals Management Service
  - National Park Service
  - Office of Policy Analysis
  - Office of Surface Mining and Enforcement
- Department of Justice
  - Land and Natural Resources Division
- Department of State
  - Bureau of Oceans and international Environmental and Scientific Affairs
- Department of Transportation
- U.S. Coast Guard
- Saint Lawrence Seaway Development corporation
- Federal Highway Administration

Independent establishments and Government corporations
- Environmental Protection Agency
  - Assistant Administrator for Water
  - Assistant Administrator for Solid Waste and Emergency Response
  - Assistant Administrator for Pesticides and Toxic Substances
- Federal Emergency Management Agency
- General Services Administration
  - Public Buildings Service
- interstate Commerce Commission
- Panama Canal commission
- Small Business Administration
  - Loan Programs
  - Pollution Control Financing Program
- Tennessee Valley Authority

Quasi-officiai agencies
- Smithsonian Institution
  - Smithsonian Environmental Research Center
  - Smithsonian Tropical Research Institute

Bilateral organizations
- international Boundary and Water Commission, United States and Mexico
- international Joint Commission, United States and Canada

SOURCE: Adapted from J. Beecher and A. Laubach, *Compendium on Water Supply, Drought, and Conservation* (Columbus, OH: The National Regulatory Research Institute, 1989).

creased flooding potential in some areas of the country as a result of climate change should be cause for concern.

Most large urban areas should be able to renovate aging infrastructure through increases in service rates. Small and medium-size water systems, however, may have much greater problems. The large costs associated with renovating infrastructure, meeting Safe Drinking Water Act standards passed in 1988 (P.L. 93-523, most recently amended by P.L. 100-572), and providing additional service to growing areas are an especially heavy burden on smaller communities. Small systems typically lack adequate managerial and technical expertise and cannot benefit from economies of scale. One recent survey of infrastructure studies concluded that the gap between investment needs and available sources of financing the renovation of the water infrastructure is between $4.5 and $6.3 billion per year over the next 20 years.

EFFECTS OF CLIMATE STRESS ON NONCONSUMPTIVE USES OF WATER

Many uses of water do not deplete the total supply of water available; these are called *nonconsumptive* uses. Prominent among these are hydroelectric-power generation, powerplant cooling, waterborne transportation, and recreation, all of which climate change may seriously effect.

Hydroelectricity is a large proportion of the total electricity generated in some parts of the country. Washington State, in particular, produces 30 percent of U.S. hydroelectricity, but hydropower is also significant in such States as California and Tennessee. Such power production is sensitive to droughts and is reduced when reservoir levels are low. Reductions in hydroelectric power can usually be filled by a shift to greater use of fossil fuels, but alternative sources of electricity cost more and cause more pollution (including carbon dioxide (CO_2) emissions). The effect of drought on power generation can be considerable: during the 1988 drought, for example, hydroelectric-power generation on the Missouri River, in the Pacific Northwest, on the Ohio River, and in the Southeast was reduced between 20 and 40 percent (57).

A primarily nonconsumptive use for water is power-plant cooling.[11] Many power plants use fresh water for condenser cooling and (sometimes) emergency cooling. Heated water discharged from power plants is returned to the stream from which it was taken. Because such water contributes to thermal pollution and can have adverse impacts on aquatic life, water temperature and quality are regulated by Federal and State Governments. When water temperatures are high, power plants often must curtail power production or use cooling towers to comply with regulations. Higher water temperatures can also reduce the efficiency of many power-plant operations, and the Nuclear Regulatory Commission mandates that nuclear power plants be shutdown if a specified upper temperature limit is reached. Other water uses may be affected if additional releases from multipurpose reservoirs are needed to moderate water temperatures (45).

Power-system operations in regions such as the southeastern United States are currently affected during critically hot summers by temperature constraints. Problems can be acute when high temperatures correspond with peak power demands. Also, on some eastern rivers, power-plant water needs are, at times, so large that there may not be enough water to dissipate heat during low-flow periods (80). Power systems could become less reliable in a warmer climate, especially during the summer (45). In turn, power-production costs and consumer-electricity prices could increase.

Waterborne transportation is also affected by drought-and with considerable adverse impacts. In 1988, water in the Mississippi, Ohio, and Missouri Rivers was so low that barge traffic was

[11] Fresh water withdrawn to produce the Nation's electricity totals about 130bgd, but currently only about 4bgd are actually consumed (66).

impaired (37). On one of the worst days, for example, 130 towboats and 3,900 barges were backed up on the Mississippi at Memphis while dredges deepened a shallow stretch of the river (57). The economic consequences of the low flows were considerable: barge and towboat owners suffered economic losses, and agricultural commodities piled up in Mississippi River ports. Conversely, railroads and some Great Lakes shippers benefited. Box 5-E describes these effects in more detail.

Recreation may seem to be a less essential use for water; however, in some areas, the economic value of water-related recreation outweighs its

Box 5-E—Navigating the Mississippi Through Wet and Dry Times

Most parts of the United States have experienced droughts or floods at one time or another. The impacts of an extended drought or major flood can be costly. The case of the Mississippi River illustrates the far-reaching effects that can occur when such extreme events lead to abnormal flows on an important navigable river. Such effects could become more pronounced if climate changes.

A significant share of the Nation's cargo moves on the Mississippi River. The river is essential for the transport of major commodities, including grain, petroleum, chemicals, and coal, both within the country and as the first step in exporting these goods. According to one recent analysis (57), "more than 300 tow and barge companies operate on the Ohio, Mississippi, and Illinois river systems, and many river ports serve the barges." The barge industry "carries 60 percent of all grain exported from the United States, and 40 percent and 20 percent of all petroleum and coal, respectively, transported within the U.S." as well as transporting "45 percent of the entire midwestern grain crop." Thus, the Mississippi-based barge industry is "a key U.S. transportation industry . . . one of the nation's major conveyors of bulk commodities," with average revenues of approximately $1 billion year.

The Mississippi's ability to maintain these transportation services is intricately related to climate. Rainfall from more than 1 million square miles (2.59 million square kilometers)[1], covering 40 percent of the United States and 13 percent of Canada, runs off and drains into the 2,340-mile-long (3,770 kilometer-long)[2] Mississippi River. From western Pennsylvania to the Great Lakes to South Dakota, water makes its way to the Mississippi through rivers including the Ohio, the Illinois, and the Missouri. The amount of water that eventually flows through the Mississippi depends on precipitation, but is also affected by human land uses that alter runoff patterns, including the planting or clearing of vegetation, commercial and residential land development, paved roads and parking lots, and various agricultural practices. The Mississippi responds to precipitation patterns throughout the region, whether rainfall is unusually high or unusually low. In addition, both the low-flow conditions caused by drought and the high-flow conditions caused by large amounts of precipitation and storms, whether or not they lead to flooding, can disrupt the Mississippi's navigation systems.

The Drought of 1988

The Drought of 1988 has earned a place in popular memory for the disruptions it caused to Mississippi River navigation. The year began with light and infrequent snowfalls in much of the watershed. This resulted in much-reduced snowmelt runoff in the spring. By early April, areas around the Ohio, the upper Mississippi and the Missouri, and lower Mississippi and the Arkansas Rivers were classified as experiencing moderate to severe drought conditions, according to the Palmer Drought Severity Index (a measurement of long-term moisture conditions). Drying continued through April and May, and spread to include all regions of the Mississippi River Basin. By mid-June, 83 percent of the Mississippi River Basin was in the throes of severe drought.

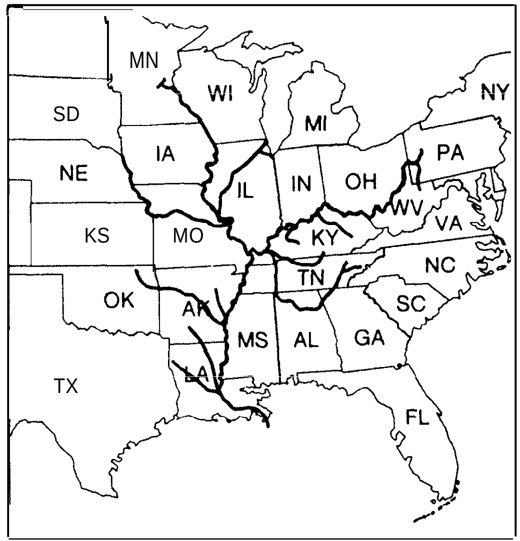
[1] To convert square miles to square kilometers, multiply by *2.590.*

[2] *10* convert miles to kilometers, multiply by 1.609.

As expected, water levels in the river responded to the drought by dropping precipitously. In normal years, water flow through the river peaks in April and May. In 1988, however, water flows began to decline in April and reached record lows during May that were to continue throughout the summer. On June 8,1988, a barge-pulling tow grounded on a section of the river near St. Louis. It was the first of a series of navigational disruptions that would seriously impede barge transport on the river through late July.

Mississippi River navigation is aided by a series of locks and dams constructed and operated by the U.S. Army Corps of Engineers along the upper Mississippi as well as on much of the Missouri and Ohio Rivers. During normal years, this intricate network of water-control structures can be operated to maintain water levels and safeguard navigation during much of the year. in 1988, however, even carefully controlled and timed water releases could not prevent low water levels. Fully loaded barges require minimum water levels of 9 feet (2.7 meters)[3] to operate safely. Not only does water at this level provide sufficient clearance to keep the barge from hitting the bottom, but it also generally ensures that the water is moving fast enough to forestall the formation of shoals, sand bars that form in shallow sections of the river and impair navigation.

Navigable Waters of the **Mississippi** River System



SOURCE: W. Reibsame, S. Chagnon, and T. Karl, *Drought and Natural Resources Management in the United States: Impacts and Implications by the 1987-89 Drought* (Boulder, CO: Westview Press, 1991).

The first action managers generally take when water levels drop too low is to start dredging the blocked areas. Constant work by several dredges for several days can often dear the channel enough to keep it open. A second strategy is to limit the number and weight of the barges pulled by a towboat so the tow is more maneuverable and the lightly loaded barges are less likely to hit bottom. A third strategy is to release more water from upstream dams, although this can interfere with other water uses at the upstream locations (including hydropower generation, recreation, and agricultural, industrial, and municipal water supplies). In the event of severe disruptions, alternate navigation routes or modes of transportation may have to be found.

Costly barge backups

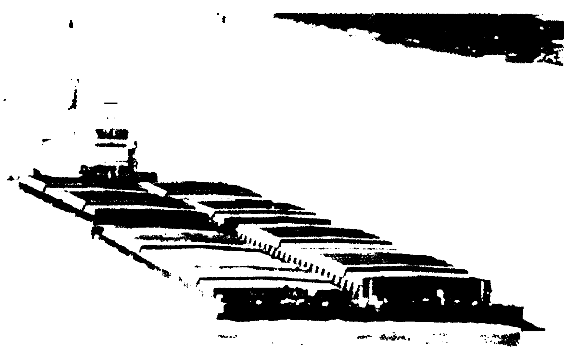
In 1986, managers drew on ail of these strategies and more. Following the June 8 grounding in St. Louis, the Corps dredged that section of the Mississippi and limited traffic to barges that drafted no more than 6 feet. Despite the Corps' efforts, water levels continued to drop. By June 15, water levels in that reach dipped to the lowest levels measured since 1872, when record keeping first began. In addition, water levels on a nearby stretch of the Ohio River dropped below 8 feet, with extensive shoaling. The Corps dosed a stretch of the Ohio for dredging from June 14 through 17. Over the next several weeks, the Mississippi and Ohio rivers were periodically dosed for dredging in locations that included Greenville, MS, Mound City, IL, and Memphis, TN. Even when the river

3 To convert feet to meters, multiply by 0.305.

(Continued on next page)

Box 5-E-Navigating the Mississippi Through Wet and Dry Times-(Continued)

U.S. ARMY CORPS OF ENGINEERS



A barge and 'towboat' on the Mississippi River. Low flows during the 1988 drought stranded thousands of barges at Memphis and other river ports. The 1993 flooding along the Mississippi and its tributaries stranded more than 2,000 barges, costing the barge industry more than $3 million per day.

remained open, river traffic and loads were reduced. By early July, river traffic was down by one-fifth, and toads totaling 15,000 tons (13.6 million kilograms)[4] of commodities had been halted.

Some barge traffic was diverted to the Tennessee-Tombigbee Waterway, a river system built and operated by the Corps that parallels the southern half of the Mississippi. The Tennessee is not usually the favored southward route because it is slower and less direct than the Mississippi, but it was able to handle more than 2.1 million tons of cargo above normal levels to relieve some of the Mississippi barge backup. As the extent of the disruption became apparent, some grain shipments were shifted to alternate ports and routes on the Great Lakes instead of the Mississippi, further absorbing some of the barge backups and storage overflows in the ports on the Mississippi.

Repercussions from the interruption in navigation were widespread. By the time of the dosing of the Ohio on June 14,700 barges were backed up at Mound City, a major grain port. With the barges not running and no empty barges arriving, grain piled up at the port. Within days, the port had to find storage space for 200,000 bushels (7,000 cubic meters)[5] of corn, and more than $1 million worth was simply stored on aty streets because there was no more room in the elevators. Thus, even farmers who managed to harvest crops despite the drought (and could potentially earn higher prices due to the lower supplies) faced the risk that their grain would spoil while awaiting shipment. Similar pileups occurred elsewhere. By June 17,700 barges were trapped in Greenville. By the 19th, 3,900 barges were stranded in Memphis. Barge traffic was sporadic through late June; in early July, another 2,000 barges were held up in Memphis.

International implications

Attempts to combat low water levels and maintain navigation even led to international controversy. It is technically feasible to increase the flow of the Mississippi River by diverting water into it from Lake Michigan through the Illinois River channel. At one point during deliberations over how to respond to the drought, the governor of Illinois proposed to triple the normal water releases from the Lake for a limited time to help restore Mississippi River levels. The increased diversion was expected to raise Mississippi levels by 1 foot at St. Louis and around 6 inches (15 centimeters)[6] at Memphis, while lowering the level of Lake Michigan by only 1 or2 inches. This proposal caused considerable controversy when introduced, however, because it ignored the history of controversy over water diversions, and because at the time of the proposal, Lake Superior water levels were well below average even though they had been at record high levels just 2 years before. Governors of four Great Lakes States threatened court action, and the Canadian ambassador delivered a formal protest to the U.S. State

4 To convert tons to kilograms, multiply by 907.

5 To convert bushels to cubic meters, multiply by 0.035.

6 To convert inches to centimers, multiply by 2.540.

Department. Residents on both sides of the Great Lakes considered the levels of the Lakes-already low due to the drought-of fundamental importance and declared that the levels should not be artificially altered for any reason. Sufficiently low lake levels could, among other things, disrupt the operation of locks, thus affecting shipping activities and the production of hydroelectric power at Niagara and on the St. Lawrence River. In the end, the Illinois governor backed off the proposal, and no water was diverted.

Winners and losers

The economic costs due to less-efficient barge transport may have reached $1 billion. Farmers, agricultural chemical manufacturers, and coal and oil companies found it more costly to ship products as barge shipping prices quickly rose from $9 to $15 per ton. Barge shipping was reduced 20 percent, costing the industry perhaps $200 million. Other losers included the consumers of shipped commodities, particularity utilities forced to pay higher prices for coal. in addition, the drought ied to a 25 percent drop in hydropower production on the river and a 15 percent decline in recreational use, and low water levels allowed sait water from the mouth of the Mississippi to travel 105 miles inland, damaging wetlands along the river.

Despite considerable turmoil and costly losses to shippers and the barge industry, there were others who benefited from the drought, partly offsetting the overall costs. Shippers on the Tennessee-Tombigbee and the Great Lakes received a considerable boost in business, and showed gains in economic competitiveness due to the greater reliability of their routes. The Illinois international Port at Chicago shipped nearly $2 million worth of grain that would otherwise have been shipped through Mississippi River ports, generating an income for the port of $0.5 million. On the other side of the Lakes, shipping traffic on the St. Lawrence Seaway rose by 7 percent during the summer months.

Perhaps the biggest winner was the Illinois Central Railroad (iCRR), a north-south system running from Chicago to New Orleans. Because its route is roughly parallel to the Illinois-Mississippi River system, the railroad has iong been a competitor with the barge industry. In 1988, the going rate for shipping by rail was $8 to $12 per ton, which put the ICRR at a considerable disadvantage in competing for cargo with the barge industry, which generally charged around $5 per ton. When barge prices increased to $14 to $15 per ton due to the backups, however, the ICRR was well-situated to compete.

The Flood of 1993

The Drought of 1988 illustrates the powerful role that climate plays in maintaining the navigational services that many have come to expect from the Mississippi. in times of drought, the iow water levels that caused shoaling and grounded tows in 1988 can also affect wintertime navigation because the river freezes up more quickly and extensively in shallow areas. Conversely, during times of above-average precipitation, floods can be disruptive as some stretches of the river become nonnavigable during high flow. Flooding along the Upper Mississippi and many of its tributaries reached levels in June and July 1993 not seen in many decades. A 500-mile stretch of the upper Mississippi, from St. Paui to St. Louis, was shut to ail commercial traffic, leaving thousands of barges stranded. Water levels did not return to normal for more than a month, wit h costly effects on grain shipments f rom Iowa, Missouri, Illinois, Minnesota, and Wisconsin. Cargoes heading north (e.g., rubber, sugar, and metal from overseas) were aiso stranded. The flooding caused many small towns to be evacuated and darnaged thousands of homes and businesses. Crop losses have been estimated to be between $5 and $10 billion.

Considerable uncertainty surrounds predictions of climate change in the Mississippi River Basin. Nevertheless, both the 1988 drought and the 1993 flooding could be harbingers of the challenges ahead for the barge industry-and for others who iive near and/or depend on the Mississippi.

SOURCES: This box is drawn largely from W. Riebsame, S. Changnon, Jr., and T Karl, *Drought and Natural Resources Management in the United States: Impacts and Implications of the 1987-89 Drought* **(Boulder, CO: Westview Press, 1891), pp. 43-112. Supplemental material came from W. Koellner, "Climate Variability and the Mississippi River Navigation** *System,"* **in:** *Societal* **Responses to** *Regional Climate Change: Forecasting by Analogy,* **M.H. Glantz (cd.) (Boulder, CO: Westview Press, 19S8), pp. 243278; Levels Reference Study Board, "Final Report of CCC GCM 2 X CO_2 Hydrological Impacts on the Great Lakes" (Hanover, NH: Levels Reference Study Board, December 1991); and Reuters Ltd., "Midwest Levees Straining: Mississippi River Continues to Rise,"** *Washington Post,* **July 8, 1993, p. A3.**


U.S. ARMY CORPS OF ENGINEERS

Recreation is an important nonconsumptive use of water, and in many areas, one of its highest-valued uses.

use for irrigation or other purposes. Low lake levels may leave recreational boating docks high and dry and may affect shoreline property values. Low flow conditions in mountain streams affect white-water rafting, fishing, and other types of water-related recreation.

Current allocation problems on the Missouri River illustrate the value of' water-related recreation, the considerable conflicts that can develop between instream and offstream uses for water, and the conflicts that can arise among different instream purposes. The Upper Missouri River Reservoir System (UMRRS) is operated by the Army Corps of Engineers for a variety of purposes, chief of which are irrigation, navigation, and flood control. The Corps, however, is under pressure from upstream States to give greater consideration to recreation and fish and wildlife interests in operating the System. When priority is given to navigation during drought periods, boating facilities in upstream lakes (for example, Fort Peck Lake in 1991) can be left high and dry, and fish habitat can suffer. Upper Missouri River States (Montana and North and South Dakota) have decried this situation because, as the Corps notes, the recreational value of the UMRRS, at $65 million annually, is now roughly four times the economic value of navigation (2). Upper Missouri River States, which would like to seethe operating rules changed to better reflect current economic realities, are now pitted against Lower Missouri River States, which want the rules to remain the same to protect the hydropower and navigation purposes of the System. Similar conflicts can be found in many places in the United States, and such conflicts are inevitably more heated during drought.

ADAPTING WATER RESOURCE SYSTEMS TO CLIMATE AND OTHER CHANGES

Water resource planning is a complex political, economic, sociological, scientific, and technological endeavor (60). Therefore, adaptation to change, whether climate or otherwise, will rarely be straightforward. Adaptation measures must accomplish several objectives if they are to be successful. They must address the sources of stress, whether due to short-term or long-term imbalances between supply and demand, threats to water quality, high costs, or other factors. They must be politically and administratively feasible--water resource systems exist in complex institutional environments, and changes must be capable of operating in conjunction with existing laws, agencies, and regulations. (Box 5-F describes some important water responsibilities of key Federal agencies.) Changes should enhance the flexibility and robustness of water resource systems because the timing and magnitude of regional climatic events may change in as yet undetermined ways. And, finally, costs and benefits arising from institutional changes must be perceived as equitable if they are to be supported and remain successful in the long run (23).

Adaptation measures in the near future are likely to be taken in response mainly to problems more pressing than climate change, but many of these measures could also address climate change concerns. Consideration of the potential for climate change in water resource planning could sometimes make a difference in the choice among types and timing of new policies or projects. Hence, even without sufficient regional da@ it

Box 5-F-important Water-Related Responsibilities of Key Federal Agencies

The Federal Government is *involved* in virtually every aspect of water resource planning, management, regulation, and development. In all, at least 35 units-including agencies, bureaus, and services-within 10 different Federal departments, as well as 7 independent agencies and several bilateral organizations, currently exercise some responsibility for water programs and projects(4). These programs are governed by more than 200 Federal rules, regulations, and laws. Some 7 House committees and 13 subcommittees, plus 6 Senate committees and 10 subcommittees exercise responsibility over distinct aspects of water resource development and management (13) (see table 5-3). Responsibilities of some Federal agencies with important water-related programs are listed below.

Department of Agriculture (USDA)

Soil Conservation service (SCS)—Helps farmers develop soil and water conservation plans and arrange for cost-share funding for implementation of conservation practices. In cooperation with other agencies, offers advice to farmers on pesticide and fertilizer use and land management. Several programs promote water quality, including the Conservation Reserve Program, the wetlands Reserve Program, the Agricultural Water Quality Protection Program, and the Small Watershed Program.

Department of the Army (DOA)

Army Corps of Engineers (the Corps)-In budgetary terms, the most important Federal water resources development agency. Responsible for planning, design, construction, operation, and maintenance of projects for flood control and floodplain management, water supply, navigation, hydroelectric power, shoreline protection, recreation, fish and wildlife management, and environmental enhancement. Reservoirs managed by the Corps, which include most of the largest reservoirs in the United States, hold about 65 percent of the Nation's stored surface water. The Corps has undertaken several climate-change-related studies, including analysis of decision making about water resources given the uncertainty of climate change.

Department of Commerce (DOC)

National Oceanic and Atmospheric Administration (NOAA)—Within the context of its coastal zone and fisheries management responsibilities, concerned with watershed management and non-point-source pollution; Office of Hydrology provides streamflow and flood-forecasting services.

Department of Energy (DOE)

Federal Energy Regulatory Commission (FERC)—Issues licenses for nonfederal hydropower projects; considers measures to preserve environmental quality, protect fish and wildlife, and maintain scenic values, as well as those to maintain dam safety, flood control, and recreational opportunities.

Federal Power Administrations (FPAs)—Five Federal power administrations market hydroelectric power, including Bonneville, Southeastern, Alaska, Southwestern, and Western Area Power Administrations.

Department of the Interior (DOI)

Bureau of Reclamation (the Bureau)—Supplies municipal water to 25 million people in 17 western States, provides irrigation water for 10 million acres (4.05 million hectares)[1] of western farmland, and operates 52 hydroelectric facilities that generate 46 billion kilowatt-hours of electricity annually (making the Bureau the Nation's 1 lth largest electric utility). The facilities operated by the Bureau provide local flood control, fish and wildlife

[1] To convert acres to hectares, multiply by 0.405.

(Continued on next page)

Box 5-F–important Water-Related Responsibilities of Key Federal Agencies=(Continued)

enhancement and recreation.The Bureau has established the Global Climate Change Response Program to study the potential impacts of global climate change on water resources in the 17 Western States.

Geological Survey (USGS)—Conducts assessments of the quality, quantity, and use of the Nation's water resources; produces annual state-by-state summaries on special topics (e.g., floods and droughts). USGS has initiated a Global Change Hydrology Program, the objectives of which include improving methods for estimating the sensitivity of water resource systems to climate variability and change across the range of environmental conditions existing in the United States and improving understanding of the effects of climate change on the hydrology of watersheds.

Fish and Wildlife Service (FWS)—Lead Federal agency for conservation of fish and wildlife and their habitats; responsible for endangered species, freshwater and anadromous fisheries, certain marine mammals, and migratory birds. Manages 700 national wildlife refuges; assesses environmental impact of hydroelectric dams, stream channelization, and dredge and fill operations. An FWS goal is to assess the significance of global climate change on fish and wildlife.

Environmental Protection Agency (EPA)

Plays a major role regulating water quality by issuing permits for discharge of pollutants into navigable waters, developing criteria that enable States to set water-quality standards, administering State grant programs to subsidize costs of building sewage treatment plants, setting national drinking-water standards, and cooperating with the Corps to issue permits for the dredging and filling of wetlands, for example. Works wfth States to promote watershed management and reduction in non-point-source pollution. EPA is the lead agency for the National Estuary Program.

Federal Emergency Management Agency (FEMA)

Undertakes hazard mitigation, preparedness planning, relief operations, and recovery assistance for floods and droughts and other natural and humanmade disasters; has undertaken a study of the possible impact of sea level rise on the National Flood Insurance Program.

Tennessee Valley Authority (TVA)

Government-owned corporation that conducts a unified program for advancing resource development and economic growth in the Tennessee River Valley region. TVA manages the 50 dams and reservoirs that makeup the TVA system. Its activities include flood control, navigation development, and hydroelectric power production. TVA is studying the sensitivity of its reservoir and power-supply systems to extreme weather.

may be important to take some actions soon or in the relatively near future to avoid climate-change-related regrets later. Projects that require long lead times for construction or implementation may deserve special attention with respect to climate change. In some instances, it may be advantageous to avoid taking certain actions (e.g., building in flood-prone areas) until better information about climate change, future water demand,[12] and other factors is available. A few measures might be motivated solely in anticipation of a changing climate, but most are likely to be taken primarily in response to other stresses.

12 Projecting future demand has been exceptionally difficult, and studies have shown that most forecasts made in the 196@ and 1970s of current water use have been substantially in error (60). Projecting demand is complicated because the future regulatory framework for water resource management and the types of adaptation that will be politically, economically, socially, and environmentally feasible are uncertain. The importance of climate change in water resource planning relative to these other sources of uncertainty is difficult to gauge.

Potential adaptation measures are considered in several categories below: demand management, water reallocation, and supply management all deal with using existing supplies more efficiently. Supply augmentation increases the amount of water available by developing new sources. Flood and drought contingency planning introduces more flexibility during emergency situations and helps to mitigate damages.

Demand Management and Water Reallocation

Until relatively recently, the preferred approach to satisfying the water needs of growing communities has been to develop untapped supplies. As new water-supply sources have become less accessible, and as developing them has become more expensive and less acceptable environmentally, managing demand and enabling voluntary water reallocation have taken on increasing importance. Demand management and water marketing could be very important in coping with climate change, both because they promote efficiency and because they enable a considerable amount of flexibility in water resource management.

The objective of demand management is to use water more efficiently, and many regulatory and water-pricing options can be used to promote the development and use of more-efficient water-use technologies and practices. Demand-management options include such measures as: 1) modifying rate structures, 2) reducing landscape water use, 3) modifying plumbing and irrigation systems, 4) conducting educational programs, and 5) metering. Temporary measures can provide great flexibility in relieving stress during droughts. Efficiency gains from permanent measures could offset or postpone the building of large and costly structures that might otherwise be needed to deal with climate change and other factors leading to increased demand.

Demand-management measures are also important because they often have short payback periods and lead to reduced capital and operating costs for water supply and wastewater treatment facilities. Water saved through demand management can be made available to protect wetlands and fish and wildlife habitats, and reduced wastewater and drainage flows can yield additional environmental advantages.

The important question is not whether demand-management practices should be pursued, but how conserved water will be used. If the water is to be used entirely to meet the needs of unlimited urban growth, for example, water-use problems are likely to recur at a later date. Flexibility can be maintained by reserving some conserved water for instream purposes.

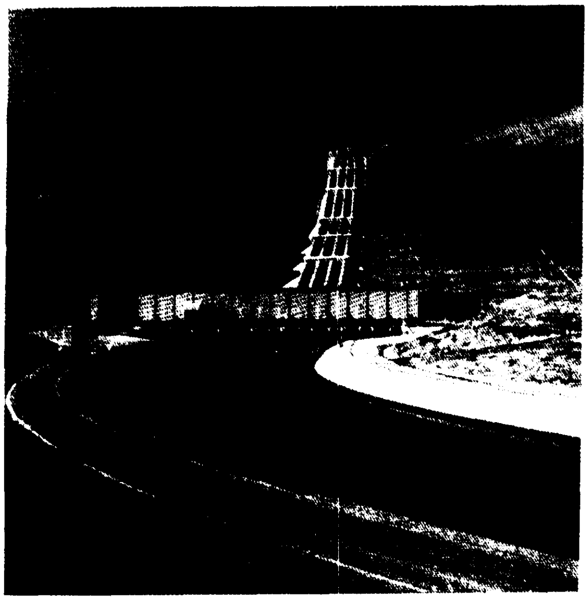
Likewise, the primary objective of enabling water reallocation is to promote more-efficient water use. Water reallocation is facilitated by allowing water to be marketed, that is, transferred from willing sellers to willing buyers. Water marketing is an important means of transferring accurate price signals regarding the value of water and is therefore closely linked to demand management (65). If owners of inexpensive water are allowed to sell it at higher market prices, they will have an incentive to conserve, and those willing to pay higher prices for water are unlikely to do so only to use it inefficiently.

Water Reallocation Through *Marketing* and Other Transfers

Water has very different costs depending on its use and typically has the lowest value in those sectors that consume the most of it. The disparity between the relatively high prices paid by urban entities and the low prices paid by agricultural users suggests that opportunities exist to use markets to allow more-efficient allocation of water.

However, the lack of institutional and legal mechanisms for facilitating markets has so far limited their development. Other types of transfer arrangements that may or may not be considered "marketing can also be effective. Most of the water trades and transfers occurring to date have

STATE OF CALIFORNIA, DEPARTMENT OF WATER RESOURCES



The California State Water Project currently transfers about 2.5 million acre-feet (3 billion cubic meters) of water annually from northern to southern California. Together with California's Central Valley Project, it comprises one of the most massive water-redistribution systems in the world. Shown is the California Aqueduct and the Ira J. Chrisman Wind Gap Pumping Plant near Bakersfield, California.

involved the transfer of water from rural agricultural uses to municipal or industrial uses; some trades, however, have been made between agricultural regions.

Properly implemented, water markets and transfers can serve to reallocate: water quickly and efficiently under current climatic conditions. Marketing arrangements can vary from "permanent' sales[13] of water to short-term, seasonal, or dry-year agreements. Box 5-G illustrates a permanent transfer in which California's Metropolitan Water District agreed to improve the Imperial Irrigation District's canal system in exchange for the water saved by these improvements. Box 5-H illustrates an innovative dry-year agreement, also in California, designed to meet demand during droughts.

Each of the types of reallocation agreements described in boxes 5-G and 5-H could also serve to provide more-efficient and flexible use of water in the event the number, duration, or intensity of extreme events increases. Indeed, severe drought conditions in the West between 1987 and 1992 may offer a glimpse of what problems a future, drier region would encounter and of some of the measures that might be taken in response. Approaches similar to California's Drought Water Bank are likely to be useful in other regions and could eventually become permanent institutions. Such sales of water to higher-value uses would ensure that as much economic productivity is maintained in a region as possible.

An additional characteristic of water markets is that they do not inherently require long lead times to establish, such as are required of new dams. California's Drought Water Bank, for example, although not without problems and not a full-fledged market, was implemented in several months. Water markets and market-like transfers may allow society to delay or avoid more-costly or less-flexible adaptation options.

Despite the advantages of water reallocation, the possibility that water transfers could adversely affect parties not directly involved in them has left some people wary. Several issues that often arise are: What review process or standard should be used to balance the benefits to farmers from water trades against the secondary economic effects on the local community? What are the obstacles facing a sale or trade when farmers receive their water from an irrigation district or pursuant to a contract with a Federal water project? How will transactions cope with surface-water return flows and groundwater recharge? Who protects freshwater fisheries, recreational white water, and other ecologic and aesthetic values of rivers (65)? Some States have taken steps to modify their water codes to address

[13] Permanent, that is, from the point of view of the entity selling the water. Such a transfer would not necessarily prohibit the water from being resold.

Box 5-G-Permanent Transfer: Conserving Water in California's Imperial Valley

Southern California has four major water sources, and all are threatened to some degree. increasingly strict water-quality regulations threaten the use of some local water supplies (9O percent of which is groundwater); importation of Colorado River supplies is being scaled back as Arizona's Central Arizona Project comes on line; litigation is forcing Los Angeles to reduce importation of water from the Owens Valley and Mono Lake Basin; and in 1982, the future of obtaining additional water from northern California was clouded as voters rejected the Peripheral Canal across the Sacramento-San Joaquin Delta (29).

Southern California's population is expanding even as its traditional water supplies contract. Los Angeles and San Diego are two of the country's IO fastest-growing counties (44), and the region's population of 14 million could grow to 18 million by the year 2010 (29). Because population growth is expected to outstrip recent declines in per capita water use, Southern California could soon face severe water shortages. As part of its efforts to avoid such shortages, the Metropolitan Water District (MWD) has been active in pursuing opportunities for water transfers. One of the largest transfers pursued by MWD is a conservation agreement with the Imperial irrigation District (iID).The IID diverts 2.9 million acre feet per year (af/year)[1] from the Colorado River and is California's largest water user, but in the early 1980's, IID was criticized by State Government and the courts for wasting water. The California Department of Water Resources was able to identify operational and physical improvements in IID's water-distribution system that could save an estimated 438,000 af of water per year (54).

in 1988, after years of intense and sometimes acrimonious negotiation, MWD and IID reached an agreement in which MWD agreed to fund IID conservation projects in return for an estimated 100,000 af of saved water per year (54). MWD is to contribute money directly to the IID Conservation Fund, which is controlled entirely by IID. Projects must be approved by a program coordinating committee appointed by MWD and IID. Projects will include lining canals; installing gates and automation equipment; constructing spill-interceptor canals, regulatory reservoirs, and tail-water recovery systems; and other monitoring and management measures. The Program Coordinating Committee is responsible for seeing that ail projects are operating within 5 years of the effective date of the agreement (54).

in addition to construction costs for the original projects, MWD is to pay for any conservation structures that need to be replaced during the term of the agreement. MWD is also to pay ongoing direct annual costs of nonstructural programs, such as those involving monitoring and management, and $23 million for indirect costs, including costs of environmental damage, lost income from hydroelectric generation, public-information programs, and litigation on related issues. in return, MWD expects to receive approximately 100,000 af of conserved water per year for 35 years at an average total cost of approximately $128/af (Pius $20/af for pumping (54)).

Many legal and institutional obstacles had to be overcome to conclude the transfer agreement. Controversy surrounded the issue of whether or not IID was legally able to sell conserved water; some argued that under anti-waste provisions of California State iaw, the conserved water should automatically revert to holders of the next priorities for Colorado River water. The issue was eventually sidestepped by referring to the agreement as a "water salvage arrangement" rather t han a sale, but t he issue may still be raised in future litigation (54). Agreements also had to be reached with the Coachella and Paio Verde irrigation districts to ensure that MWD would be allowed to receive the conserved water because these irrigation districts' Colorado River priorities are lower than IID's but higher than MWD's.

Despite the numerous institutional obstacles and other difficulties, the MWD-IID transfer arrangement is seen as a success by both parties. MWD is satisfied to receive additional water supplies at a reasonable price, and IID has been pleased to receive an improved distribution system at MWD's expense (54).

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[1] 3.6 billion cubic meters/year; to convert from acre-feet to cubic meters, multiply by 1,234.

Box 5-H—A Drought-Year Option: California's Drought Water Bank

In December 1990, California was in the midst of its fourth consecutive year of drought. Reservoir storage was only 32 percent of capacity, statewide precipitation averaged only 28 percent of normal for the 1990-1991 water year, and most snowpacks were less than 30 percent of normal. Both the State Water Project (SWP) and the Central Valley Project (which, respectively, account for about 7 and 22 percent of California's water supplies) were forced to cut back sharply in water deliveries. SWP, for example, announced cutbacks of 90 percent to municipal users and was forced to suspend all deliveries to agricultural users. The State Department of Water Resources (DWR) was predicting that the drought would likely continue into the new year, and the State Water Resources Control Board had prepared a list of draconian regulatory measures that might need to be taken to mitigate the crisis (30).

On February 15,1991, with no expectation of sufficient rain for the season, Governor Pete Wilson announced a four-point plan to deal with the drought. As part of the plan, he established the Drought Water Bank. Intended to operate only during the emergency, its charge was to purchase water from willing sellers and sell it to entities with critical needs (7). Bank members could be corporations, mutual water companies, or public agencies (other than DWR) that had responsibility to supply water for agricultural, municipal and industrial, or fish and wildlife needs. Members were required to meet rigorous criteria (e.g., they must have already made maximum use of all available supplies) to qualify as having critical needs. Sellers were assured that transfers would be considered a reasonable beneficial use of water, not constitute evidence of waste and not be evidence of surplus water beyond the terms of the agreement. The Bank was not intended as a precedent for California water policy or law, but was undertaken solely to help cope with 1991 drought conditions.

Water for the Bank was acquired through land fallowing (i.e., not planting or irrigating a crop), using groundwater instead of surface water, and transferring water stored in local reservoirs. Most of the 351 contracts negotiated were for fallowing land, but the largest acquisition came from transferring stored water. The Bank initially paid sellers $125/per acre-foot (af)[1] but after rainfall in March exceeded expectations, estimates of water needs were lowered, and a few sellers were offered $30/af. The bank, in turn, sold the water for $175/af (sometimes

1 To convert acre-feet to cubic meters, mutiply by 1,234.

these issues, but State water codes are not uniform and not equally conducive to transfers.

Water transfers have a controversial history to overcome—the earliest often took place without adequate consideration for equity, regional economics, the environment, or areas of origin. Water transfers have sometimes been referred to as "water grabs" because gains to the receiving water users have often come at the expense of a loss of water security and opportunity for water users in the area of origin. The classic example is the Owens Wiley of eastern California, where early this century agents for the City of Los Angeles made several disguised purchases of land for the purpose of diverting the associated water hundreds of miles to the south. The economic and environmental impact on Owens Valley was devastating, and the Valley has never recovered (53). Box 6-D describes how water transfers have hastened the decline of farmingin Colorado.

Transfers do not necessarily result in losses, however, and the transfers described in boxes 5-G and 5-H contain features that make them beneficial to buyers and sellers, and they have generally been successful in increasing available supplies without significantly endangering "third-party" interests. As experience is gained with transfer mechanisms and States ensure protection of third-party interests, some current concerns should be allayed (50).

Promotion of interstate, as well as intrastate, transfers could help make management of water the amount paid to sellers, contract administration costs, and conveyance losses. Buyers also paid the cost of conveying water from the Sacramento-San Joaquin Delta to their service area

Surprisingly, the Bank was able to purchase about 820,000 af of water in about 45 days. Eventually, about 400,000 af were disbursed to Bank members for critical needs, and 260,000 af were carried over into 1992 for SWP. Some of the excess water acquired was lost in conveyance or was used to maintain water-quality standards in the Delta The rest was used to replenish carry-overcapacity as insurance against the possibiiitythat the drought could continue into 1992.

in ail, particularly given the lack of experience California had with water trading and the crisis nature of the program, the Water Bank was considered very effective in reallocating water. Many were concerned, however, that water trading would have adverse impacts on local economies and on the environment. indeed, there were some losers; however, the adverse economic impacts were minimal, and overall, the Bank created substantial gains for California's agriculture and economy. Fallowed iand accounted for only about 10 percent of planted area in major counties, and even where fallowing represented the largest portion of decline in planted area, the overall net effect on county personal income and total employment was relatively small. The jobs that were lost in exporting regions were more than offset by the jobs gained in importing agricultural regions. Estimated income gains in importing agricultural regions ($45 million) were more than three times greater than estimated income losses in exporting regions ($13 million) (30). Estimated net benefits in urban areas were OVer $90 million, even without accounting for the value of increased carry-over storage.

Many people believe that the Bank has just scratched the surface of its potential for facilitating transfers. Some, however, are concerned with this success. Environmentaiists worry that there is currently no mechanism for allocating water to fish and wildlife. Local officials remain concerned about the possible impact an expanded water bank could have on their tax base and on social-services budgets. Rural communities fear that banking could accelerate either their demise or their development into suburban areas. Considerable disagreement exists about whether the Water Bank should be permanent or implemented onty during emergencies. Neither rural areas nor environmentalists want urban areas to use the Water Bank as an excuse for forgoing water development, conservation, or reclamation programs. Minimizing future Bank impacts on local economies may be possible by, among other things, ensuring a wide regional distribution of fallowed area, increasing reliance on groundwater exchanges, and switching to less-water-intensive crops (30).

resources more flexible and efficient, especially where infrastructure for transferring the water already exists. Such transfers, for example, could be useful in the Colorado River Basin. Without some vehicle for transmitting price signals across State borders, low-value irrigation uses in the Upper Basin States have the potential to displace high-value urban uses in the Lower Basin, where water may have 10 times the value. Several proposals for interstate marketing of Colorado River water have already been made, including recent ones motivated by the California drought that began in 1986 (9). Increased aridity in the Southwest, possibly as a result of climate change, will likely focus additional attention on interstate transfers in the future.

Demand Management Through *Pricing* Reform

Water conservation could be promoted not only by allowing markets to provide accurate price signals, but by changing some pricing practices that lead to inefficient water use. Perhaps one of the biggest obstacles to more-efficient water use is that Americans are frequently charged much less for water than it costs to supply it. Water is usually treated as a free resource in the sense that no charge is imposed for withdrawing water from a surface or underground source. Users may pay for storing water and for transporting it to where it is used (although sometimes at highly subsidized rates), and also for treatment of the water and disposal of the return flows, but there is rarely any charge to reflect the value of water for a given use, that is, the *opportunity costs* of putting water to one use at the expense of another (22). As a result, few people have incentives to use water efficiently. Policies that underprice water have been much criticized for not promoting efficient use in urban areas and on lands irrigated with federally supplied water (91).

Urban pricing structures often include such economically inefficient practices as: 1) using average-cost rather than marginal-cost pricing,[14] 2) using decreasing block rates—in which the cost of the last units consumed is lower than the cost of initial blocks, 3) recouping a significant fraction of facility costs through property taxes rather than through charges based on water use, 4) failing to meter individual consumers, and 5) failing to use seasonal pricing if marginal cost varies by season. These common practices provide inappropriate price signals to consumers and lead to overuse of water. They also result in overinvestment in water-supply facilities relative to investment in other methods of providing or conserving water and relative to expenditures on other goods and services (92).

The large Federal subsidies received by farmers who contract for water with the Bureau of Reclamation (the Bureau) likewise lead to overuse of water. The Bureau, which was established in 1902 with the principal goal of assisting the development of family farms in the arid West, now supplies about 30 million af of water per year in the 17 Western States—about 25 percent of western irrigation. The cost-recovery provisions in reclamation law provide Federal subsidies for irrigation, and these have grown substantially over time. Subsidies on irrigation capital costs, such as interest-free repayment of capital, have reached levels of over 90 percent, and historically, program-wide subsidies of irrigation capital costs have been estimated at 85 percent (91).

Interest-free repayment for irrigation appears to be an anachronism in the 1990s. The West has been settled, and States now have their own water resource programs. Where farmers must pay prices that reflect the market value of water, there will be greater motivation to use water more efficiently. However, small price increases will likely do little to motivate changes in use if the gap between the price paid and the market price remains large.

Improvhg Conservation Practices

Many technical and regulatory possibilities exist for using water more efficiently (see table 5-2). Additional water-conservation research could also help realize new savings opportunities and bring down costs of existing ones.

Conservation is likely to have more potential for reducing water use in irrigated agriculture than in cities, given that 85 percent of all water consumed is for irrigation. Moreover, in the agricultural sector in Western States, traditional water law has been a powerful disincentive for practicing conservation. For example, where the prior-appropriation doctrine is practiced, farmers must use the water they have appropriated or they face losing it. Savings of agricultural water can be obtained by such practices as lining canals, recovering tail water at the end of irrigated fields, and better scheduling of water deliveries. Savings might also be made possible by developing more water-efficient crop varieties or crops with a higher tolerance for salt (18).

The High Plains of Texas illustrate the potential for conservation in agriculture (see box 6-G for details). Here, the high costs of pumping groundwater for irrigation motivated a substantial public education program and widespread use of water-saving technologies. Where irrigation costs are low, as in much of California's Central Wiley, there is little incentive to spend money on water conservation.

Significant savings are available through urban conservation efforts as well, and the rate of

[14] *Marginal-cost* pricing is the cost of providing the last increment of water. When the average cost is less than the marginal cost, as in many western cities, pricing at the average cost encourages excess use of water.

demand growth in this sector is much higher than it is for agriculture. Municipal water-conservation programs are in operation in cities from Boston to San Diego, yet in most parts of the country, a strong water-conservation ethic has not developed. Nevertheless, examples of innovative municipal programs abound, and many of these programs could be applied more broadly. One innovative and flexible program is the Conservation Credits Program of Southern California's MWD. Under the terms of this program, MWD, a wholesale water corporation, pays $ 154/af (less than its cost for developing other new supplies) for demonstrable water savings from qualifying local-agency conservation programs, with an upper limit of one-half of the program cost, To qualify, local-agency projects must result in decreased demand for MWD imported water, be technically sound, and have local support (44).

Many of the approved conservation projects are aimed at implementing the 16 Best Management Practices (BMPs) proposed by MWD and other urban water districts.[15] These include retrofitting showerheads and toilets; conducting home-water audits, distribution-system audits, and large-landscape-water audits; finding leaks in distribution systems; instituting landscaping requirements; and several other practices expected to save substantial amounts of water (44). MWD's goal is to conserve 830,000 af/year by the year 2010.[16] If conservation programs are perceived as equitable and fair, people are more likely to support them.

As important as conservation can be, it does have its limits. In areas where comprehensive conservation has begun, demand management may not yield large additional savings (47). To the extent that conservation is successful and growth in demand continues (e.g., through increases in population), long-term water-management flexibility through decreased water use will be harder to achieve. The limits of

Table 5-2—Ways to Use Water More Efficiently

Effective water-saving measures for urban areas

Modify rate structure to influence consumer water use, including:
- **shifting from decreasing** block rates to uniform block rates
- shifting from uniform rates to increasing block **rates**
- **increasing rates during summer months**
- **imposing excess-use charges during times of water shortage.**

Modify plumbing system, including:
- **distributing water-saving kits, including replacement showerheads and flow restrictors**
- **changing plumbing standards**
- **requiring or offering rebates for ultra-low-flow toilets.**

Reduce water-system losses, including:
- **using watermain-leak-detection** survey teams followed by water main repair or replacement as necessary to reduce system losses
- monitoring unaccounted-for water
- conducting indoor-outdoor audits
- starting a meter-replacement program
- recycling filter plant backwash water
- recharging groundwater supplies.

Meter all water sales and replace aging or defective meters in a timely way.

Reduce water use for landscaping, including:
- imposing lawn watering and other landscape-irrigation restrictions
- developing a demonstration garden
- publishing a xeriscape manual
- using nonpotable water for irrigation
- imposing mandatory water-use restrictions during times of water shortage.

Conduct water-conservation education of the public and of school children, including special emphasis during times of water shortage,

Effective water-saving measures for farms

Use lasers for land leveling.
install return-flow systems.
Line canals or install piping to control seepage.
Control phraetophytes (although these plants may be considered valuable habitat).
Use sprinkler and drip irrigation systems.
Schedule irrigation by demand.
Use soil-moisture monitoring.
Use deep pre-irrigation during periods when surplus water is available.
improve tillage practices.
Use evaporation suppressants.
Use lower-quality water.
install underground pipelines.
Grow drought or salinity-tolerant crops.

SOURCE: W. Anton, "implementing ASCE Water Conservation Polk-y," in: Water Resources Planning and Management: Proceedings of *the Miter Resources Sessions at Water Forum '92,* Water Forum '92, Baltimore, MD, Aug. 2-6, 1992.

15 M. Moynahan, Metropolitan Water District of Southern California, personal communication, August 1992.

16 Ibid.

conservation are far from being reached, but in the absence of new developments in conservation technology, conservation can be expected to have diminishing returns. ultimately, additional solutions may be needed. Moreover, once the easy options have been implemented, additional conservation may require higher costs and important lifestyle changes, and these may be resisted by the public.

Policy *Options: Improving Demand Management*

Demand management, where practiced, has generally been a State or local concern rather than a Federal one. However, if it chooses to do so, Congress and/or the Executive Branch could stimulate demand management in various ways.

Option 5-1: *Amend the Clean Water Act to allow Federal grants to States for wastewater treatment projects to be used for conservation investments. These* State revolving funds (SRFS) can now be used for sewage treatment facilities but generally not for conservation. However, to the degree that conservation reduces the volume of water that needs to be treated, the cost of sewage treatment is reduced. Grants for SRFS are set to expire in 1994. Congress could continue this funding when it reauthorizes the Clean Water Act and, in Title VI of the Act, could make conservation explicitly eligible for revolving-fund loans. States might, in turn, offer favorable loan terms to communities that achieve suggested water-efficiency goals.

Option 5-2: Lead *by example by promoting greater water-use efficiency in Federal facilities. The* Federal Government owns or leases about 500,000 buildings of various sizes and some 422,000 housing units for military families. It also subsidizes utility bills for some 9 million households of low-income families (77). Thus, Federal facilities and subsidized housing represent an opportunity for the U.S. Government to play an important role in promoting water-use efficiency. Currently, however, Federal agencies have little incentive to conserve water. Most agencies do not even meter their water use or have the baseline data needed to determin the payback period and cost-effectiveness of efficiency measures.

The Energy Policy Act of 1992 (P.L. 102-486) does encourage water conservation in Federal facilities, but, in contrast to the act's detailed treatment of energy conservation, it treats water as an afterthought. Congress should clarify its intent regarding water conservation, including, for example, how funds authorized for efficiency programs are to be divided between energy and water conservation. Congress might direct agencies to: 1) establish programs to reward innovative and/or cost-effective water-conservation measures, 2) use models that predict water use [e.g., the Army Corps of Engineers Institute for Water Resources Municipal and Industrial Needs (IWR-MAIN) model (73) to identify opportunities for improved water-use efficiency, and 3) amend Federal acquisition regulations to facilitate Federal procurement of efficient water-Use technology.

Option 5-3: *Increase funding for the development and use of water-saving technologies. The* Water Resources Research Act of 1984 (P.L. 98-242) authorizes funding for such purposes. However, no funds were appropriated for the act's competitive matching-grant fund in 1993. Moreover, no funds have ever been appropriated under sections 106 and 108 of the act, which specifically authorize grants for water-related technology development, including conservation and water-reuse technologies.

Option 5-4: *Reform tax provisions to promote conservation investments. The* Tax Reform Act of 1986 (P.L. 99-514) clamped down on the ability of cities and States to use tax-exempt bonds to finance any projects except those that clearly benefit the public (72). The benefits of most conservation technology (e.g., plumbing retrofits and advanced irrigation systems) have been considered to be mostly private and, hence, the technology has not been eligible for tax-exempt financing. To promote more conservation investment, Congress may wish to revise the tax code to define conservation investments as having substantial public benefits and, hence, to be eligible for tax-exempt-bond financing.

Option 5-5: *Reform pricing in Federal water projects.* Although it may be difficult to reform the pricing of water supplied by existing Federal projects, Congress could eliminate subsidies on future projects, such as for interest-free repayment of construction costs or loans. Alternatively, Congress could require, through legislation, that all entities that stand to benefit from new, subsidized, federally developed water study and, if necessary, reform their current pricing structures before water is delivered (92). Ignoring possible price reforms would result in inefficient expenditure of Federal funds.

Policy Options: Facilitating *Water* Marketing

As with demand management, Federal law usually defers to State law regarding water marketing and other transfers. However, the Federal Government could help facilitate mutually beneficial transfers in several ways. It could provide stronger leadership, improve the implementation of its own policies, influence State Governments through the use of incentives or disincentives, and clarify some ambiguous elements of reclamation law. Present uncertainty over the rules governing a market can slow and raise the effective costs of transactions. The Federal Government could also have some influence in helping to ensure that transfers are fair for those not directly involved in the exchange and that they do not adversely affect instream uses of water.

Option 5-6: *Urge the Department of the Interior (DOI) to provide stronger leadership in facilitating water transfers. In* December 1988, DOI adopted a set of principles for facilitating voluntary water transfers involving Bureau of Reclamation facilities. However, the Bureau has not effectively implemented these directives, and they have not been applied consistently in all regions (42). Stronger leadership could include an unambiguous public statement by DOI and Bureau officials endorsing water transfers as a means of solving water resource problems, more emphasis within the Bureau on transfers, and consideration of the recommendations made by the Western Governor's Association (WGA). WGA recommended that DOI work with it to develop a package of amendments to reclamation law to facilitate transfers (%).

Option 5-7: *Clarify reclamation law on trades and transfers.* Reclamation law was written when western settlement and water development were being emphasized and when little or no consideration was given to the transfer of water rights or to contractual entitlements on federally constructed water projects. There are several ambiguities in this body of law regarding the transferability of water. For example, can conserved water be transferred, or does a farmer who saves water by using it more efficiently lose rights to it?[17] It is also at times unclear whether State or Federal law governs transfers on Federal projects. Clarification might be accomplished through a formal solicitor's opinion by DOI or, alternatively, through new legislation.

Option 5-8: *Clarify rules regarding the marketing of Indian water. The* nature of water rights for many Indian tribes is still open to question. A key issue is whether Indian water rights, once quantified, will be salable or leasable, and, if so, with what restrictions. Allowing water entitlements of Indian reservations to be leased with no more restriction than non-Indian rights would facilitate greater efficiency and flexibility of water use. Equity issues regarding Indian water are important and usually controversial. Indians have often been treated unfairly. At the same time, many non-Indians have come to depend on inexpensive water that may legally belong to Indian tribes, and current users could, in theory,

[17] At issue is whether the 1902 Reclamation Act (32 Stat. 388) imposes any additional requirements, beyond those Of State law, for water on Federal projects.

be required by Indians to pay significantly more than they do now. Indian claims have often been settled through legislation, and in some cases, the legislation has specified the degree to which Indian water is leasable (21). Language ensuring the ability of Indians to market water or transfer entitlements could be included in all future Indian water settlements.

Option 5-9: *Provide ways for Federal agencies to buy water for environmental purposes.* Federal participation in water markets could play a role in preserving or enhancing instream uses, a goal that could become increasingly difficult to achieve if water demand increases and/or supply decreases. Water rights for instream-flow purposes are usually held by States but are often junior in nature and could thus be the first to be curtailed during a drought. Stronger protection could be acquired by allowing public agencies charged with protection of fish and wildlife and other instream uses of water to participate in water markets. In States that allow non-State agencies to acquire instream rights, Federal agencies such as the Fish and Wildlife Service could be funded to acquire water rights where existing statutes afford inadequate protection. Flexibility would be enhanced by allowing agencies to make not only permanent purchases of water rights but also short-term purchases during drought periods, when instream uses of water are most likely to be under stress (92).

Supply Management

Opportunities exist for signicant gains in water-use efficiency through better management of existing (i.e., developed) water supplies. Such opportunities may be realized by: 1) improving coordination of water resource management, 2) enhancing the flexibility of reservoir and reservoir-system operations, 3) expanding the conjunctive use of ground and surface water, and 4) taking advantage of new analytical tools and forecast systems.

Improving Coordination

In large part, water resource systems throughout the United States have developed independently of one another, their geographical limits usually coincident with political rather than watershed boundaries. Not surprisingly, water resource management in the United States has evolved in a fragmented and uncoordinated fashion. Coordination has not mattered greatly where water is abundant, but it is becoming increasingly important in those parts of the United States where water resources are becoming relatively more scarce and/or polluted. It will become even more important if global climate change results in decreased water supplies in some areas.

The most efficient way to manage water resources is the comprehensive river basin or watershed approach. At its best, such an approach would entail managing reservoirs in the watershed to meet multiple demands as a single system rather than individually, managing groundwater and surface water jointly, managing water-quantity and water-quality issues together, and integrating floodplain and wetland management with other aspects of water resource management. Managing in this way would not only increase usable water supplies but would also benefit other valuable uses for water (e.g., for habitat and wetlands preservation and for recreation). River basin management would also improve the flexibility and efficiency desirable in policies suited to a changing climate. Comprehensive planning and management is likely to become increasingly important wherever opportunities for developing new supplies grow scarce and water becomes subject to greater competition among competing uses.

The concept of river basin management is not new and, in fact, is widely accepted in theory among water resource professionals, ecologists, and others. However, such management practices are the exception rather than the rule. Although many are aware of the benefits of more-integrated management, coordination and cooperation to this end have been very difficult. Responsibilities for water supply are generally separate from those for water quality; responsibilities for groundwater are often separate from those for surface water; Federal goals and responsibilities within a basin may conflict with State or local ones; and Federal and State boundaries seldom coincide with groundwater basins or surface watersheds. The diversity and inflexibility of water-rights laws, inadequate incentives for efficiency in water use, and inadequate research, information, and training support for improved water resource coordination practices can also make river basin planning difficult (72).

Nevertheless, river basin and watershed planning is attracting renewed attention. The U.S. Environmental Protection Agency strongly supports the approach, and its regional offices are now participating in about 35 small watershed projects around the country (82). Moreover, legislation recently introduced to reauthorize the Clean Water Act (S. 1114, the Water Pollution Prevention and Control Act of 1993) contains important watershed-management provisions, including some for designating areas for watershed management, developing watershed-management plans, and providing for incentives and public participation.

Reservoir and Reservoir-Systern *Management*

Individual reservoirs are often designed and constructed by one jurisdiction (e.g., a water district). The operating rules for the reservoir are also usually centered around meeting the needs of the clients of the constructing agency, given the storage and delivery constraints imposed on the reservoir when it was constructed. Where there are several reservoirs on a river system (possibly operated by different jurisdictions or even in different States), yield of the system as a whole can often be increased if joint operational rules are considered. For example, rather than meeting the downstream demands of a particular area solely from the reservoir owned by that jurisdiction, more than one upstream reservoir may often be used. If the timing and amount of releases can be coordinated, often everyone can gain.

Discovering and taking advantage of these opportunities involve a good deal of coordination among different water agencies and include such tasks as developing flow and storage models that are accepted by all of the jurisdictions involved; simulating likely stress events, such as floods and drought; studying trial responses to such simulated events; and developing written agreements for joint operation of facilities. It often takes years and the commitment of key individuals to implement these steps, but the effort can be very successful.

For example, starting in 1977, the Interstate Commission on the Potomac River Basin (ICPRB) sponsored several studies of the potential for joint, rather than independent, operations during drought periods among the three principal Washington, DC, water suppliers. Using a river-simulation model developed at Johns Hopkins University, ICPRB determined that existing reservoir capacity was underutilized, and that if the local water suppliers would coordinate the timing of withdrawals from upstream reservoirs, they would be able to increase system yields dramatically and avoid spending large sums on construction of new reservoirs. A series of written agreements was approved in 1982 specifying how joint operations would be carried out during droughts. Joint management of existing facilities in the Potomac River Basin increased system yields by over 30 percent (about 90 million gallons per day). Between $200 million and $1 billion was saved, compared with previously evaluated structural alternatives for meeting future supply needs, and environmental impacts were substantially reduced (63).

The potential exists throughout the Nation for improving operational efficiencies of multi-reservoir systems through systems analysis. Moreover, the Federal role in contingency planning and systems-analysis studies could be large because federally constructed reservoirs are often intermingled with nonfederal reservoirs on the same river system. The Colorado River System is one important prospect for application of more-efficient operating rules. The Bureau of Reclamation operates all major storage facilities on this river, whose water is so crucial to the arid Southwest. Potentially, results of Federal simulations of long-term water availability on the Colorado (including analysis of various climate change scenarios) could ease the way for Colorado River Basin States to begin considering new operating rules of mutual benefit.

An important reason for the difficulty in making efficiency and flexibility improvements in the management of reservoir systems (and individual reservoirs) pertains to the process by which Federal water projects are authorized and regulated. The two agencies responsible for most large Federal water projects are the Army Corps of Engineers and the Bureau of Reclamation. Both the studies and the projects these agencies undertake are authorized by Congress. The projects are usually based on a detailed feasibility study by one of the two agencies. Both the study and the subsequent congressional authorization typically emphasize individual projects, and the operating agencies are closely bound to use projects only for the original purposes specified in authorizing legislation. Rarely do the computed benefits from a project reflect what might be achieved if the operation of the project were integrated in a systematic way with other existing and proposed projects, either Federal or local.

Initially, most new projects are more than adequate to serve the existing demands. Over time, however, demands may increase, and structural or operational changes may be required. Historically, structural changes (i.e., construction of new storage facilities) have been emphasized, and opportunities for "creating' more water through better management and/or reallocation have received little attention. This may occur because there is no regular review process devoted to finding such opportunities and because whenever changes in operating policies are proposed, there are inevitably people who believe their interest lies in maintaining the status quo (64).

Conjunctive Use of *Groundwater* and Surface Water

Groundwater and surface supplies are managed independently inmost States and are governed by different legal systems and separate agencies. The integrated management of ground and surface water, often referred to as *conjunctive management,* has the potential to significantly improve water-system performance and increase the flexibility and reliability of water resource management (see box 5-I).

Storage of water underground is desirable because it makes possible the use of water that otherwise would not be captured (20). Conjunctive management can be used to balance seasonal variations in water supply and demand, enabling groundwater to be used in lieu of surface water during dry periods; to eliminate the need for additional treatment and surface-distribution facilities; to allow water suppliers to meet customer demands more cheaply and easily than would be possible through independent management of separate systems; and to enhance yields through less-conservative operation of existing storage facilities (e.g., a conjunctive management study of Houston found that system yields could be increased by 20 percent (63)). Another conjunctive use is blending surface and groundwater to produce an overall usable medium-quality supply (e.g., by blending high-quality surface water with brackish groundwater not otherwise usable).

Cities such as Los Angeles, Phoenix, Albuquerque, and Houston already have conjunctive-use plans, but conjunctive management is still not used in most major population centers (72). Not all communities have access to groundwater supplies, but conjunctive management may be feasible for some that do not, as long as they are linked to a river or distribution system. Each plan is unique, and the most equitable and efficient approaches are closely tailored to the physical characteristics of the water resources (e.g., rates

Box 5-I-Seasonal Storage: The Metropolitan Water District's Interruptible Water Service and Seasonal Storage Programs

Rainfall and snowmelt tend to be seasonal events, so the availability of water supplies in communities that rely on surface water can vary widely during the course of the year. Water demand also varies with the seasons, typically being much higher during the summer and lower during the winter. Balancing supply and demand in the face of these variations is possible only with the use of storage facilities. Southern California's Metropolitan Water District (MWD) has used its Interruptible Water Service (IWS) Program and its Seasonal Storage Program (SSP) to encourage conjunctive management as a method of enlarging local storage capacity.

The IWS Program began in 1981 when MWD offered to sell water at discounted rates to member agencies that could demonstrate an ability to continue serving customer needs in the event that water deliveries from MWD were interrupted (44). Operation of the program allowed MWD to take advantage of excess supplies in the Colorado River and the State Water Project by delivering the water to local agencies when it was available and ceasing the deliveries when it was not. Most of the local agencies chose to meet the IWS requirements by developing new artificial-recharge and pumping facilities to store the water underground and then pump it back out during supply interruptions.[1]

The IWS Program led to problems for some participating agencies, however. Retail agencies were required only to demonstrate sufficient local production capacity to continue making customer deliveries in the event of MWD interruptions, rather than agreeing to actually store the water in new or underutilized facilities. Some agencies found that they were able to demonstrate this capacity on paper much more easily than they were actually able to produce the water when needed.[2]

MWD discontinued the IWS Program and replaced it with the SSP in 1989. The concept is the same: discounted water is used to encourage MWD's retail-agency members to develop local facilities for storing excess winter flows for subsequent use during low-flow, high-demand summer months. But terms of the SSP require local agencies to actually store the water, either directly in surface reservoirs and aquifers or indirectly by using the water in lieu of existing groundwater pumping (44). MWD has found that the SSP has encouraged development of local storage capacity, eased peak demands on the MWD delivery system, and worked better for the retail agencies than the program it replaced. An additional benefit is that MWD's energy costs for pumping the water to its service area are lower in the winter than in the summer.[3]

1 D. Adams, Director of Resources, Metropolitan Water District of Southern California, Los Angeles, personal communication, July 1992.

2 Ibid.

3 Ibid.

of discharge, the degree to which groundwater is connected to surface supplies, the rate and amount of lateral movement within the groundwater basin, and the susceptibility of the basin to degradation from saltwater intrusion or other sources).

As with integration of surface-reservoir systems, conjunctive management can provide the robustness and flexibility desirable for adaptation to climate change. Similarly, however, a profusion of ground and surface-water laws, regulations, and agencies may be involved in a single conjunctive management project, so agreements can take a great deal of time to negotiate. This amount of time may diminish as experience with different schemes grows.

Analytical Tools and Forecast Systems

The state of the art of analytical tools used by water resource managers has improved significantly in recent years. Various types of models currently being developed or refined could dramatically improve water resource decisionmaking, for example, by providing information about how benefits from competing demands for water could be optimized, how pursuit of a particular water-management goal could affect competing goals, how major land-use changes in a basin (e.g., urbanization) could affect water availability, or how environmental quality could be improved. Many of these tools, however, are not yet available or are not being used routinely.

Several agencies have small programs or initiatives to develop and implement tools for advanced hydrologic and climate forecasting to reduce risk in water-management decisions. For example, both the U.S. Geological Survey and the Bureau of Land Management have been working with the University of Colorado's Center for Advanced Decision Support for Water and Environmental Systems (CADSWES). CADSWES is helping the agencies develop anew generation of water resource modeling systems. A joint pilot project using these new systems has recently been planned to study the sensitivity of several western areas-the Gunnison River Basin and the American, Carson, and Truckee Basins-to climate change (51).

The National Oceanic and Atmospheric Administration's (NOAA's) National Weather Service also has an advanced modeling initiative, the Water Resources Forecasting System (WARFS). The goal of this program is to provide improved stream-flow forecasting, building on existing river and flood-forecasting services and NOAA's weather- and climate-forecasting capabilities, its planned Next Generation Weather Radar program, and its Automated Surface Observing System. The Denver Water Department and the Bureau of Reclamation, among other groups, have recently used the methodology in a pilot program to increase water yields from three reservoirs serving the Denver area while optimizing benefits from other competing demands such as hydropower and recreation (39). The Extended Streamflow Prediction component of WARFS will allow a hydrologist to make extended probabilistic forecasts of values of stream flow and other hydrological variables, which can be used for flood-control planning, drought analysis and contingency planning, and hydropower planning.

The Army Corps of Engineers has developed several models that, among other things, enable communities to evaluate demand-management programs and allow systems operators to consider alternative operating strategies (e.g., the Corp's IWR-MAIN model). Much of the new software available is significantly more uier-friendly than earlier versions, enabling models to be built quickly, more easily, and at a fraction of the cost. The Corps' research laboratories have also been developing innovative methods and models for analyzing water-environment problems that are not traditionally part of its mission.

The new analytical tools, promising as they are for improving water resource management, are based on the assumption that the climate of the future will be similar to the climate of the past. Thus, historic patterns of temperature and rainfall have been assumed to provide a good indication of the range of expected future values. Climate change may mean that the assumption of a stationary climate may no longer be the best predictor of future conditions. Hence, some procedures currently used to plan and design dams and other structures and to conduct hydrologic analyses may need to be modified to account for this additional source of uncertainty. Among these procedures may be those used in flood-frequency analysis for floodplain planning, in determining the probable maximum flood or design flood for darn design and darn-safety analysis, in statistical analyses of historic runoff patterns for reservoir-system planning, and in stream-flow forecasting for reservoir operations and flood control.[18]

[18] B. Miller, Tennessee Valley Authority, personal communication, 1993.

Policy Options: Improving Supply Management

Systems integration and the reallocation of supplies based on current needs could provide significant gains in water-management efficiency and flexibility, and there appear to be many opportunities for such gains. Several ways that the Federal Government could promote better management are considered below.

Option 5-10: *Resurrect the former Water Resources Council or create a similar high-level coordinating body.* A new council or committee could play an important role in improving cooperation and coordination among the many Federal agencies with water-related responsibilities and among Federal, State, and local governments and the private sector. The new council might be strengthened relative to the original one by appointing a full-time chair, who would report directly to the President. It could be charged with reviewing interagency and intergovernmental policies and programs to promote consistency, fairness, and efficiency and, more generally, with elaborating and overseeing national water policy. The original council was established by the Water Resources Planning Act of 1965 (P.L. 89-80). Legislatively, this council still exists, but Congress would need to restore funding for it.

Option 5-11: *Promote the reestablishment and strengthening of Federal-State river basin commissions as another way to improve coordination among agencies.* River basins, not political jurisdictions, are the natural management units for water. Integrated management can only work if the multiple parties with jurisdiction in any given watershed can be brought together in some way to explore common problems and pursue joint solutions. Section 321 of the Water Pollution Prevention Control Act of 1993 addresses watershed management and could be broadened, if desired, to explicitly address the formation of new Federal-State commissions. The Interstate Commission on the Potomac River Basin (ICPRB) or the Delaware River Basin Commission (DRBC) could serve as models.

ICPRB is jointly funded by member States and the Federal Government. It serves as a neutral ground for the basin States and the Federal Government to discuss mutual problems. Although ICPRB has no regulatory authority, it does provide sophisticated technical assistance in solving problems around the basin. The combination of political neutrality and technical competence has allowed ICPRB to successfully mediate many disputes. To promote establishment of this type of river basin commission, Congress could establish a grant program to make funds available (e.g., for establishing technically competent staffs) to groups of States that choose to negotiate such compacts.

DRBC, in contrast, was established with considerable authority to control the diversion of surface and groundwater within the Delaware River Basin; coordinate Federal, State, and private reservoir releases during droughts; and limit pollution discharges. Individual States have retained veto power over all decisions, but DRBC has proved relatively effective as a setting for negotiating disputes. A Federal representative is a co-equal member of the commission. The DBRC policy was fully implemented only after many years and much controversy, but in its present shape, it could serve as a model for other States.

Option 5-12: *Require the Army Corps of Engineers and the Bureau of Reclamation to undertake periodic audits to improve operational efficiency.* Currently, the agencies do not systematically reassess project operations to meet changing social and economic trends (although extreme events may trigger a reallocation study), nor is legislation authorizing a project systematically reviewed to determine whether it needs to be updated. Congress would need to give the operating agencies a clear mandate to do such studies, and appropriate additional money for this task.

Option 5-13: *Enhance the ability of the Army Corps of Engineers and the Bureau of Reclamation to modify operations of projects to meet changing conditions.* Currently, operating rules based on project authorizations going back many decades appear to give the operating agencies little latitude to improve operations or to respond in the most effective manner to droughts, and what little flexibility exists is difficult to exercise when water is in short supply (64). Many changes either require or are perceived to require legislation before they can be legally implemented. The authorization for a project need not require that the expected benefits of the project be derived from that project alone.

To fully achieve the potential benefits of operating several reservoirs as a system, either for dealing with the possible impacts of climate change or for simply improving the current management of water resources, Congress could give the Army Corps of Engineers and the Bureau of Reclamation the administrative flexibility to deliver the expected benefits in the most effective manner (or, in cases where such flexibility is available, clarify its extent). New legislation, perhaps as part of the next omnibus water bill, likely in 1994, would probably be required. Where additional benefits can be created through systems management (e.g., additional water and increased power revenues). Congress would need either to direct the agencies in how to distribute these benefits or direct them to develop a procedure for doing so.

Option 5-14: ***Tie*** *funding of Federal water projects to adoption of improved water-management practices by the States-such as* developing State groundwater management plans, facilitating transfers, and improving demand management. There is some precedent for using incentives or disincentives to encourage desirable activity. For example, in exchange for supporting funding of the Central Arizona Project, the Secretary of the Interior required that the State of Arizona adopt a groundwater law aimed at reducing pumping to a safe annual yield (92). Similarly, it may be possible for the Federal Government to require a State to adopt laws that facilitate water transfers before the State can receive Federal funding for projects or other activities.

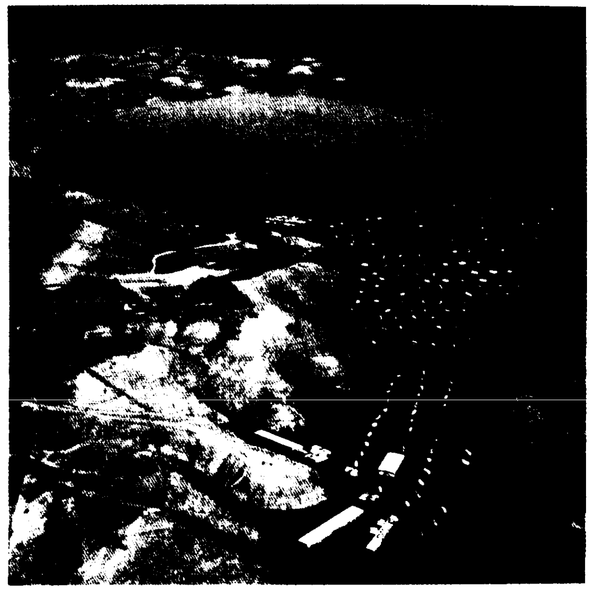
Option 5-15: *Increase finding for the development and promotion of new analytic tools in systems-analysis studies. These* new tools promise a substantial payoff in improved water resource management, but funding for agencies to develop them has been inadequate. NOAA, for example, has so far been unsuccessful in getting sufficient funds for its WARFS initiative. Water resource research funding for the U.S. Geological Survey (USGS) has been cut substantially in recent years. Congress might also want to consider facilitating the development of analytical tools that incorporate climate uncertainty into traditional hydrologic analyses.

Available modeling and forecasting tools (e.g., the IWR-MAIN model) have not been widely disseminated and used by State and local agencies. If Congress wishes to promote the greater dissemination of these tools, it could increase funding under Section 22 of the Water Resources Development Act of 1974 (WRDA, P.L. 93-251). These funds are available for training and technical assistance to States and water utilities for a variety of traditional water resource management needs. Section 22 could also be extended to cover problems that cross over from water resource management to environmental systems management (e.g., watershed management and wetland restoration).

Extreme-Events Management: Droughts and Floods

Natural climate variability almost guarantees that the signal of climate change will be difficult to detect. Drought and floods are among the most extreme expressions of this variability, and whether or not climate change is definitively detected, they will continue to occur. However, more-intense, longer-lasting, or more-frequent extreme events such as these could occur in some areas in a warmer climate (43).[19] If this happens, societal vulnerability would increase and would pose new challenges for public institutions and the private sector.

Both floods and droughts cause significant losses to human and natural systems. For example, costs and losses from the 1988 drought, during which roughly 40 percent of the United States was severely affected, have been estimated to be at least $39 billion (57). For this reason, potential changes in the extremes of these events are perhaps of even more concern than are long-term changes in temperature and precipitation averages. Effective management of floods and drought is extremely important if their impacts are to be minimized. Just as in the supply-management issues discussed above, lack of coordination among and within levels of government has been and continues to be a key constraint to more-effective management. Some near-term improvements in how extreme events are managed would help mitigate any surprises that climate change could bring.



Six years of drought in the western United States reduced water supplies stored in reservoirs and ma& water resource management much more difficult. Low water levels are conspicuous in the amount of bare earth exposed in this aerial view of Luke Oroville. The California State Water Project begins here, where water from the Feather River watershed is stored.

Droughts

Drought, although difficult to define precisely, is generally the consequence of a natural reduction in the amount of precipitation received over an extended period of time (usually at least a season). A drought's severity can be classified by its duration, intensity, and geographical extent. Factors such as high temperatures, high winds, and low relative humidity are often associated with the occurrence of a drought and can significantly aggravate its severity. The demands made by human activities and vegetation on a region's water supplies are sinificant factors affecting how large the societal and ecological impacts of a drought will be. Population growth and increasing competition for water will lead to greater vulnerability to drought; the potential for climate change provides an additional incentive to improve drought management.

Drought impacts are usually less obvious than flood impacts (e.g., drought rarely results in structural damage). Impacts typically accumulate slowly over a considerable period of time, and they may linger for years after the drought itself has ended. For these reasons, the effects of drought on society, the economy, and the environment are more difficult to quantify, and the provision of disaster relief is thus more challenging. Droughts can provide instructive, if imperfect, analogs to climate change, illustrating problems that could occur more often in a warmer climate (24, 57).

Government responses to previous droughts (e.g., in allocating water from Federal multipurpose reservoirs, providing disaster assistance,

19 Extreme events could also become less intense, shorter, or less frequent in different areas-the picture is not yet clear-but the results would be of less concern and are not pursued further here.

fighting fires, and protecting wildlife refuges) suggest that drought policies could be much more effective than they are now (100). U.S. drought policy is essentially based on the sentiment that drought is a rare and random event rather than on the reality that it is a normal part of climate variability. As such, Government response to drought has typically been reactive rather than proactive, usually focused on crisis management rather than risk management. Significantly, only 23 States had drought plans in 1992, and most of these were inadequate (99, 100). The weakness of the reactive approach is evident in the uncoordinated, untimely, and largely ineffective response efforts that have characterized past droughts (101). Drought relief, at least as it is usually provided now, has often been a disincentive to adopting strategies to minimize risks associated with drought, such as purchasing crop insurance, and may unintentionally reinforce some poor management practices (see ch. 6).

Many studies, including, those of the Western Governors Policy Office (1978), the General Accounting Office (1979), the National Academy of Sciences (1986), the American Meteorological Organization (1990), and the Interstate Council on Water Policy (1987, 1991), summarized in a recent report (100), have called for improvement of drought contingency planning. Most have urged development of a national drought plan that would better define the respective roles of the various agencies that have drought-management responsibilities; promote coordination among Federal agencies and among Federal, State, and local levels of government; establish eligibility, repayment, and other requirements for drought assistance; and provide such assistance in a more timely, consistent, and equitable manner. Although such objectives appear to have considerable merit, not much progress toward meeting them has been made to date. A new study by the U.S. Army Corps of Engineers-a recently completed 4-year assessment of drought management—could provide the basis for developing a national policy for improving water management during drought (95).

The United States may benefit from studying the new Australian drought policy. It applies only to agricultural drought and is based on the philosophy that drought should not be considered a natural disaster but, rather, as part of a highly variable climate and one of the risks farmers face in managing farm operations. Rather than emphasize drought relief, the Australian Government stresses provision of high-quality information so farmers can make better decisions, offers incentives to farmers to adopt sound drought-management practices, and discourages farmers who pursue unsustainable farming practices in drought-prone areas from relying on drought relief (98). The long-term goal of this policy, which could also be used to promote sound practices in other sectors affected by drought (e.g., urban areas), is to reduce vulnerability to drought, increase productivity, improve the allocation of resources, and enhance self-reliance.

Executive Order 12656, signed by President Reagan in November 1988, is intended to guide emergency water planning and management responsibilities of Federal agencies. The order specifies a lead role for the Corps of Engineers for national security emergency preparedness for the Nation’s water resources, including coordination of planning activities at the national, regional, State, and local levels (75). This order could provide a vehicle for bringing together relevant agencies to focus on both drought and flood management. However, it has thus far had little impact. The Corps’ own 1992 study of the status of emergency preparedness concluded that, despite the order, coordination of activities had not improved. Among other things, the study noted the absence of an overall Federal framework clearly defining the agency responsibilities described by the order, an absence of a clear definition of the types of disasters for which plans are to be developed, the low level of staffing and funding assigned to emergency planning, and, perhaps most significantly, resistance on the part of other Federal agencies and State officials to giving the Corps control over emergency planning (75).

Floods

Floods affect smaller areas than do droughts and are shorter-lived events but are, along with droughts, among the most costly of weather-related phenomena.[20] The importance and challenge of managing floodplains and mitigating flood losses are underscored by the costs of floods in dollars and lives: between 1979 and 1988, average damages from flooding amounted to about $2.4 billion per year, and an average of 95 deaths each year is related to flooding (102). Parts of each of the 50 States have experienced flooding (28) and, in all, about 7 percent of the U.S. land area is subject to occasional flooding. Principal areas subject to flooding are along rivers and adjacent to lake shores and sea coasts. Flash flooding along arroyos and ephemeral streams is of special concern in the arid Southwest (102).

Since the 1930s, considerable progress in mitigating flood damages has been made. Both structural (e.g., building reservoirs and levees) and nonstructural approaches (including flood forecasting and implementing floodplain regulations) have been used. The success of the National Flood Insurance Program (NFIP), created in 1%8, is supported by the fact that more than 18,000 of the 22,000 flood-prone communities in the Nation now participate in the program, and most of the 40,000 stream miles in the United States have been mapped for flood risk (103). Also, important technical improvements in flood forecasting and warning systems have been made.

Despite the progress, however, flood darnage is increasing at about 1.5 percent every year (about $200 per 1,000 people per year) (19). An update of a 1987 study for the Federal Emergency Management Agency estimated that 9.6 million households and $390 billion in property are at risk from flooding (5). Mitigation has fallen well short

STATE OF CALIFORNIA, DEPARTMENT OF WATER RESOURCES

Every State has experienced some flooding at one time or another, and as more people move into flood-prone areas, the exposure of people and property to potential flood risks increases. The homes shown here were flooded in 1986 when the Yuba and Bear Rivers overflowed their banks near Marysville, California.

of what was expected when current policies and activities were initiated. Also, some trends and disturbing problems indicate that despite recent efforts, vulnerability to flood damages is likely to continue to grow: 1) populations in and adjacent to flood-prone areas, especially in coastal areas, continue to increase, putting more property and greater numbers of people at risk, 2) flood-moderating wetlands continued to be destroyed (see vol. 2, ch. 4), 3) little has been done to control or contain increased runoff from upstream development (e.g., runoff caused by paving over land), 4) many undeveloped areas have not yet been mapped (mapping has been concentrated in already-developed areas), and people are moving into such areas without adequate information concerning the risk, 5) many dams and levees are beginnin g to deteriorate with age, leaving prop erty owners with a false sense of security about

[20] See chapter 4 for a more detailed discussion of floods in coastal areas.

how well they are protected, and 6) some policies (e.g., provision of subsidies for building roads and bridges) tend to encourage development in floodplains (38).

Climate change could increase flood risk. Although considerable uncertainty exists, climate change could bring more-frequent and/or more-intense floods. Given that development in and near floodplains is expected to last a considerable period of time and that 'the Nation's ability to predict the magnitude and frequency of future events is still limited, it may be prudent to consider the potential effects of climate change when decisions are made (or revised) about the type and amount of development allowed in vulnerable areas. In the absence of sufficient data, flexible and cautious policies are preferred.

An important constraint to better floodplain management mirrors a common constraint in other areas of water resource management: many Federal agencies have some flood-control responsibilities, and they are often unable to work in a coordinated fashion. The four principal Federal agencies involved in construction, operation, and maintenance of flood-control facilities are the Army Corps of Engineers, the Bureau of Reclamation, the Soil Conservation Service, and the Tennessee Valley Authority. The multiple missions of these agencies overlap, and agencies may disagree on who is in control and what structures should be built and for what purposes. The Federal Emergency Management Agency (FEMA) plays an important role in administering the NFIP and disaster assistance. The involvement of State and local agencies, the private insurance industry, and developers, all with different goals, adds to the difficulty of coordination (19).

In practice, no truly unified national program for floodplain management exists, nor are there many examples of effective regional bodies. Such a unified plan could be of" great value in sorting out the respective roles of" each level of government and the private sector, in establishing the relative importance of multiple floodplain management objectives (including flood-loss reduction and natural-value protection), and in promoting implementation strategies.

An even broader problem is that floodplain management is usually addressed separately from other aspects of water resource planning and land-use policy. Ideally, regional floodplain management would be considered as part of a broader plan addressing in addition water-quality and -quantity issues, habitat and open-space preservation, and other land-use and development concerns (19) (see vol. 2, chs. 4, 5, and 6).

Policy options for Improvlng Drought Management

Previous drought-assessment and -response efforts have suffered from the lack of coordination of activities at the Federal level and from lack of coordination among Federal, State, and regional drought-management activities. Greater integration of activities could be fostered in several ways and could help reduce vulnerability to future droughts and enable scarce resources to be used more effectively.

Option 5-16: *Create an interagency drought taskforce with the authority to develop a national drought policy and plan.* Congress could do this or the authority of existing Executive Order 12656, which was established to guide emergency water planning and management responsibilities of Federal agencies, could be used. Such a plan should define specific, action-oriented response objectives and contain an integrated strategy for implementing them. Leadership of the task force could be either a designated lead agency or the Office of the President. All Federal agencies with drought-related missions and representatives of State Government, regional organizations, and the private sector should be included. Results of the Corp's National Drought Management Study, the most recent Federal effort, would provide a good point of departure (95).

As part of the development of national policy, Federal agencies' drought-relief programs should be reviewed, including, for example, soil- and water-conservation programs and the Federal Crop Insurance Program. These reviews should

Table 5-3—Possible Risk-Management and Risk-Minimization Measures the Federal Government Could Consider to Lessen the Effects of Drought

Assessment programs	
	Develop a comprehensive, integrated national drought-watch system (NDWS)
	Inventory data availability in support of an NDWS
	Develop new indexes to assist in the early estimation of drought impacts in various sectors
	Establish objective "triggers" for the phase-in and phase-out of relief and assistance programs
Legislation, public policy	
	Develop a national drought policy and plan
	Examine Federal land-use policies to ensure appropriate management of natural resources and consistency with national drought policy
	Review all Federal drought-relief-assistance programs, Federal crop-insurance program, and other agricultural and water policies for consistency with national drought policy
Public-awareness programs	
	Establish a national drought-mitigation center to provide Information to the public and private sectors
	Improve data information products and delivery systems to provide timely and reliable information to users
	Develop and implement water-conservation-awareness programs
Drought-preparedness planning	
	Promote the establishment of comprehensive State drought plans
	Promote intergovernmental cooperation and coordination on drought planning
	Evaluate worst-case scenarios for drought management
	Evaluate the potential effects of climate change on regional hydrology and its implications on Federal and State water policies
	Promote the establishment of drought plans by public water suppliers
	Conduct post-drought audits of Federal drought-assessment and -response efforts

SOURCE: D. Wilhite, "Drought Management and Climate Change," contractor report prepared for the Office of Technology Assessment, December 1992.

include taking an inventory of current assistance programs and their eligibility requirements, identifying overlapping responsibilities, and examining the distribution of financial resources to relief recipients. Reviews could also examine the timing and effectiveness of relief.

Additional components of a national drought policy could also include:

1. *Adopting risk-management and risk-minimization practices such as those listed in table 5-3.* **Federal agencies could consider following the lead of Australia, where the government does not ignore the need for assistance during severe drought but promotes more self-reliance while at the same time protecting the natural and agricultural resource base. Drought relief, for example, could be made contingent on adopting ways to minimize** drought risk (e.g., buying crop insurance) (see ch. 6).
2. *Supporting post-drought audits of assessment and response efforts.* **All episodes of severe drought in the United States provoke some degree of response from the Federal Government. At times, such as during the 1974-77 and 1988-89 droughts, massive levels of drought relief are targeted for the stricken area. However, comprehensive post-drought audits of assessment and response efforts are not routinely conducted. Audits could identify successes and failures of recent efforts and provide a basis for revising drought policies to improve future responses. An interagency task force might direct university or private research groups to conduct the audits to avoid appearance of bias.**

3. *Developing a national drought-watch system. The* climate-related monitoring activities of the Federal Government are split among many agencies and subagencies, which means that a comprehensive national assessment of drought conditions does not exist. Given that recognition of drought can be slow, a national early-warning system would be useful to support a more proactive national drought policy and plan. Several specific actions might be considered: 1) create a national drought-watch team, possibly under the authority of the interagency drought task force, to routinely assess precipitation, temperature, soil moisture, groundwater levels, stream flow, snowpack conditions, runoff potential, and reservoir and lake levels, and 2) create a national agricultural weather-information office within the U.S. Department of Agriculture (USDA) to address more adequately the needs of the agricultural community for climate-related information. Such an office would provide a focus for existing USDA weather-related programs and would oversee needed new ones.

Policy Options for Improving Flood Management

The Federal roles in flood management include overseeing national flood policy, coordinating floodplain management efforts, providing technical guidance and education, and regulating and funding some State, local, and private activities. Some options that may promote these roles and introduce greater efficiency and flexibility into flood management are considered below. Others, including possible reforms of the NFIP, are discussed in the context of coastal development in volume 2, chapter 4.

Option 5-17: *Create a national flood-assessment board, to consist of representatives of Federal, State, and local agencies and the private sector. The* board could establish a set of national goals for floodplain management together with a timetable for their achievement, assess existing Federal flood programs and responsibilities, recommend changes in missions of Federal agencies to eliminate overlap, and assign responsibilities where gaps occur.

Such a board could also promote the refinement and implementation of State floodplain management plans. Much energy has already been expended on developing State and local mitigation plans, but these plans are often more paper exercises than practical guides to action. Plan implementation could be aided by developing a model floodplain management plan, conducting regional training programs, and expanding efforts to educate the public about the nature of flood hazards and the natural values of floodplains.

The board could facilitate multiobjective flood plain management. Floodplains may contain homes, businesses, recreation sites, fish and wildlife habitats, and historic sites, among other things. Each of these features is usually managed separately rather than as an integrated package, and conflict among different interests is often the result. The Federal Government could do more to facilitate State and local programs to manage in a more integrated fashion by, for example, providing technical assistance and grants-in-aid. As part of the Clean Water Act reauthorization, Congress could provide incentive grants to States or communities that undertake multiobjective watershed-management initiatives.

Finally, the board might be directed to conduct an evaluation of various programs and activities (such as FEMA's) to determine their effectiveness or to assess how to improve the acquisition and utilization of data on flood damages. An interagency flood-insurance task force has been proposed in Title V of H.R. 62, the National Flood Insurance Compliance, Mitigation, and Erosion Management Act of 1993, that could, as currently envisioned, undertake this activity. However, State, local, and private participation on the flood-assessment board would, in general, improve its effectiveness.

Option 5-18: *Direct the National Flood Insurance Program to base risk calculations on anticipated development, rather than on current development.* Recognition of the impact of increased runoff on flood damage is a weak area in the National Flood Insurance Program. Currently, floodplain delineation is based on the development that exists in the basin at the time the hydrologic and hydraulic studies are done (19). As development in the basin increases, peak flows and volumes increase, which will result in a change in the 100-year flood, possibly turning it into a 50-year or lo-year event. A changing climate would also alter future flood risks and might similarly be considered to the extent possible. The long-term benefit of this policy would be to prevent or alter construction in areas that could become (or are likely to become) flood-hazard zones in the future.

Supply Augmentation

Several alternatives exist for augmenting supplies of water. These include, among others, expanding the capacity to store water that could not be used immediately and would otherwise not be available for use later, desalting sea (or brackish) water, diverting water through new pipelines and aqueducts from low- to high-demand areas, and treating and reusing wastewater.

Reservoirs and Climate Change

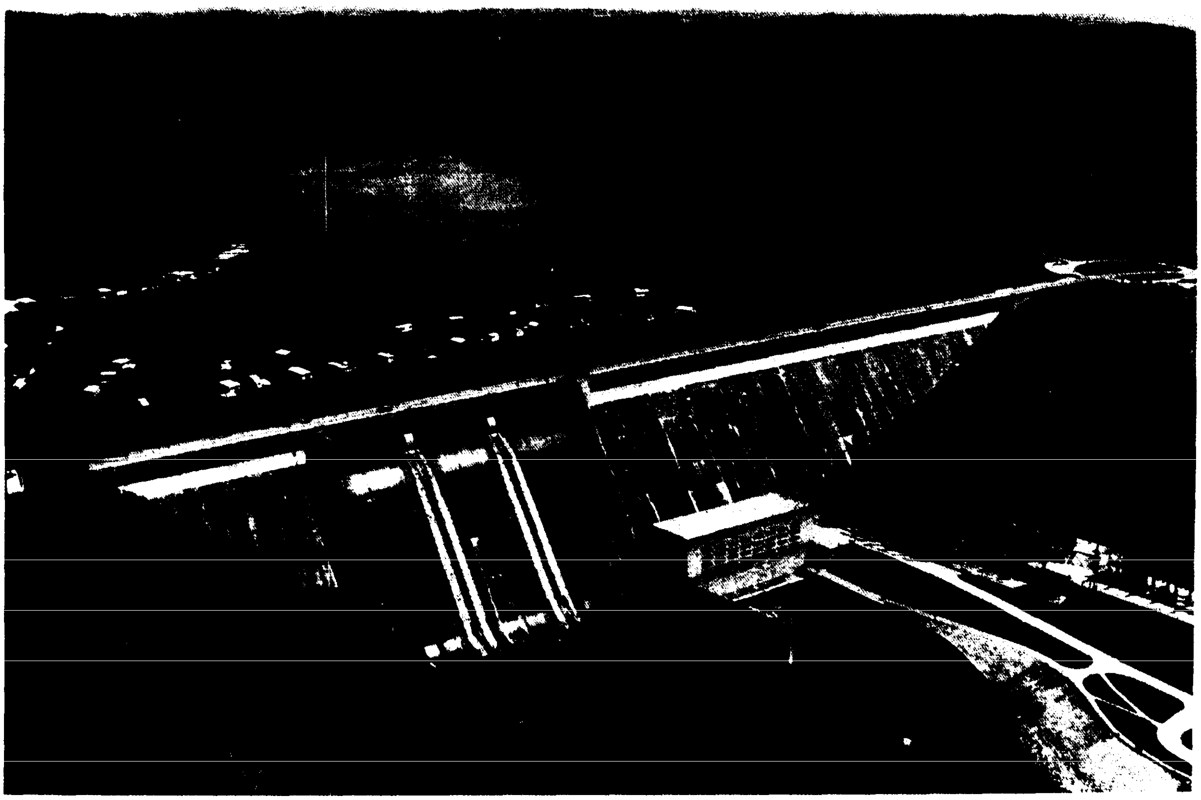
Periods of high water demand rarely correspond to times of high water supply. Building reservoirs has been a common solution to the problem of storing water during high-flow periods and releasing it for later use as needed. Currently, there are more than 2,650 reservoirs in the United States with capacities of 5,000 af or more. The combined capacity of these reservoirs is about 480 million af, of which 90 percent is stored by the 574 largest. There are also at least 50,000 smaller reservoirs, with capacities ranging from 50 to 5,000 af (14).

After decades of reservoir building, the Nation's reservoir infrastructure is largely in place. There are still opportunities to build additional reservoirs, but the pace of new construction has slowed dramatically in the past decade. One reason for the slowdown is the high cost of new reservoirs and the scarcity of available funds. A second is the fact that there are relatively few good undeveloped sites left. In addition, public attitudes about the environment have changed, and many people no longer believe that the benefits of new-reservoir construction outweigh the costs. Reservoirs have destroyed substantial riparian habitat, blocked free-flowing sections of rivers, interrupted migration corridors, and deprived downstream wetlands of sediment. Consequently, it is now very difficult politically to build major new dams.

Currently, climate change is not explicitly considered by the Nation's largest reservoir operator-the Army Corps of Engineers, the Bureau of Reclamation, the Soil Conservation Service, or the Tennessee Valley Authority-in renovating or managing existing reservoirs or in planning and designing new ones. Uncertainty about the regional impacts of climate change on runoff makes it difficult to justify changing design features or operating rules at this time (67). Also, the high fixed-discount rate used in cost-benefit analyses heavily discounts those benefits of a new project that might occur several decades in the future. Hence, when standard economic discounting rules are used, specific features integrated into reservoir design to anticipate climate change would be difficult to justify economically. Finally, the Corps argues that reservoir-design criteria have been based on an engineering-reliability -based strategy that builds in considerable buffering capacity for extreme meteorologic and hydrologic events. Thus, many of the 500 largest existing reservoirs may already have the capacity and operating flexibility desirable to cope with a changing climate (27).

Still, many existing reservoirs are currently in need of major or minor rehabilitation. As rehabil-

TENNESSEE VALLEY AUTHORITY



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itation work is undertaken, engineers could consider whether regional climate change data or costs justify modifications based on anticipated climate change. The need for more storage space or flood-control capacity could sometimes be satisfied by undertaking such structural modifications as increasing the height (which often also requires increasing the bulk) of a dam and enlarging its spillway. (Even without considering climate change, many small, nonfederal dams and a few Federal ones lack adequate spillway capacity.) Enlarging a reservoir is not without environmental costs because additional land would be inundated. Where feasible, temperature-sensitive fish species downstream from a dam could be accommodated by mixing the colder, deeper water in a reservoir with warmer, surface water. Such temperature control can be accomplished by retrofitting multiple-level outflows to a dam's outlet works .21 Enlarging one reservoir in a reservoir system may also allow the entire system to be operated more flexibly (see Supply Management, above).

Despite concerns about reservoirs, some new ones are likely to be required (even if not specifically in response to climate change). Generally, anew reservoir would be a robust response to the uncertainty of climate change-it would

21 This would cost about $85 million for Shasta Darn in Northern California, for example.

allow greater operational flexibility whether the future brought more intense droughts or more floods. However, a reservoir is also a fixed, permanent structure, so before large amounts are spent on an irreversible decision, the costs and benefits of a new reservoir should be weighed against those of other adaptation options. For those new reservoirs required, overbuilding as a response to uncertainty may no longer be appropriate or feasible. Given high costs, the trend toward reduced Federal contributions to water-project construction, and upfront financing requirements, new reservoirs are likely to be smaller and will probably be designed with less buffering capacity for extreme events (56). With less margin for error, complementary strategies, such as emergency evacuation and flood-warning plans and water conservation and reallocation, become relatively more important (67). These strategies, however, incur greater residual risks to people, the consequences of which must be taken into account in a full analysis of social, economic, and environmental benefits and costs.

U.S. DEPARTMENT OF THE INTERIOR, BUREAU OF RECLAMATION

The Yuma Desalting Plant is the world's largest reverse osmosis unit. Located in southwestern Arizona just north of Mexico, the plant desalts highly saline drainage water from farmlands east of Yuma before the water enters the Colorado River. This operation lowers the overall salinity of the Colorado and enables the United States to meet its treaty obligation to deliver water of acceptable quality to Mexico.

Desalinization

Desalination is not likely to be an important water-supply option in the United States in the next two decades. The costs of desalinating water, especially sea water, are still very high relative to most other options. However, desalination has several characteristics that make it worth considering as a supplementary source of reliable water, especially in water-short coastal cities.

Desalination plants are currently very expensive to build and operate relative to most other options. High energy costs are an especially significant constraint. However, in principle, desalination of sea water offers consumers access to an inexhaustible and noninterruptible source of supply that is free of competition for water rights (46). Desalination offers a flexible way to maintain deliveries during prolonged dry periods. It is completely independent of rainfall or of deliveries from outside the service area. When not needed, a desalination plant can be shut off, saving some operational expenses. Desalination plants can also be used in conjunction with traditional stored supplies to allow more-efficient use of these supplies during wet or normal years (e.g., more water can be drawn from a reservoir than might otherwise be safe). Incremental adjustments to the size of a plant can be made to respond to changing circumstances.

The case of the City of Santa Barbara illustrates the potential of desalination to provide flexibility during prolonged dry periods. Santa Barbara has very little groundwater and is not yet connected to the California State Water Project (SWP), so it normally relies on local surface-water sources to meet 90 to 100 percent of its 16,000-af/year water demands.[22] This reliance on local surface-water

22 B. Ferguson, City of Santa Barbara Water Department personal communication, July 1992.

sources left Santa Barbara quite vulnerable to the recent California drought. To reduce its vulnerability to future droughts, city voters-by a wide margin-approved plans to build a small ($40 million) reverse-osmosis plant to convert sea water to fresh water. Despite its cost, the city sees its desalination plant as a good way to droughtproof its water-supply system. The 7,500-af/year plant has been operational since March 1992. It was operated briefly during its commissioning period but has been on standby since local water-supply reservoirs have filled because of favorable weather conditions.

The siting of desalination plants is not as constrained to specific locations as are reservoirs. Because desalination plants occupy much less space than dams and reservoirs, it may be easier to find suitable land for them. On the other hand, desalination plants can still be sizable industrial facilities, which some find objectionablein coastal settings. In most cases, the high capital and energy costs of desalinated water constrain the near-term penetration of this technology in the United States. Brine disposal is also of some concern and may add to the long-term operating costs of such a facility.

Interregional Diversions

Over the years, many ideas have been proposed for diverting large amounts of water from water-surplus to water-deficit areas of the continent. Many plans have been proposed to bring water from the Pacific Northwest via pipelines and aqueducts to the populated regions of the Southwest. Among these have been proposals to divert water from the Columbia River, the Mississippi River, and several Canadian rivers. None of these proposals are currently being seriously considered by water planners. All are prohibitively expensive, most would likely entail unacceptable environmental impacts, and the massive quantities of water that they could supply are probably unnecessary. Politically, such projects are not now feasible. Few, if any, potential water-exporting areas are willing to give up water that may ultimately affect their growth potential or that may be needed for instream uses. Conversely, it is debatable whether additional growth should be subsidized in water-short areas, especially if there are indications that those regions could become drier as a result of climate change.

Interrgional diversions should not be ruled out completely, however. Climate change could cause a reconsideration of major diversions in the more distant future.[23] Moreover, in areas of increased precipitation, “high-flow-skimming” diversions may be attractive. Many of the existing plans are technically feasible, and although currently unlikely, some rivers now classified as wild and scenic could, in theory, be diverted. As long as other less-expensive and environmentally more sound options are available, little support of interregional diversions is likely to develop.

Reclaiming Water

Traditionally, water has been supplied to municipal residents, used, treated, and then discharged as wastewater effluent (12). Much of this wastewater could be recovered and reused where potable-quality supplies are not needed. Landscape watering, industrial cooling, groundwater recharging, and toilet flushing are among the many uses to which reclaimed water could be put. Reclaimed water could be treated to drinking-water standards at greater cost, but this may not be necessary because its use on golf courses and the like would enable high-quality water now used for these purposes to be shifted to potable uses.

The use of reclaimed water is one of the most promising new sources of water supply, especially because virtually all water uses create wastewater and, therefore, generate a reliable

[23] Note that future demographic changes in current water-surplus areas would also be an important consideration.

Box 5-J-The Use of Reclaimed Water in St. Petersburg

Freshwater supplies for the city of St. Petersburg, Florida, are limited because it is located at the end of a peninsula. The city's growing population led the Southwest Florida Water Management District to declare St. Petersburg a "water shortage area" in the early 1970s. At about the same time, the State legislature mandated that wastewater treatment plants discharging to polluted Tampa Bay start to treat their wastewater to a quality equal to that required for drinking water. St. Petersburg responded to these two actions by initiating a program to terminate disposal of wastewater into Tampa Bay and at the same time to ensure an adequate drinking supply through the year 2020 by recycling the city's wastewater (71).

Several financial, institutional, and educational barriers had to be overcome before the reclaimed-water program could be implemented. Because it proved to be too expensive to treat wastewater to potable standards, the city decided to use reclaimed water only for irrigation and industrial-cooling purposes. This required not only upgrades to existing treatment plants and storage facilities, but a new distribution system completely separate from the potable-water system. St. Petersburg was able to afford the cost of building a separate water-delivery system only because Federal (i.e., Environmental Protection Agency) and State funding was available to offset some of the planning, design, and construction costs (71).

The city had to work closely with the State Department of Environmental Regulation to write regulations that would allow for the distribution of reclaimed water, and it had to overcome initial public skepticism. A public-education campaign resulted in both acceptance and pride in the innovative program on the part of city residents.

Since 1992, St. Petersburg has had four treatment plants, which treat and chlorinate water to a high standard of quality, with all pathogens being completely removed. Approximately 10 million gallons per day (mgd)[1] of reclaimed water is routed through a separate distribution system to 7,340 customers who use the water for irrigation and cooling. The city hires inspectors to ensure that cross-connections between the two systems do not occur, but the reclaimed water is of high enough qualit y that occasional mistakes have not resulted in any adverse health effects to consumers.

The reclaimed-water treatment and distribution system has the capacity to reach 11,000 customers with potential demand of 20 mgd; the dty feels that it can reach this level of service in another 5 years. Total water demand in the city (potable and nonpotable) is approximately 42 mgd, so reclaimed water for nonpotable uses could eventually account for half of all St. Petersburg water deliveries.

By substituting reclaimed water for potable water in irrigation and cooling, the city estimates that it has eliminated the need for expansion of its potable-water-supply system until the year 2030 (59). St. Petersburg prides itself on becoming "the first major municipality in the United States to achieve zero waste-water discharge to surrounding surface waters" (71), and now receives money for water that it previously had to pay the State for permission to dump into the bay. Other communities in the United States and beyond have recognized the city's accomplishments by sending a steady stream of visitors to learn firsthand about the city's dual-distribution system.

[1] 38 million liters per day; to convert from gallons to liters, multiply by 3.785.

supply. Many communities are already using or plarming to use reclaimed water (see box 5-J), but the costs of reclaiming water are high. Moreover, costs may not decline much with advances in water-treatment technology because a major expense is for construction of separate distribution systems. Development of this new source often requires an active campaign to educate the public about the quality of reclaimed water. Compliance with environmental and health regulations is currently a major source of delay for reclamation projects, but as wastewater reclamation and reuse become more common, these delays are likely to diminish.

The Metropolitan Water District (MWD) of Southern California has sought to encourage development of wastewater reclamation facilities and to help its member agencies overcome financing problems by offering agencies $154 for each acre-foot of "new water" produced, provided that this water replaces an existing demand for imported water from MWD. Together with the $322/af it would cost local agencies to buy an equivalent amount of imported water from MWD, the subsidy makes reclamation projects economical for many local agencies.[24] MWD also finances up to 25 percent of the cost of initial feasibility studies in order to encourage consideration of reclamation possibilities. California hopes to be using 500,000 af of reclaimed water per year by 2010 (6).

Policy Options for Encouraging Structural Improvements

Option 5-19: *Require that the potential for climate change be considered in the design of new structures or the rehabilitation of old ones.* Climate change uncertainty adds another complex dimension to project scaling. Because climate could potentially change during the long lifespan of these structures, steps taken now to increase flexibility could prevent problems from developing decades in the future. In particular, the Nation's water agencies could be directed to evaluate the costs and benefits of adding additional volume, spillway capacity, or temperature controls to existing or new structures.

Option 5-20: *Appropriate funds for wastewater reclamation, desalination, or other water-supply research.* Congress could consider using the authority of sections 106 and 108 of the Water Resources Research Act of 1984.

FIRST STEPS

Water resource management has two essential objectives: to ensure that enough water of adequate quality is available during normal and drought periods for all necessary demands--including environmental ones-and to ensure that water in the form of life- and property-threatening floods does not get out of control. Growing stress on water resource systems and the possibility that new stresses such as climate change will arise make these objectives increasingly difficult to accomplish. The demand- and supply-management options discussed in this chapter (table 5-4) are likely to be increasingly important as means to cope with growing stress on water supplies. These options contribute greater flexibility, greater efficiency, or both to water resource management and thus aid, generally, adaptation to climate change.

Considering climate change alone, there are no compelling arguments why any one supply- or demand-management option should be preferred to another. All are important and would contribute, if sometimes only in small ways, to improved water resource management in a changed climate. However, the system is very inefficient now, given numerous institutional obstacles, lack of incentives to conserve water, overlapping and sometimes conflicting responsibilities of Federal agencies, and lack of coordination among levels of government. Fundamental changes are needed in the way water is valued and used; those changes can begin with steps that both relieve existing stresses and make sense for climate change. Implementing the suggestions below—drawn from the whole range of options discussed above-would likely create the conditions for future progress in water resource planning and management.

- **Improve extreme-events management.** Perhaps the most important actions that should not be delayed concern improving the management of extreme events. Floods and droughts will continue to occur even if they cannot be linked definitively to climate change. Improving flood and drought management now could help minimize both near-and long-term losses. Important first

[24] D. Adams, Director of Resources, Metropolitan Water District of Southern California, Los Angeles, personal communication, July 1992.

Table 91-Summary of Options to Improve Water Resource Management

Institutional	
	Resurrect the former Water Resources Council
	Reestablish and strengthen Federal-State river basin commissions
	Create an interagency task force to develop a national drought policy
	Create a national flood-assessment board
	Integrate floodplan management into basin-scale planning
Research and development	
	Fund the development and use of water-conservation technologies
	Fund the development and use of waste-water-reclamation technology
	Increase funding for development and promotion of new analytic tools
	Incorporate flexibility into the design of new structures or the rehabilitation of old ones
Direct Federal levers	
	Revise the tax code to promote conservation investment
	Provide stronger leadership to facilitate water transfers
	Clarify reclamation law on trades and transfers
	Reduce Federal obstacles to Interstate transfers
	Clarify the rules regarding the marketing of Indian water
	Allow Federal agencies to buy water for environmental purposes
	Expand the scope and/or nature of the Western Water Policy Review
	Conduct post-drought audits
	Direct the Interagency floodplain Management Task Force to promote the preparation of State floodplain management plans
Economic Incentives and disincentives	
	Allow state revolving-loan funds to be used for conservation investments
	Reform pricing in Federal water projects
	Tie funding of State water projects to adoption of Improved water-management practices
	Encourage adoption of risk-management and -minimization practics to mitgate drought effects
Operational	
	Encourage water conservation in Federal facilities
	Require operating agencies to undertake periodic audits to Improve efficiency
	Give Federal operating agencies greater ability *to modify* project operations to meet changing conditions

a An order of priority has not been established.

SOURCE: Office of Technology Assessment 1993.

steps could be for Congress to direct the executive branch to create an interagency drought task force with authority to develop a national drought policy and, similarly, a national flood-assessment board to establish national goals for floodplain management. Title V of H.R. 62, the National Flood Insurance Compliance, Mitigation, and Erosion Management Act of 1993, establishes a flood-insurance task force. This bill could be broadened to create a more comprehensive flood-assessment board. The President could establish an interagency drought task force without additional authority, but Congress may wish to direct the Administration to do so.

- Promote management of reservoirs on a basin-wide level. Operation of reservoirs within the same basin as a single system rather than individually, as is often the case, could greatly improve the efficiency and flexibility of water-quantity management. Making such operations easier would also assist development of the more integrated approach desirable for managing water quality, wetlands, flooding, and drought. New legislation, perhaps as part of the next omnibus water bill, could grant the Army Corps of Engineers and the Bureau of Reclamation greater administrative flexibility to do this.

- **Promote water marketing.** Among many institutional problems that Congress may wish to consider are those related to water marketing. As long as adequate attention is given to protecting third-party interests, water markets could provide an efficient and flexible means of adapting to various stresses, including a changing climate. Of the several options identified in this report for reducing impediments to creating water markets, early action to clarify reclamation law on trades and transfers and to define the Federal Government's interest in facilitating the creation of markets would be most useful. Congress could urge the Department of the Interior to provide stronger leadership to assist transfers. Evaluation of water marketing should also be thoroughly considered in the Western Water Policy Review, authorized in late 1992 by P.L. 102-575, the Central Wiley Project Improvement Act.
- **Promote use of new analytical tools.** Further development, dissemination, and use of new modeling and forecasting tools could greatly assist water resource management. Some current development efforts (e.g., NOAA's WHS initiative) have not been adequately funded, and the most advanced tools now available are not yet being used by many States or water utilities. Small sums spent now promoting dissemination and use of these tools could save substantial sums later. Section 22 of the Water Resources Development Act of 1974 authorizes funding for training and technical assistance to States and could be used to promote use of analytical tools. Congress may also want to consider providing funds to develop or refine tools that incorporate climate uncertainty into traditional hydrologic analyses.
- **Promote demand management.** Several "targets of opportunity" for improving water-use efficiency are likely to present themselves in the 103d Congress. The upcoming reauthorization of the Clean Water Act stands out. State revolving funds (created under Title VI of the act) have been a successful means for funding wastewater treatment plants. In CWA reauthorization, Congress could consider making conservation projects eligible for revolving-fund loans. This would not only promote demand management but would reduce the amount of water that needs treating. The Federal Government could also make a contribution to promoting efficient water-use practices by setting an example in its own numerous facilities. The Energy Policy Act of 1992 proposes just this but concentrates primarily on energy conservation rather than water conservation. A technical-adjustment bill to the Energy Policy Act may be considered in the 103d Congress and would provide a way to clarify and underline congressional intent toward water conservation in Federal facilities.
- **Expand the scope of the Western Water Policy Review.** With the enactment of Title XXX of the Reclamation Projects Authorization and Adjustment Act of 1992 (P.L. 102-575), Congress authorized the President to oversee a major water-policy study. Under the heading Western Water Policy Review, Title XXX directs the President to undertake a comprehensive review of Federal activities in the 19 Western States that affect the allocation and use of water resources and to make a report to appropriate congressional committees by the end of October 1995 (87).

Congress has authorized or undertaken more than 20 major studies since 1900 to provide a basis for improving national policies that affect water management. Some have led to important changes in policy; others have been largely ignored. Despite the uneven record of these studies, a new study is warranted: two decades have lapsed and many demographic, economic, environmental, and attitudinal changes have occurred since the last comprehensive study of water resource problems was completed by the presidentially appointed National Water Commission (NWC) in 1973. Some of the areas that need detailed attention now include demand management, quality-vs.-quantity issues, instream-water values, social and environmental impacts, water marketing and pricing, land use in relation to water resources, cost sharing and upfront financing, comprehensive urban water planning, ways to promote integrated river basin planning, and development of analytical tools. Climate change is not mentioned as a factor motivating the Western Water Policy Review, but the study could provide an opportunity to assess more fully how climate change may affect water resources and to evaluate policy options that might help with adaptation to a warmer climate.

Congress could expand the scope and/or nature of the Western Water Policy Review. Water problems are not all in the West, so a more general review of national water policy may make sense. Expanding the currently authorized study would, however, greatly increase its complexity. Also, other committees of Congress may want to become involved, and broader State or regional representation would probably be required. Broadening the study could be accomplished by amending the legislation or by Executive Order. If the Western Water Policy Review is not expanded to include the entire United States, Congress could authorize a similar follow-on study of eastem water issues.

The Western Water Policy Review may also provide an opportunity to explicitly consider land-use practices and water resource issues jointly. One shortcoming of most previous water-policy studies is that land and water use were not considered together. However, the relationship between the two is a close one, and there appear to be significant opportunities to improve both water-quantity and water-quality management by improving land-use practices. Fur-

WATER-FIRST STEPS

- **Improve extreme-events management**
  - Direct the executive branch to create an interagency drought task force with authority to develop a national drought policy.
  - Direct the executive branch to create a national flood assessment board to establish national goals for floodplain management.
- **Promote management of reservoirs on a bssin-wide level**
  - --Grant the Bureau of Reclamation and the Army Corps of Engineers greater administrative flexibility to manage reservoirs basin-wide in the next 1994 Omnibus Water Bill.
- **Promote water marketing**
  - --Clarify reclamation law on trades and transfers
  - -Urge the Department of the interior to provide stronger leadership to assist transfers.
  - --Require evaluation of water marketing in the Western Water Policy Review, authorized by P.L 102-575.
- **Promote use** of new analytical tools for water modelling and forecasting
  - -Use funds under Section 22 of the Water Resources Development Act of 1974 to promote use of analytical tools as part of the training and technical assistance to States.
- **Promote demand management**
  - --Make conswvation projects eligible for revolving-fund loans in the Clean Water Act reauthorization.
  - -Clarify the stated congressional intent of promoting water conservation in Federal facilities with a technical-adjustment bill to the Energy Policy Act of 1992 (P.L 102-486).
- Expand **the scope of the Western Water Policy Review**
  - --Evaluate land-use practices and water resource issues jointly.
  - --Include an analysis of the eastern States now or authorize their study after the western review is completed.