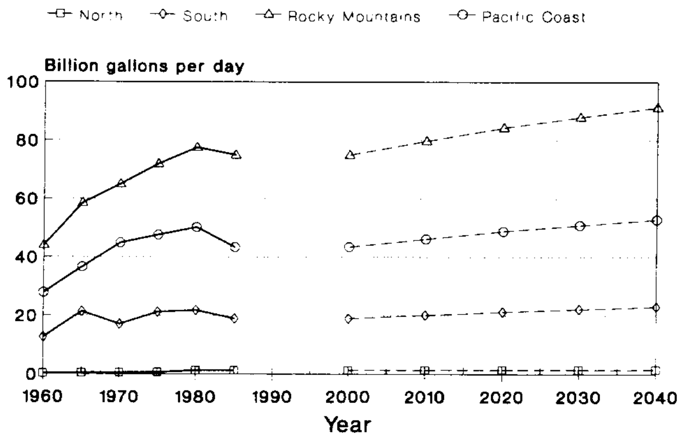


Figure 19.—Irrigation, freshwater withdrawals by region.

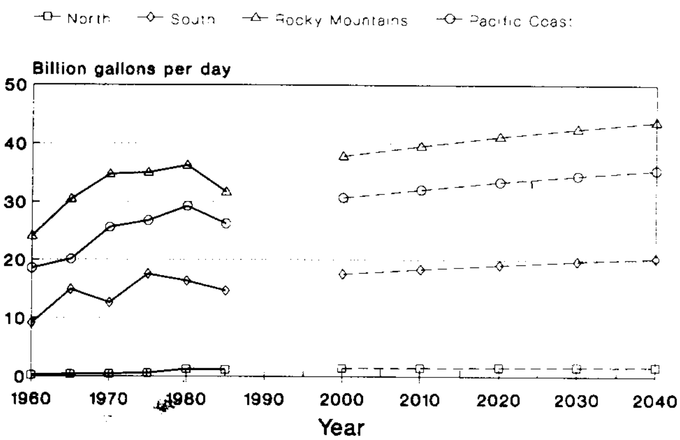


Figure 20.—Irrigation, freshwater consumption by region.

MUNICIPAL CENTRAL SUPPLIES

Municipal central supplies refers to water withdrawn by public or private water supply utilities who distribute treated water through a network of pipes to household, commercial, and industrial users. This use category contrasts with domestic and industrial self-supplied use—those entities each withdraw water for their own needs from surface or groundwater sources. Municipalities may contract with a private firm to supply water or have their own supply and treatment systems.

Municipal systems serve a variety of users. Foremost are individual households; however, commercial establishments—stores, restaurants, and light industry—are also usually served by municipal supplies. There comes a point for many industries when a corporate decision must be made whether or not to rely on municipal supplies for their entire water needs. Such a decision is fundamentally one of cost. A firm may use water in their manufacturing process as a major component of the product as in brewing beer, or as an adjunct such as cooling in steel mills. In the former case, the quantity required by a new facility is so large that it could overwhelm the municipal supplier's ability to provide it. In this case, it is often less expensive for the firm to develop its own supply. In the latter case, water of a lower-than-potable quality is needed, so paying a municipal supplier to treat the water to potable levels is more costly than developing an independent supply. Finally, if high costs are associated with production process interruptions due to water shortages, then an auxiliary private supply may be developed as a safeguard against interruptions.

In addition to providing water for household, commercial, and some industrial uses, municipal central-supplies also include water for public uses. Public uses include fire protection, street washing, municipal parks, and swimming pools.

Water use and trends.—The total water withdrawals for municipal supplies reached 36.5 bgd in 1985, an increase of 7% over 1980. The trend in municipal withdrawals is one of steady increases over the past 25 years (table 8 and fig. 21). Consumption, on the other hand, has remained constant since 1980 at 7.1 bgd (table 9 and fig. 22). Regional withdrawal and consumption patterns are shown in figures 23–24.

Historically, larger cities used surface water as the municipal source while smaller towns used groundwater. Between 1980 and 1985, there was an increase in groundwater withdrawn and a decline in surface water withdrawn (figs. A.8–A.9). This pattern supports the observed trends in population migration from cities to rural settings. The percentage of the population served by municipal systems increased 2% since 1980 to 83% in 1985. This percentage may be near the upper limit that can be reasonably served by central systems given costs of extending water mains into rural areas having low population.

Some evidence is emerging from per-capita use rates of municipal supplies that water conservation is occurring. Per-capita household use in 1980 was 120 gallons per day (gpd), 117 gpd in 1975, and 115 gpd in 1970. The 1985 data show per-capita household use at 105 gpd—a significant reduction given the short-term trend. Two factors probably play a large role in this reduction. The first is that municipalities have recently begun major renovations of water supply systems. New technology developed in the last 20 years has given municipalities a clear understanding of the status of leaks in water mains and distribution systems for the first time and also a means of fixing problems without the tremendous cost of excavating and replacement. Excavation and repaving are the most significant costs associated with repairing leaks. Miniature television cameras and new leak detection developed in the 1970s now permit direct observation of the inside of pipes to locate leaking sections without excavation. Pipe sections and joints needing repair can be pinpointed before digging. Techniques have also been developed to reline existing pipes with plastics and polymers to improve leak resistance, again without excavating major sections of water main. Thus, technology makes it much more economical to fix leaks than to add additional water withdrawal and treatment capacity. Because per-capita use is measured by the volume of water entering the distribution system at the treatment plant, repairing leaks reduces per-capita use.

The second major factor affecting per-capita use is household adoption of water conservation measures. A

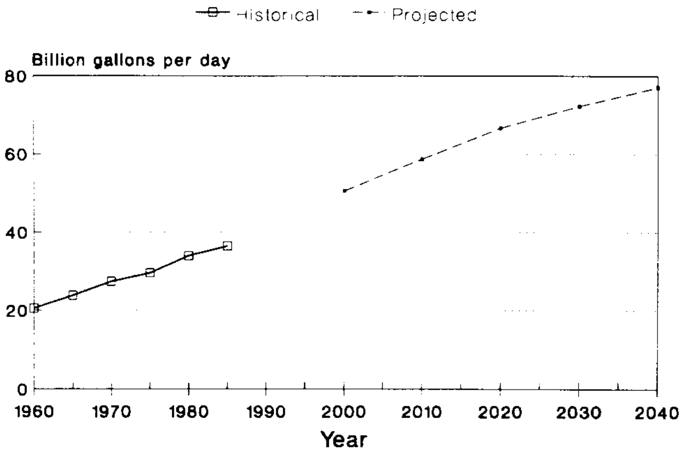


Figure 21.—Municipal supplies, total freshwater withdrawals.

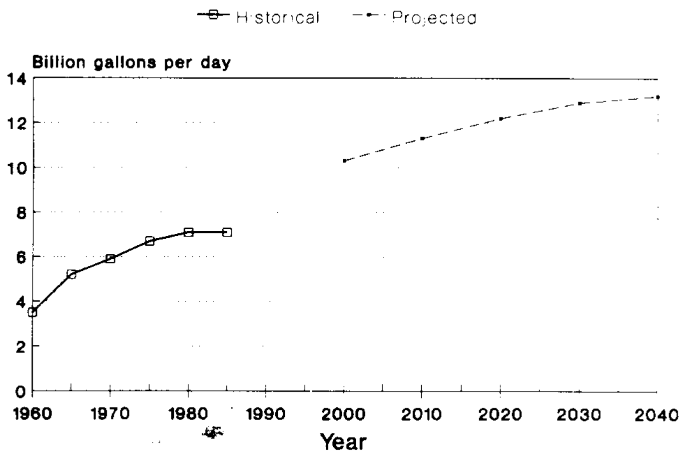


Figure 22.—Municipal supplies, total freshwater consumption.

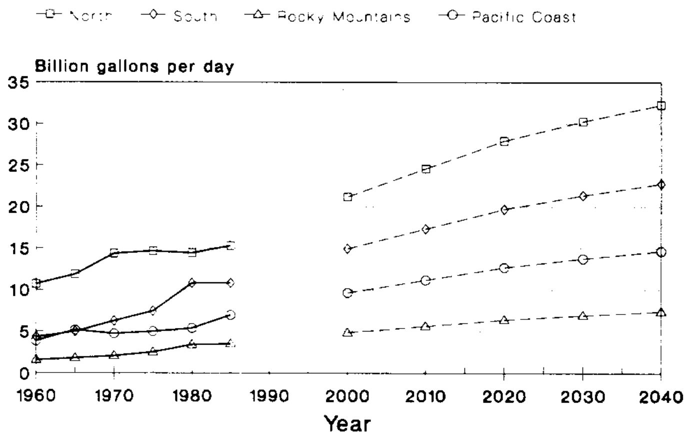


Figure 23.—Municipal supplies, freshwater withdrawals by region.

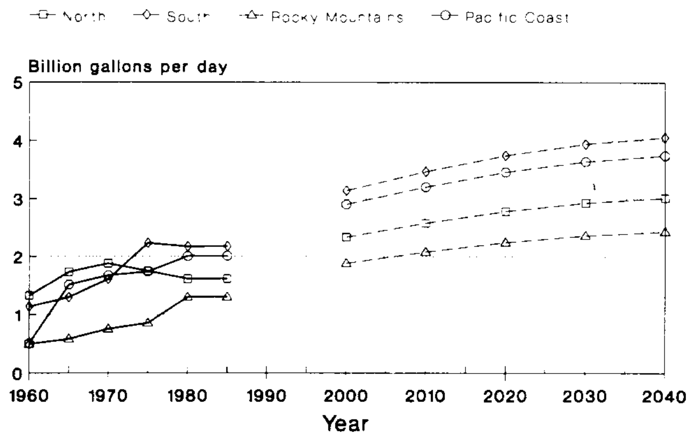


Figure 24.—Municipal supplies, freshwater consumption by region.

variety of improvements have been made in residential plumbing fixtures and home appliances to decrease water use. Showerheads that use less water, water-saver cycles on laundry and dish washers, and commodes that use less water per flush have all been developed since the 1960s. These measures have gradually been adopted in sufficient numbers to reduce per-capita water use. Per-capita use trends also show some regional variation—use in the West is higher than in the East. Lawn watering is likely the key to explaining much of the regional variation.

Potential for changes in the projections.—Over time, water main servicing and water-saving fixtures and appliances will become more heavily used. The extent to which adoption of these items is hastened or delayed will cause the actual municipal withdrawal level to also fluctuate.

INDUSTRIAL SELF-SUPPLIED WATER USE

Self-supplied industrial water use is categorized in this Assessment as water withdrawn and consumed by industries for their own use, except cooling thermoelectric power plants. Major water using industries that have developed their own supplies include steel, chemicals and allied products, paper and allied products, mining, and petroleum refining. Water is used by industries primarily for cooling, washing, conveyance, and as part of the final product. As previously described, the decision to supply one's own water is a corporate one made on the basis of cost-efficiency.

Water quality legislation of the early 1970s imposed more stringent regulation upon industries that were discharging waste into streams. Many firms supply their own water. Water quality regulations required industries to discharge waste streams to municipal systems which were then authorized to charge the industry for treating the wastewater or to build a separate waste treatment facility.

Because many industrial waste flows contain pollutants that are not effectively removed by conventional municipal waste treatment plants, many small- to medium-sized municipalities were reluctant to handle industrial flows. If they decided to accommodate the flow, costs charged the industry were often quite high because special treatment processes had to be installed for the entire municipal plus industrial flow volume. Consequently, constructing a separate industrial waste treatment plant was often the strategy selected. Building such plants was costly. In an effort to reduce capital expenses, much effort was devoted to reducing the volume of waste needing treatment. Like municipalities, many industries have begun ambitious leak detection and repair programs. Consultants and contractors providing these services flourished. Opportunities to recycle water were also explored in an effort to reduce flow volumes needing treatment.

Water use and trends.—Industrial self-supplied water withdrawals declined 33% between 1980 and 1985 to 26.4 bgd (fig. 25). This level is far below the recent trend in industrial withdrawals; withdrawals have hovered at 39 bgd since 1970 and have been greater than 33 bgd since 1960. Surface water withdrawals dropped 30% since 1980 and groundwater withdrawals dropped 41% (tables 8, A.4, and A.10 and figs. A.10–A.12). Consumption decreased 9% since 1980 to 4.1 bgd (tables 9 and A.15 and fig. 26). Increased recycling is expected to increase consumption. Regional patterns in withdrawal and consumption are shown in figures 27–28.

Projections of industrial self-supplied water use are the weakest of the six categories of uses. Figures 25 and 27 show how the historical trend has fluctuated; these data have no significant association with historical trends in GNP. A major reason is the types of industries that are heavy water users in comparison with industries that have contributed to GNP growth in recent years. Heavy water users have shown mixed performance during the past 10 to 20 years. While paper, chemicals, and allied products show some increases in outputs in recent years, steel, mining, and petroleum refining have not fared as well.

The steel and petroleum industries took a beating in the recession of the early 1980s. Growth in those industries is practically nonexistent. In addition to more stringent water pollution regulations, these industries had to comply with more stringent air pollution regulations. The consequence is that much of the capital normally used for plant expansion or efficiency was diverted to pollution abatement; thus, industries are overburdened with obsolete or inefficient production facilities. These industries are among the most heavily unionized industries remaining in the U.S., which adds another layer of complexity to the process of adjusting to a new production environment.

Potential for changes in the projections.—Because historical trends are not very responsive to basic assumptions used in this Assessment, the potential for projection changes is great. Major industries using self-supplied water have been heavily impacted by the early 1980s recession and the recovery of some is not yet underway. It is impossible to say how much of the

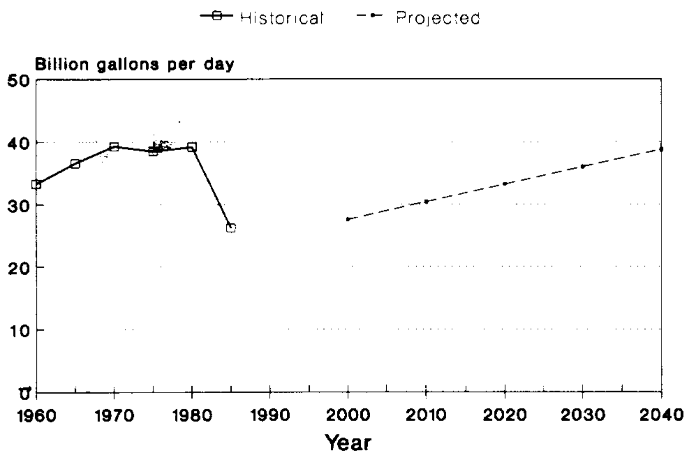


Figure 25.—Industrial self-supplied water, total freshwater withdrawals.

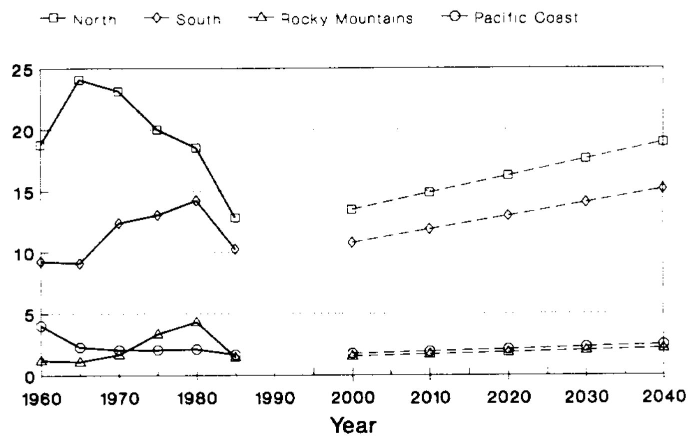


Figure 27.—Industrial self-supplied water, freshwater withdrawals by region.

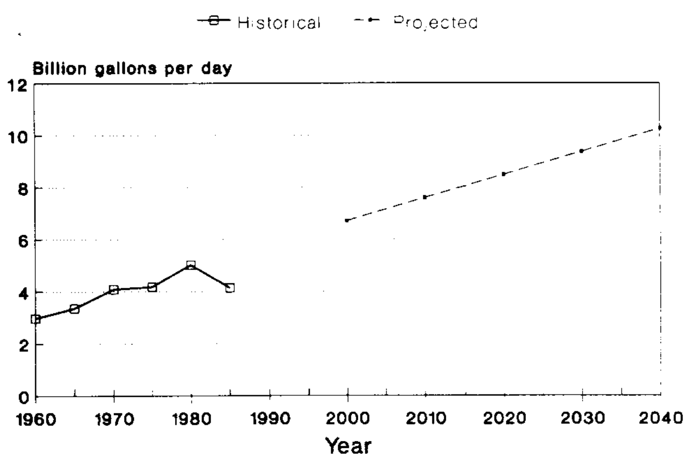


Figure 26.—Industrial self-supplied water, total freshwater consumption.

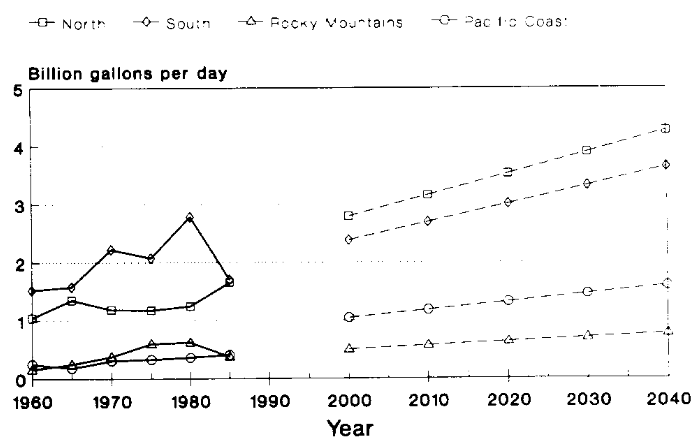


Figure 28.—Industrial self-supplied water, freshwater consumption by region.

reduction in water use is attributable to long-term trends versus short-run industrial economic conditions. Certainly if these industries were all vibrant and had rosy futures, projections of self-supplied water use would show increases over time.

The U.S. economy shifted in recent years from one driven by the engines of basic heavy industry—steel, mining, and railroads—to an economy driven more by "high tech" and service industries—such as computers, electronics, food service, and health care. The U.S. economy emerged from the depths of the Great Depression by the mobilization of the basic heavy industries for World War II. The economy literally fought its way out of the Depression. In the past 20 years, considerable production in these heavy industries moved to other countries, such as steel-making to the Far East. Consequently, our environment is cleaner. The Ohio River no longer flows rust-red south of Pittsburgh, Pennsylvania; West Virginia's rivers are no longer yellow with sulfuric acid from coal mining; and the Cuyahoga River below Akron, Ohio no longer burns in Cleveland's harbor.

But a price has been paid for our cleaner environment not only in terms of expenditures for pollution control, but also in terms of jobs exported and a loss of heavy industry. Ignatius (1988) reported that 245,000 steel workers lost their jobs between 1979 and 1988. In the decade from 1977 to 1986, 24 steel companies disappeared in mergers or bankruptcies. Firms that survived drastically reduced their capacity. USX Corporation, the successor to U.S. Steel, reduced its capacity from 33 million tons per year in mid-1983 to 19 million tons in 1987. Railroads, barge lines, and coal companies—all dependent upon the steel industry—shared in the decline in business and economic activity. One factor contributing to these changes was the capital, operation, and maintenance costs of water and air pollution cleanup and abatement.

A prevailing view of the U.S. economy beyond 1990 is that service industries will continue to grow in importance. Service industries tend to use much less water than heavy industry, largely because cooling and washing requirements are much lower, so volumes of water to be treated will grow at a slower rate than recently.

Waste flows from service industries fall into two categories. The first are flows very similar to household waste generated by industries such as food or financial services. Treating them at municipal plants will cause no unusual problems other than making certain sufficient capacity exists. The second type of waste flow from service industries is very dissimilar from conventional household flows. These flows contain pollutants such as products of biochemical reactions that are more difficult to process in conventional waste treatment plants than the sediments and BOD for which they were designed. Specialized in-plant treatment facilities using advanced methods such as reverse osmosis, activated carbon adsorption, or incineration will be needed to treat these waste flows. The trend towards providing this level of treatment at the waste source will increase.

Industrial self-supplied water use projections in this Assessment are based on a period when industrial production is in a state of flux. Consequently, projections are subject to uncertainty. In the discussion on factors that might influence how projections change, the general conclusion is that the rate of increase in volumes has ceased, unless a major recovery of the heavy water-using industries occurs. A decline in total flow volume for self-supplied industries may have begun; the 1990 USGS data will be needed to confirm that point. Another general conclusion is that the character of the waste flows is also likely to change as service industries emerge as a more prominent sector of the U.S. economy.

DOMESTIC SELF-SUPPLIED WATER USE

Domestic self-supplied use reflects the population not served by municipal central-supplied water systems and occurs primarily in rural areas. USGS estimates the number of people who supply their own water by subtracting number served by central systems from the total U.S. population. The percent of population served by domestic self-supplied water has dropped steadily from 31% in 1955 to 17% in 1985.

Water for rural use includes water for household consumption, drinking water for livestock and other uses such as dairy sanitation, evaporation from stock-watering ponds, cleaning, and waste disposal. Because water for these uses is drawn largely from wells serving individual dwellings or business locations, and because these water supply systems are rarely metered, few "hard" data on rural water use exist. Consequently, information presented in this section and the subsequent one on livestock use represent the best estimates of the USGS on trends in water use in rural areas.

Total rural use is broken into two components—domestic self-supplied use and livestock use. The former includes estimates of household use and use around the home such as vehicle washing and lawn watering. Waste disposal in rural areas is also individualized, primarily through septic systems. The latter category includes estimates of livestock consumption and sanitation such as manure disposal via holding lagoons and pasture irrigation. Livestock use will be discussed further in the next section.

In the 1930s and 1940s, many rural households lacked indoor plumbing. Per-capita water use rates on the order of 10 to 15 gpd were common. Wind, and later electricity, was commonly employed to fill elevated tanks that supplied water by gravity to plumbing. In 1955, about 20% of rural homes had running water, with per-capita use between 50 and 60 gpd. Since then, more and more rural households use electric water pumps to fill pressurized tanks. Installation of modern appliances in rural homes served by pressurized systems increased per-capita consumption to about 80 gpd. (Houses served by municipal central supplies use about 105 gpd per capita.[3]) The difference in per-capita water use is due in part to differences in water pressures between individual and municipal systems. Municipal systems commonly operate at 60 pounds per square inch (psi) of water pressure while individual systems commonly operate between 25 and 40 psi.

Water use and trends.—Total withdrawals for domestic self-supplied water were 3.3 bgd in 1985, a drop of 0.6% from 1980 (fig. 29). Populations served by domestic self-supplied systems remained essentially constant at 40 million people over this time period.

Groundwater is the primary source of water for domestic self-supplied use (figs. A.13–A.14). In 1985, only 1.8% of domestic self-supplied water came from surface sources. This represents a 67% drop from the 5.4% in 1980 that came from surface sources. Consumption from 1980 to 1985 remained constant at 2.0 bgd (fig. 30). Regional patterns are shown in figures 31 and 32.

Total withdrawals for rural domestic uses are projected to increase 76% between 1985 and 2040. New groundwater withdrawals are the source of this increase (tables 8, A.5, and A.11 and figs. A.13–A.14). Consumption is projected to decrease 10% over the same period (tables 9 and A.17 and fig. 30). Increasing withdrawals in the face of decreasing consumption reflects the conversion to pressurized water systems for most rural households by 2040 and the addition of appliances to households.

Potential for changes in the projections.—As water-conserving appliances make broader inroads into rural construction and home remodeling, the rate of increase in water withdrawals will slow. Water-conserving fixtures were discussed under the municipal section above. If installation of these fixtures and appliances proceeds more quickly than recent trends, the rate of increase in withdrawals will be faster than projected.

In all areas of the U.S. except the North, a higher percentage of water supplied to rural households is consumed than is withdrawn. The North has 46.5% of domestic self-supplied withdrawals but only 30% of the consumption. The South has 33.9% of withdrawals and 42.5% of consumption; the Rocky Mountains 9.1% and 14.8%, respectively; and the Pacific Coast 10.5% and 12.7% respectively. Consumption in this context means loss to evapotranspiration or consumption by humans. The rural areas of the North are more densely populated than are rural areas elsewhere, so a larger percentage of withdrawals occur in the North. As rural areas in other parts of the country become more densely settled, withdrawals there will become more prevalent. Population shifts underway from the North to the South and West will result in greater withdrawals and consumption, in absolute terms, in those regions. If the population migration occurs more rapidly and if the "back to nature" out-migration from urban areas increases, projected increases in withdrawals and consumption will be greater.

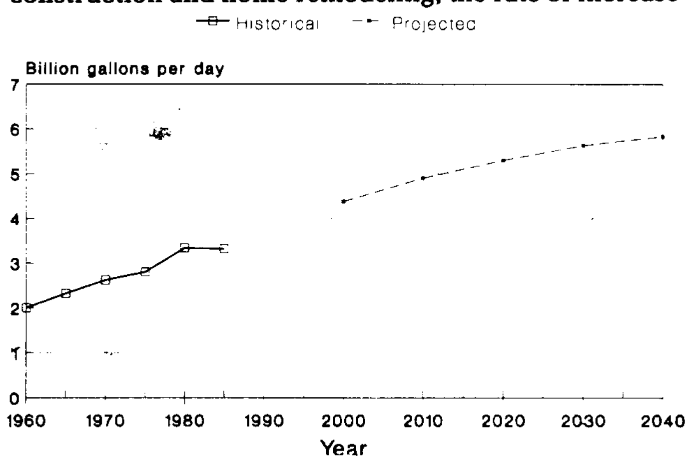


Figure 29.—Domestic self-supplied water, total freshwater withdrawals.

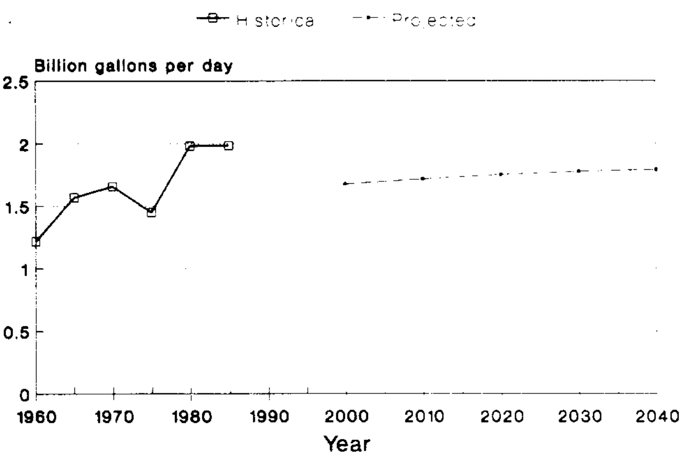


Figure 30.—Domestic self-supplied water, total freshwater consumption.

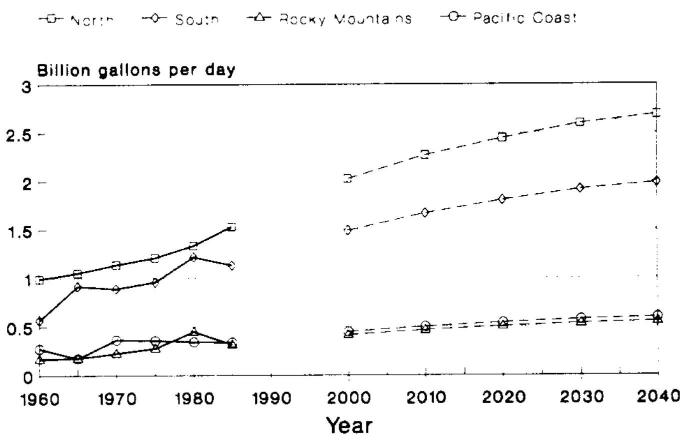


Figure 31.—Domestic self-supplied water, freshwater withdrawals by region.

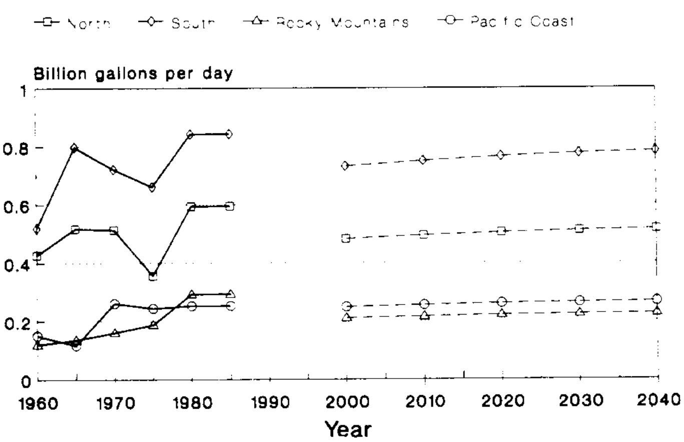


Figure 32.—Domestic self-supplied water, freshwater consumption by region.

LIVESTOCK WATERING USE

Livestock watering includes water provided for drinking by livestock and water used to maintain livestock sanitation. It includes the water pumped by windmills to stock ponds on western rangeland and water used to flush manure from dairy barns and feedlots into a waste holding lagoon. Since 1985, it also includes water used on farms for aquaculture and other non-irrigation purposes.

The heaviest use for livestock watering occurs in regions with high livestock populations. The Missouri, Arkansas-White-Red, Texas-Gulf, Upper Mississippi, Ohio, Mid-Atlantic, and South Atlantic-Gulf are water resource regions with the largest livestock watering withdrawals. Red meat production and dairying are major industries in those regions.

Water use and trends.—The quantity of water withdrawn for livestock and aquaculture in 1985 was 4.5 bgd, twice the quantity withdrawn in 1980 (fig. 33). Consumption showed a 20% increase (fig. 34). The large increase in use is attributed to an acceleration in aquaculture—fish farming. Growing fish for human consumption emerged as a rapid-growth industry in Idaho (salmon and rainbow trout) and Mississippi and Arkansas (catfish). These three states accounted for 42% of the Nation's total livestock and aquaculture water use, largely because of increases in aquaculture (Solley et al. 1988) (figs. 35 and 36). A related reason for the doubling of livestock and aquaculture water use since 1980 is that some states previously reported water use for fish farming in the industrial self-supplied category. In 1985, all aquaculture use is consolidated in the livestock category.

Potential for changes in the projections.—Livestock watering needs are a function of animal populations, which in turn, are a function of demand for red meat, dairy products, and fish. Basic assumptions for the Assessment include a projection of red meat demand at 110 pounds per capita per year—a demand assumed constant between 2000 and 2040.[4] Thus, demand for red meat and dairy products is projected to grow at the same rate as population.

Since the Assessment in 1979, there has been a marked change in per capita consumption of red meat. Recent scientific studies linking diet to coronary heart disease and other maladies concluded that animal fat plays a role in increasing risk of heart attack. Consumers responded to these findings by reducing annual consumption of beef and pork and increasing consumption of poultry and fish. Beef producers responded to the change by altering cattle production to reduce beef fat content. This was accomplished by reducing the length of feedlot stays and boosting forage consumption. It is too early to determine whether red meat consumption will recapture market

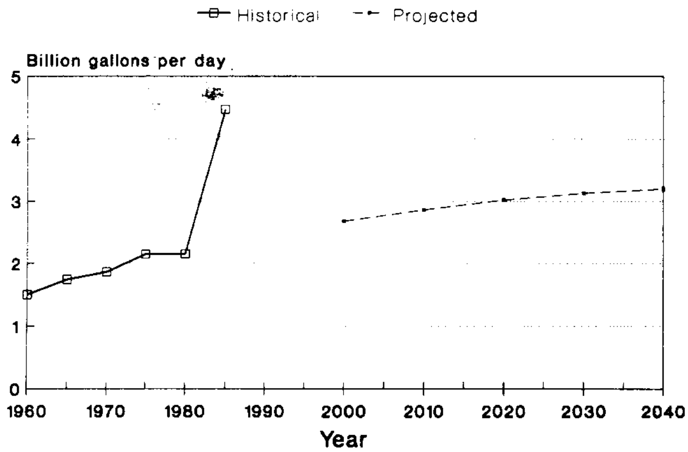


Figure 33.—Livestock watering, total freshwater withdrawals.

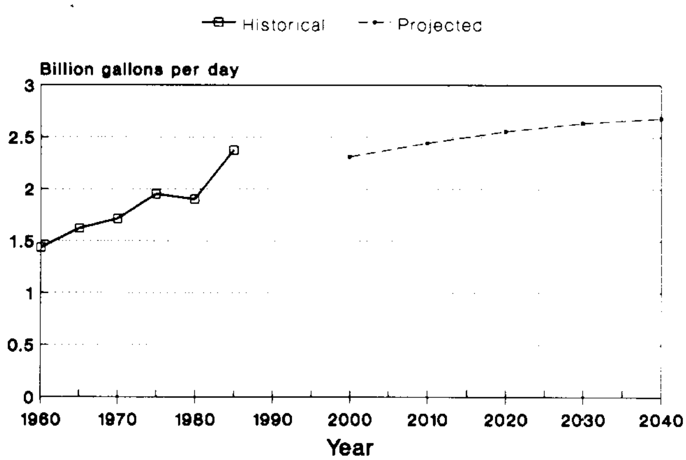


Figure 34.—Livestock watering, total freshwater consumption.

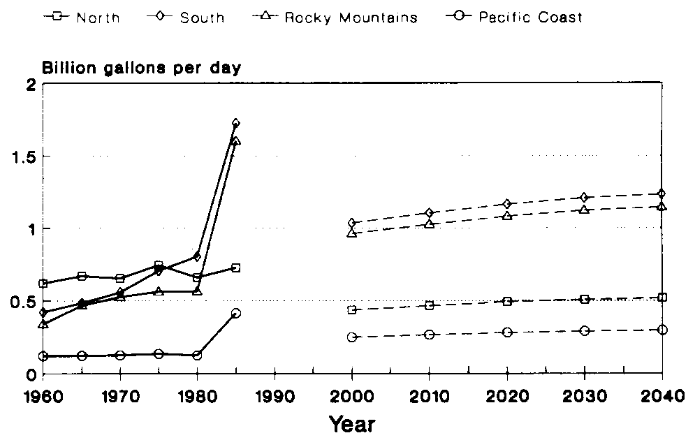


Figure 35.—Livestock watering, freshwater withdrawals by region.

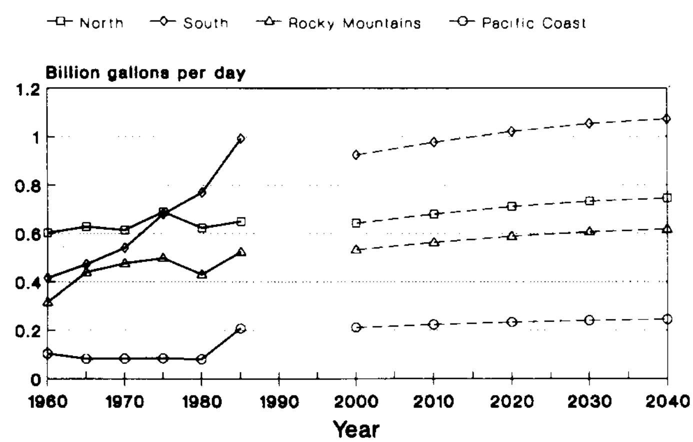


Figure 36.—Livestock watering, freshwater consumption by region.

share and rise back to previous consumption levels. If this occurs, the cattle population will increase and livestock water use levels will be affected. Joyce (1989) discusses the relationship of domestic beef production and imports to future demands for red meat.

Projections of livestock water use reflect historical trends where aquaculture was not a significant component of livestock water use. If a permanent change in meat demand occurred so that poultry and fish consumption remains high compared to red meat, then projections of withdrawals reported here will most certainly underestimate future withdrawals (figs. 33 and 35).

The main use of withdrawals for fish farming is to refill existing ponds and fill new ponds. Pond levels are lowered as part of the production cycle; water drained off typically moves to surface streams. This is why livestock water consumption does not show the large increase that withdrawals show. Pond evaporation is the main consumptive water use. If aquaculture continues to grow as in the past five years, withdrawals will increase significantly by 2000.

COMPARISON WITH PREVIOUS PROJECTIONS[5]

Forecasts of water use were made over the past three decades by many agencies and commissions. Notable examples are studies by the Senate Select Committee on National Water Resources (U.S. Congress 1961), Wollman and Bonem (1971) in a Resources for the Future publication, The National Water Commission (1973), and the Water Resources Council (1978).

When the Second National Water Assessment (Water Resources Council 1978) was released, there was much discussion about its projections because they deviated significantly from projections made by the Senate Select Committee (SSC), the National Water Commission (NWC), and Wollman and Bonem (RFF). Viessman and DeMoncada (1980) presented a comparison of withdrawal and consumption projections to the year 2000 from SSC, RFF, NWC and WRC. They noted that all projections have underlying assumptions. For the most part, population, economic activity, and technological factors were important factors determining projected water use levels. They also pointed out that projections such as those in the studies cited are only intended to guide decisions and are not to be accepted as "hard" forecasts of the future. The same point was made earlier in this chapter for projections presented here. This section reviews previous projections and compares them to the projections updated in this Assessment in light of the withdrawal and consumption data gathered by USGS since previous studies. The year 2000 will be used as the focus for making comparisons because that year is common to all projections.

Senate Select Committee on National Water Resources.—The SSC estimated that total freshwater withdrawals in 2000 would reach 888.4 bgd. This is about 2.5 times total withdrawals in 1975. Consumption in 2000 was projected at 156 bgd, an increase of 62% over the 1975 level. A medium level population projection of the 48 contiguous states was used—244 million in 1980 and 329 million in 2000. Other assumptions were: the economy would grow at the same rate as in the past; adequate water supplies will be available under prevailing general pricing policies; industrial water use will grow at a high rate; and with the exception of improved irrigation efficiency, existing inefficient methods of water use will continue.

Projections by Wollman and Bonem.—The RFF study of water use was an outgrowth of work done by the SSC. Projections were made for 1980, 2000, and 2020 based upon assumptions of high, medium, and low rates of economic growth. Wollman and Bonem state that their findings were neither predictions nor projections. Rather, they were an attempt to portray the problem likely to be encountered if current trends continue. Estimates of withdrawals and consumption were based on projected patterns of population and economic activity in conjunction with appropriate water use coefficients. Population projections for 1980, 2000, and 2020 were used as the basis for projecting levels of water use in the U.S. Population projections were used to estimate municipal water use and waste, waste collection costs, rural domestic requirements, and to update projections of the food processing industry. It was assumed that regional economic activity would grow or decline relative to growth of the national economy at rates consistent with trends at that time. Estimates of GNP and other indices were used to arrive at projections of other industrial water uses. The net result was that withdrawals were projected to be 563 bgd under the medium growth scenario and 1128 bgd under the high growth scenario. Consumption was projected to be 148 and 190 bgd respectively for the medium and high scenarios.

The National Water Commission Projections.—In its 1973 report on Water Policies for the Future, the NWC commented that variables in policy and technology combined with hard-to-forecast growth rates in population and economy tend to cast doubts on projections of future water needs based only on past trends. They devised a variety of alternative futures in which factors affecting water use were explicitly considered. The NWC analysis incorporated four levels of population and a variety of assumptions about water demand and supply variables. The result was a set of three trends in withdrawals and consumption. Withdrawals were 1510, 1000, and 490 bgd respectively for the high, medium, and low trend scenarios. Consumption projections were 185 and 125 bgd for the high and low trends.

Compared to other projections, the NWC high scenario is by far the largest. Assumptions inherent in this scenario called for no change in industrial self-supplied and thermoelectric steam cooling withdrawals and a continuation of once-through cooling with no limitations on temperatures of waste flows discharged to streams. The NWC report acknowledged that substantial reductions in withdrawals would result from adoption of advanced cooling technologies. Other scenarios use this cooling technology to varying degrees.

Second National Water Assessment.—The second National Water Assessment released in 1978 concluded that many changes occurred since its first report in 1968. It was noted that population had not grown at the rate anticipated in the previous assessment and that greater awareness of environmental values, water quality, groundwater overdrafts, limitations of available water supplies, and energy concerns were having a pronounced impact on water resources management.

The WRC water use projections called for withdrawals of 306 bgd and consumption of 135 bgd by the year 2000. The amount of water withdrawn for manufacturing is projected to decrease by about 60% by 2025, accompanied by an increase of 137% in consumption. Withdrawals for power generation are anticipated to decrease by about 24% by 2025 due to conversion from once-through cooling to cooling towers. This decline is expected to be accompanied by a substantial increase (600%) in water consumption. However, because consumption was less than 0.5% with once-through cooling, an increase of the magnitude projected would still leave consumption below 3% of total withdrawals. The first national water assessment conduced by the WRC was released in 1968. Withdrawals were projected to be 804 bgd and consumption 128 bgd in the year 2000.

In a study of national water supply problems, the General Accounting Office (GAO 1977) questioned WRC's assumptions on industrial water withdrawals because stringent assumptions of the Clean Water Act may be modified. Further, GAO believed that industries may find it cheaper to continue using water on a once-through basis with wastewater treatment than to construct costly recycling facilities.

The WRC also projected that irrigation water withdrawals are expected to decline about 8% from 1975 to the year 2000 because of increasing depletions of deep groundwater in southwestern regions. Consumptive use in that sector was also expected to increase less than 2% because of water use conflicts and the likelihood that no new large-scale irrigation projects will be publicly funded. GAO challenged these premises, citing that in northerly regions, water and agricultural conditions were more suitable for irrigation increases than in the Missouri and Souris-Red-Rainy water resource regions. They also challenged WRC assumptions concerning slower growth in food and fiber requirements and that no new large-scale irrigation projects would come to pass.

COMPARISON OF THE DEMAND PROJECTIONS

Historical freshwater withdrawals and consumption are plotted along with projections from various sources in figures 37 and 38. Data for 1980 and 1985 are also plotted on the chart. These more recent data clearly show that withdrawals and consumption trends have followed the WRC 1978 water projections. Analysis of the WRC assumptions reveals that in the past decade, many of their assumptions have been upheld—more so than the GAO report believed. The result appears to be a major structural change in long-term trends for withdrawals and consumption, stemming largely from changes in national water resource policies due to legislation of the early 1970s.

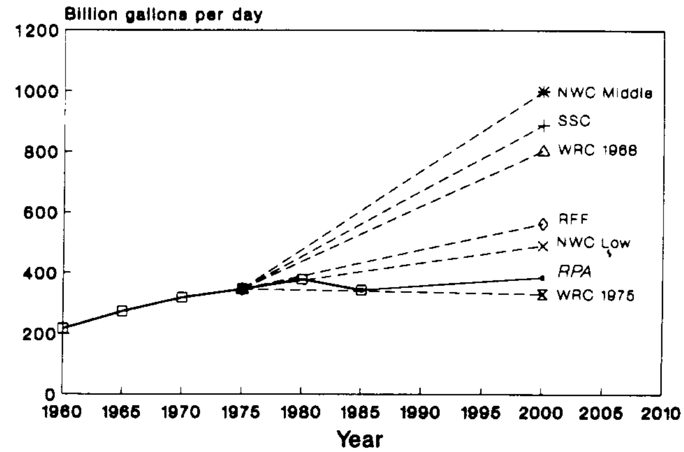


Figure 37.—Freshwater withdrawals, 1960-1985, with projections from other studies to the year 2000.

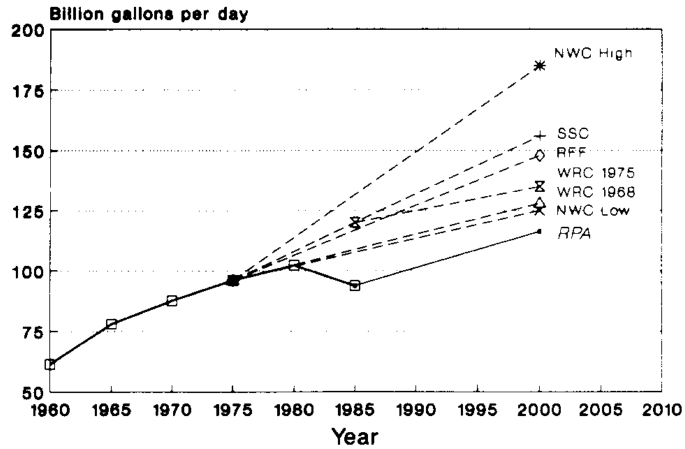


Figure 38.—Freshwater consumption, 1960-1085, with projections from other studies to the year 2000.

Osborn et al. (1986) studied the SSC and WRC projections from the first national water assessment. They compared projections of water use with estimates of actual use in 1980 to assess the accuracy of water use forecasts. They concluded that water use projections must be based on methods that help explain effects of water demand determinants on use. Further, they concluded that a detailed analysis of factors that have influenced recent trends in withdrawals and consumption was needed. Recent federal planning guidance (Water Resources Council 1983) has paralleled these findings, calling for specification of factors underlying historically observed patterns of water use and requiring application of statistical techniques to estimate relationships between water use and explanatory variables. The demand analyses in this report have followed those guidelines.

SUMMARY

Total demand measured by withdrawals amounted to 343.7 bgd in 1985 and is projected to rise to 526.6 bgd in 2040. Surface sources provided 75% of withdrawals in 1985; this is projected to rise to 78% in 2040. Total demand measured by consumption amounted to 93.8 bgd in 1985 and is projected to rise to 143.1 bgd in 2040.

Irrigation is the largest withdrawal use and also the largest consumptive use of water today and is projected to remain the largest consumptive use to 2040. Consumption by irrigation in 1985 totaled 73.8 bgd and is projected to rise to 101.1 bgd by 2040. The largest demands for irrigation will be in the Rocky Mountains and Pacific Northwest and the fastest growth will be in the North.

Thermoelectric steam cooling is the second largest withdrawal use of water and is projected to become the largest withdrawal use by 2040. Withdrawals for cooling in 1985 totaled 130.4 bgd and are projected to increase to 228.3 bgd in 2040 due mainly to the projected increase in electricity needed by an expanding economy. Coal will remain the predominant fuel throughout the projection period.

Demands projected in this Assessment for the year 2000 are lower than levels projected in previous studies. However, recent demand data indicate a structural change in demand due to pollution control requirements of the Clean Water Act. Projections in this report account for the structural change.

Implications of demand projections presented in this chapter will be discussed further in Chapter 6. But first, the quantity of water available for use—water supply projections—must be presented (Chapter 4) and comparisons made between projected demands and supplies to identify regions and timeframes where water shortages are likely to occur if water resource management continues as it has in recent years (Chapter 5).

NOTES

1. Survey procedures in the first two studies (MacKichan 1951 and 1957) focused on withdrawals. Very little data on consumption was provided. MacKichan and Kammerer (1961) provided the first estimates of consumption by use and by state. Because water that is withdrawn but not consumed is returned to streams after use, it is available for subsequent withdrawals downstream. Water that is consumed, on the other hand, is not available for withdrawal and use downstream. Hence, consumption data is the more limiting for estimating demand. Analyses begin with 1960 data, the first year specific consumption data is available.

2. Electrical generating capacity in the U.S. could be increased 15% without building new power plants and the cost of operating generators could be cut 60% if the newly-invented "high temperature" superconducting materials can be made practical (Rensberger 1988). These estimates were made by researchers at the Argonne National Laboratory in collaboration with five other major energy research centers.

3. The difference between the 105 gpd figure cited here and the 184 gpd figure cited in the municipal self-supplied section is that the 184 gpd includes total volume of water supplied by central systems to commercial and industrial establishments and for public uses.

4. Veal and lamb, the two other components of red meat demand, are projected at a constant four pounds per capita per year over the projection period. Pork consumption is also projected to remain constant at 60 pounds per capita annually. See Darr (1989) for additional details.

5. Information about historical studies in this section of the report is drawn largely from Viessman and DeMoncada (1980). Data for 1980 and 1985 come from Solley et al. (1983) and Solley et al. (1988).

CHAPTER 4: THE SUPPLY SITUATION FOR WATER

The supply of water has two components—quantity and quality. The focus of this chapter is on projecting water supplies and related land resources to 2040. This chapter begins with a discussion of the quantity aspects of supply and quantity projections over time. Effects of irregular occurrences of oversupply (floods) on land and developments are reviewed. A discussion of projected water quality follows. The chapter concludes with an overview of trends in the supply of wetlands. Existence of wetlands is related both to water supply and water quality trends.

WATER SUPPLY QUANTITY

Analysis of the supply of water is different from analysis of the supply of other renewable resources. For timber, forage, outdoor recreation and wilderness, and wildlife and fish, managers can take steps to increase the quantity of the resource available for use in the long run. For water and minerals, on the other hand, supplies are essentially constant over time. Minerals are a "stock" resource[1] which, for all practical purposes, cannot be renewed in the period covered by this Assessment. Water, on the other hand, is a renewable resource in the sense that rain falls each year to replenish surface water and groundwater. Yet, there is little that water managers can do to influence the quantity of rain that falls in a given year[2]. So, in a sense, water supply is a hybrid—a renewable resource because rain falls each year and a stock resource because the quantity of precipitation expected each year is the long-term average incapable of being altered significantly over wide areas by managers.

In Chapter 2, the current resource situation for water was discussed. A generalized water budget was presented that accounted for groundwater depletion rates and instream flows necessary for optimum wildlife and fish habitat (table 2). A generalized budget was developed based on supply (the average annual streamflow) expected in a year of average precipitation (the annual precipitation expected to be exceeded 50 percent of the time). In drier years, less precipitation and less annual streamflow are expected. For comparison, two additional supply scenarios are presented (table 12). The 80% level represents average annual streamflow expected with an annual precipitation level that is expected to be exceeded 80% of the time (8 out of 10 years). The 95% level represents average annual streamflow expected with an annual precipitation level that is expected to be exceeded 95% of the time (19 out of 20 years). Annual precipitation rates and streamflows lower than the average can be expected 5 years in 10. Annual precipitation rates and streamflows lower than the 80% level can be expected to occur 2 years in 10. Annual precipitation rates and streamflows lower than the 95% level can be expected 1 year in 20. So the 80% and 95% precipitation levels represent droughts of two different severities.

ADEQUACY OF INSTREAM FLOW[3]

Optimal habitat.—Sixty percent of average flow is the base flow recommended to provide excellent to outstanding habitat for most aquatic life during their primary periods of growth and for the majority of recreation uses (Tennant 1975). Channel widths, depths, and velocities at this base flow will provide excellent aquatic habitat. Most normal channel substrate will be covered with water, including most shallow riffle and shoal areas. Side channels that normally carry water will have adequate flows. Few gravel bars will be exposed and the majority of islands will serve as wildlife nesting, denning, nursery, and refuge habitat. The majority of stream banks will provide cover for fish and safe denning areas for wildlife. Pools, runs, and riffles will be adequately covered with water and provide excellent feeding and nursery habitat for fishes. Riparian vegetation will have sufficient water. Fish migration is no problem in any riffle areas. Water temperatures should be adequate for fish. Invertebrate life forms should be varied and abundant. Water quality and quantity should be suitable for fishing and floating canoes, rafts, and larger boats, and general recreation. Excellent to outstanding stream aesthetics and natural beauty will be maintained.

Good survival habitat.—Thirty percent of the average flow is a base low recommended to sustain good survival habitat for most aquatic life forms (Tennant 1975). At this base flow level, channel widths, depths, and velocities will generally be satisfactory. Most substrate will be covered with water except for very wide, shallow riffle or shoal areas. Most side channels will carry some water. Most gravel bars will be partially covered with water and many islands will provide wildlife nesting, denning, nursery, and refuge habitat. Stream banks usually will be sufficient to provide cover for fish and wildlife denning habitat. Many runs and most pools will be deep enough to serve as cover for fishes. Riparian vegetation will not suffer from lack of water. Large fish can move over most riffle areas and water temperatures are not expected to become limiting in most stream segments. Invertebrate life is reduced but not expected to become a limiting factor to fish production. Water quality and quantity should be good for fishing, floating, and general recreation, especially with canoes, rubber rafts, and smaller, shallow draft boats. Stream aesthetics and natural beauty will generally be satisfactory.

Poor survival habitat.—Tennant (1975) described conditions for 10% of average flow. This flow rate is the minimum instantaneous flow recommended to sustain short-term survival habitat for most aquatic life forms. Channel widths, depths, and velocities will all be significantly reduced and aquatic habitat degraded. Stream substrate or wetted perimeter may be about half exposed except in wide, shallow riffle or shoal areas where exposure could be higher. Side channels will be severely or totally dewatered. Gravel bars will be substantially

Table 12.—Expected annual stream outflows (billion gallons per day) resulting from variations in precipitation levels and instream flow requirements by water resource region

Water resource region	Expected average annual stream outflow[1] Mean[3]	80%[4]	95%[4]	Instream flow requirement[2] Mean	Dry
New England	76.8	61.4	46.8	69.0	46.1
Mid-Atlantic	93.9	72.3	57.3	68.8	56.3
South Atlantic-Gulf	207.5	147.3	110.0	188.7	124.5
Great Lakes	73.9	57.6	45.1	63.9	44.3
Ohio[5]	137.7	108.9	79.9	122.0	82.6
Tennessee	42.9	37.3	32.6	38.5	25.7
Upper Mississippi[6]	79.8	59.8	42.3	69.7	47.9
Lower Mississippi[7]	463.7	301.4	213.3	359.0	278.2
Souris-Red-Rainy	7.2	4.0	2.2	3.7	2.2
Missouri	51.7	34.6	20.2	34.0	15.5
Arkansas-White-Red	57.2	33.7	19.4	46.2	17.2
Texas-Gulf	31.2	13.4	6.9	22.9	9.4
Rio Grande	2.2	.6	.4	2.3	0.7
Upper Colorado	7.9	5.5	3.1	8.0	2.4
Lower Colorado[8]	1.6	1.4	1.2	6.9	0.5
Great Basin	4.6	2.8	2.1	3.4	1.4
Pacific Northwest	279.8	232.2	195.9	214.0	169.7
California	69.4	43.0	28.4	32.6	20.8
Alaska	921.0	801.3	709.2	797.3	553.6
Hawaii	13.6	9.9	7.6	11.8	8.2
Caribbean	4.8	3.3	1.5	4.2	2.9

[1]*The average annual stream outflow expected given three different expectations about precipitation levels.*

[2]*The instream flow requirements for the mean precipitation expectation provide optimal fish and wildlife habitat (Water Resources Council 1978). Instream flow requirements for good survival habitat in dry years are assumed to be 60% of average annual streamflows arising from the mean precipitation level for the New England, Mid-Atlantic, South Atlantic-Gulf, Great Lakes, Ohio, Tennessee, Upper and Lower Mississippi, Pacific Northwest Alaska, Hawaii, and Caribbean regions. In the other regions, the instream flow requirements for good survival habitat in dry years are assumed to be 30% of annual streamflow arising from the mean precipitation level (Tennant 1975 and Flickinger 1987).*

[3]*Average annual streamflows for the year of average precipitation are from Foxworthy and Moody (1986, table 7).*

[4]*Average annual streamflows for the 80-percent and 95-percent precipitation expectations were estimated by computing the percentage reductions in supply presented in U.S. Forest Service (1981, table 7.10) and applying those to the mean flow rates from Foxworthy and Moody.*

[5]*The Ohio region estimates exclude outflows from the Tennessee region.*

[6]*The Upper Mississippi region estimates exclude outflows from the Missouri region.*

[7]*The Lower Mississippi regions estimates represent conditions in all the upstream regions (Ohio, Tennessee, Upper Mississippi, Missouri, and Arkansas White-Red regions).*

[8]*The estimates for the Lower Colorado region represent conditions in both the Upper and Lower Colorado regions.*

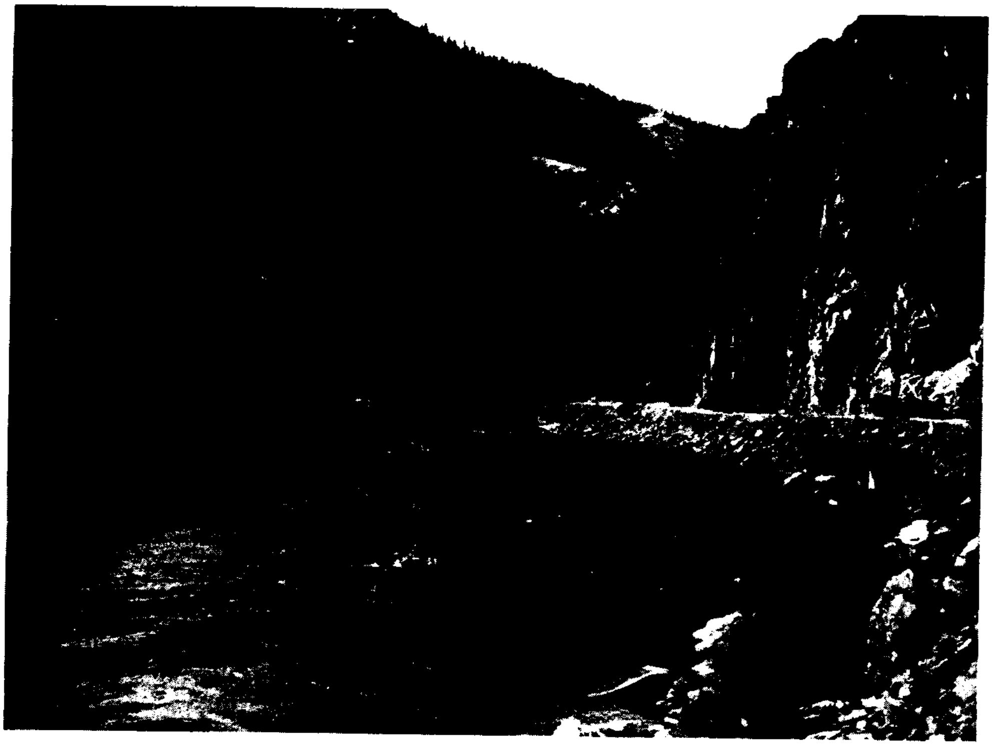
Source: After U.S. Forest Service (1981, table 7.10)

dewatered and islands will usually no longer function as wildlife nesting, denning, nursery, and refuge habitat. Stream bank cover for fish and fur animal denning habitat will be severely diminished. Many wetted areas will be so shallow they no longer serve as cover. Fish will generally be crowded into the deepest pools. Riparian vegetation may suffer from lack of water. Large fish will have difficulty migrating upstream over many riffle areas.

Water temperature often becomes a limiting factor, especially in the lower reaches of streams in July and August. Invertebrate life will be severely reduced. Fishing will often be very good in deeper pools and runs because fish will be concentrated. Many fishermen prefer this level of flow. However, fish may be vulnerable to over harvest. Floating is difficult even in a canoe or rubber raft. Natural beauty and stream aesthetics are badly degraded. Most streams, at times, carry less than 10% of the average flow. From this description, it is plain that if streamflows less than 10% of the mean annual streamflow occur for several weeks, this low flow rate will usually have serious adverse effects on aquatic habitat.

Instream Flow Rates and Regional Water Balances

When instream flow requirements for optimal habitat (Water Resources Council 1978) and good survival habitat (Tennant 1975 and Flickinger 1987) are compared with instream flows based upon precipitation expectations (table 12), several points are worth noting. First, even with average precipitation, the Rio Grande, Upper



Instream flow levels providing good survival habitat for wildlife and fish also provide sufficient water for fishing, floating, and general recreation.

and Lower Colorado, and Great Basin areas will not have enough water instream to meet optimal habitat requirements. Second, and a counterpoint to the statement just made, only the Texas-Gulf and Rio Grande regions cannot provide good survival habitat in drought years. Although habitat is not optimum, flows in dry years in western regions nevertheless provide good habitat for survival. Only in the Rio Grande water resource region will dry-year precipitation at less than the 80% level not provide satisfactory survival habitat. Third, in the year of average precipitation, flows in eastern water resource regions provide optimal fish and wildlife habitat. Even in the 80% year, flows are significantly greater than minimums necessary for good survival habitat. Fourth, precipitation expected 1 year in 20 will result in flows less than those necessary for good survival habitat in the South Atlantic-Gulf, Ohio, Upper and Lower Mississippi, Texas-Gulf, Rio Grande, Hawaii, and the Caribbean water resource regions.

To this point, discussion has focused on annual precipitation and average flow rates. It is well known, however, that precipitation is not distributed uniformly throughout the year in many parts of the U.S. Thus, there are often times when suboptimum flow rates occur. Many water resource regions have main streams and tributaries whose flows are well below the good survival habitat level at some time during the year—even during a year of relatively abundant precipitation. Many streams also approach or go below the minimum short-term survival flow level.

Daily and seasonal flow variations in streams are not only a function of precipitation, but also a function of water control practices associated with reservoirs and dams. There are four major uses of stream flows that are served by reservoirs and dams. They include flood control, irrigation, navigation, and generation of electric power.

In the western regions, because of poor seasonal distribution of precipitation (much falling as snow), reservoirs have been built to capture springtime runoff primarily for irrigation and flood control purposes. Instream flow rates in western regions are rarely optimal, but also seldom less than the levels necessary for good survival habitat. Only the Texas-Gulf and Rio Grande regions cannot provide good survival habitat when precipitation falls to the 95% level (more precipitation expected in 19 out of 20 years).

Water control practices associated with dams on the Ohio and Mississippi Rivers to enhance navigation cause a more serious impact on the adequacy of instream flows. Good survival habitat cannot be maintained in exceptionally dry years. Navigation water releases are a function of barge traffic. When barges are not using the locks, minimal water may be released to assure sufficient volume for commercial needs in dry periods.

Hydroelectric releases are a function of electricity needs. Hydropower reservoir discharges vary widely during the day in response to fluctuating demand for electricity. Because of increased use of air conditioning and the switch to electricity as a preferred energy source in the mid-1970s, peak electricity demands on midsummer weekday afternoons often result in water releases for hydroelectric purposes that are many times the off-peak release rates. In the mid- and southern Appalachians, reservoir releases for recreation are becoming more prevalent. White water rafting schedules are coordinated among outfitters and reservoir operators such as the Corps of Engineers to guarantee quality recreation experiences. High release rates are common on weekend mornings.

All these factors contribute to wide daily or hourly fluctuations in flow rates in rivers. Fluctuations can have negative as well as positive impacts on wildlife and fish habitat and other instream water uses. In recent years, maintaining adequate wildlife and fish habitat has become an important factor that reservoir operators must consider when planning operations directed primarily at satisfying other needs.

The effect of forests and other vegetation on runoff and streamflows, especially in reducing wide variations in flow, has long been known. Troendle (1983) and Douglas (1983) summarized the state-of-the-art about using vegetation management to influence timing of streamflows. They concluded that timber harvesting patterns and frequencies can be planned to trap snow at high elevations and extend snowmelt into the summer. The result is that high springtime peak flows are reduced. It has also been demonstrated that maintaining vegetation keeps soil infiltration and percolation rates higher than on bare sites. Thus, less runoff occurs and storm flow peaks are reduced. Many suburban areas have adopted zoning regulations in recent years specifying the use of vegetated areas to delay or temporarily store runoff and cut peak storm flows. In rural settings, managing riparian vegetation accomplishes the same objective. These nonstructural methods are now viewed as realistic alternatives to structural methods, such as dam construction and channelization, for reducing wide swings in streamflows.

FLOODING

The principal question in the preceding discussion about adequacy of instream flows focused on water shortages. In contrast, flooding impacts result from water excesses. In 1985, despite state-of-the-art communications and weather forecasting models, 44 people were killed by floodwater and property damage totalled more than $366 million (USGS 1986, table 1). Not included in these estimates was Hurricane Elena, which caused hundreds of millions of dollars in damage and resulted in the evacuation of a million people.

Almost half of all flood damages are to agriculture. Crops and livestock are destroyed and soil is washed away. Two-thirds of the total flood damages occur in rural areas. In urban areas, flood damages destroy homes and places of employment. The Federal Emergency Management Agency (FEMA) determined that about 20,000 of the 34,000 communities in the United States have some flood hazard areas (FEMA 1986). Flood-related costs also include funds spent for relief and reconstruction, lost productivity, and the general disruption of local and regional economies during and after a flood.

The impact of flooding on wildlife, fish, and ecosystems is mixed. In upstream areas, wildlife food and habitat are often washed away or covered with flood debris causing severe damage to natural systems. In some cases, however, flooding may transport beneficial nutrients that improve downstream ecosystems. For example, when the Bonnie Carret Spillway on the Mississippi River above New Orleans is opened (a mile-long series of floodgates) to divert floodwater into Lake Pontchartrain, shrimping in the lake that year is adversely affected due to the silt and the decline in salinity. However, two or three years after a spillway opening, nutrients brought by flood waters work their way up in the ecosystem and shrimp populations and sizes soar for a year or two.

Since 1941, annual flood damages in the U.S. have not been less than $50 million. Average annual damages between 1940 and 1970 exceeded $500 million (1984 dollars). Annual damages have exceeded $5 billion several times since 1970, the highest being $12 billion in 1972 when Hurricane Agnes devastated the Susquehanna River basin.

Despite increasing trends in annual flood damages,[4] there is no evidence that storms are increasing in magnitude or frequency. Increases in damages result from intensified development in flood-prone or flood-susceptible areas (Water Resources Council 1978) and from concentrating higher-valued agricultural production on flood plains (Department of Agriculture 1987).

Average annual flood damage per square mile varies considerably among water resource regions. The wide variation is related partly to weather patterns, partly to regional stream character, and partly to values of streamside property subjected to flooding.

Floods have serious effects on humans outside the flooded area. Floods overrun sewage treatment facilities often located along streams. Resulting contamination of flood waters and everything flood waters touch impacts public health in both physical and psychological senses. Many problems continue long after flood waters recede. The yearly loss of life from floods has usually been less than 100, but exceeded 500 in 1972.

Floods can be devastating or beneficial to agricultural interests. They can wipe out crops and dump tons of infertile sand, gravel, clay, and other debris on productive lands. Floating debris, such as trees and parts of buildings, can cause significant damage to bridges, culverts and roads, and other structures in the floodplain. Loose debris that is carried in floods often forms dams when trapped against bridges. These obstructions often cause flood waters to carve out alternate routes past the flow constriction, thus eroding abutments and approaches to the bridges or damaging additional structures as a pool forms behind the dam. If the debris dam breaks, such as when a bridge is washed off its supports, the resulting surge of water and debris can cause additional damage to structures downstream. On the positive side, slow-moving floods can deposit fertile, highly-productive sediments on cropland and wetlands. The infusion of nutrients can boost crop, wildlife, and fish production in subsequent years.

Average annual flood damages are projected to increase to $6.7 billion (1987 dollars) by the year 2000

Two-thirds of annual flood damages occur in rural areas.

(Forest Service 1981). Agricultural damages are expected to be more than $2.7 billion in 2000 while urban damages are projected to increase by 36% to $2.5 billion. All other damages are expected to average about $1.5 billion. By 2040, total annual damages are projected to reach $9.7 billion. It was not possible to project deaths due to flooding because past annual totals vary widely.

Regional estimates and projections of flood damages are closely correlated with population densities. Highest damages are likely to occur in the South Atlantic-Gulf, California, and Missouri regions. Agricultural damages are most important in the Upper and Lower Mississippi and Missouri regions. However, they are also significant in the Ohio, Arkansas-White-Red, Texas-Gulf, Great Basin, California, and Pacific Northwest regions. Urban damages will be more prominent in California, New England, Mid-Atlantic, and the Great Lakes regions.

SUMMARY

This analysis of water supply quantity includes no assumptions about water consumption by offstream uses. That information is presented in Chapter 5 where supply and demand projections are compared. The quantity of precipitation is a stochastic variable in any given calendar year; consequently, so is streamflow. If precipitation is below normal, the chance of detrimental impact on fish and wildlife habitat and other instream uses increases. If precipitation is above normal, the chance of detrimental impact due to flooding increases. No long-term trends in precipitation have been observed this century; consequently, the quantity of water supplies has no discernable trend. Annual fluctuations are sufficiently large to make water resource management a challenge in spite of the absence of a long-term trend.

WATER SUPPLY QUALITY[5]

The natural quality of water in the Nation's streams and lakes is largely a reflection of the characteristics of the land and vegetation from which the water flows. Because of natural variations in land and vegetation, water quality in streams and lakes is neither uniform nor static. Water is constantly moving, even in lakes and reservoirs. As it moves, its quality changes. Quality is influenced by natural features, including geology, and topography, soil, and vegetation.

The natural quality of water is also affected by the actions of people. These include road construction, urban development, farming, mining, timber harvesting, livestock grazing, and discharge of municipal and industrial wastes. Acid deposition also affects natural water quality, both near and far from the point where chemicals are released to the atmosphere.

Water is often used and reused several times and for many purposes during its journey to the sea. Water quality can be improved or degraded as it is used and returned to a stream. Because water is ever-moving and ever-changing, quality is difficult to inventory and measure. Without good inventories of water quality over time, making projections is virtually impossible.

It is important to recognize that water quality determines its useability for specific purposes. Water quality can be suitable for one purpose but not be suitable for another. For example, a clear alpine lake may be excellent for aesthetic enjoyment and trout fishing, but very poor for swimming because the water temperature rarely exceeds 50° F. Another example is natural water quality that is ideal for swimming and for fish, wildlife, and livestock consumption, but unsatisfactory for a particular industrial use because of dissolved solids such as iron.

BASELINE WATER QUALITY FROM FORESTS AND RANGELANDS

To show the relationship of water quality to its natural environment, water quality data from relatively undisturbed forest and range land watersheds is displayed by division, province, or section as described by Bailey (1976) (USDA Forest Service 1976)(table 13). Bailey's hierarchical system for land classification begins with the largest, broadest definition as a domain, and proceeds downward in size and in specificity through division and province to section, which is the smallest and most discrete unit. Each section describes a more or less continuous geographical area and is characterized by distinctive fauna, climate, landform (including drainage pattern), soil, and vegetation that distinguishes it from adjacent sections. Within such sections, ecological relationships between plants, soil, and climate are essentially similar, thus similar management treatments give comparable results and have similar effects on the environment. Ecoregions are considered to be biological and physical areas of specific potential.

The watersheds where quality data were collected were small (10 to 200 square miles), relatively undisturbed areas (no major land disturbing activities within at least the last 5 years). Each contained more than 90% forest or range land or both and had a minimum of 5 years (10 years when possible) of water quality records that included total dissolved solids, dissolved oxygen, water temperature, and suspended sediment. These data from STORET[6], show how baseline water quality parameters vary by ecoregion (table 13). Water quality in all of the undisturbed watersheds exceeds the minimum water quality standards of most states. There is, however, a substantial amount of variability in various measures of quality among divisions, provinces, and sections.[7]

The baseline water quality levels in table 13 represent the best water quality that can be attained from managing forests and rangelands. Thus, maintaining this quality in streams becomes the goal for forest and range managers. Management activities often result in changes in water quality. Some changes are short-term and others longer-term. Some changes have only a local effect; others are more regional. For example, timber harvesting in the South is usually followed by regeneration the following year. The speed with which vegetation reoccupies the harvested site means that bare soil is rarely exposed for more than three years. Consequently, harvesting and regeneration operations only impose a short-term effect upon water quality from site runoff. Timber harvests on southern National Forests average 40 acres in size. Water quality effects from runoff from such a small area will also tend to be localized. Through careful planning and attention to details in implementation, significant long-term adverse water quality effects from land management activities can be avoided or mitigated.

APPROACHES TO IMPROVING WATER QUALITY

The Clean Water Act determines how the Federal government and states regulate point- and nonpoint-source pollution. Although amended in 1977, 1981, and 1987, basic directives embodied in the original 1972 Act continue to guide the Nation's water pollution control programs.

Point Sources

Two types of approaches were established by the Act for controlling pollution from point sources. One is the technology-based approach and the other is a water quality-based approach. Technology-based controls consist of uniform EPA-established standards of treatment that apply to industries and municipal sewage treatment facilities. These effluent standards are limits on the amounts of pollutants that may be discharged to streams. Limits are derived from technologies available for treating wastewater and removing pollutants. Limits are applied uniformly to every facility in an industrial category regardless of stream condition into which the effluent is discharged.

Water quality-based controls, on the other hand, are based on water quality in the stream receiving the effluent. This approach relies on water quality standards set by the states on the basis of stream use (e.g. fishing and swimming) and criteria (or limits on pollutants) necessary to protect those uses. Individual discharge requirements are based on effluent quality needed to ensure compliance with water quality standards. Details on how these approaches are being implemented for point sources are described in Environmental Protection Agency (1987).

Point-source pollution is generated primarily by industries and municipalities and is generally incidental to forest and range lands. However, some operations associated with forest and range lands do generate point-source pollution. Some are relatively permanent and generate pollution on a year-round basis, and others are temporary or seasonal.

Common sources of potential point-source pollution on forest and range lands include rock crushing and gravel washing, log sorting and storage, wood processing, mining, food processing, developed recreation sites, feedlots, boats, remote work centers (logging and mining camps), summer homes, and organization camps. These point-sources of pollution are found in every region, though not all are considered pollution problems in all basins. In fact, pollution from these sources is generally not significant on a national basis, but can be

Table 13.—Concentrations of selected water quality parameters (at three percentiles of the data distributions) from undistributed forest and range watersheds in the United States, by division, province, and section

Division, province, and section	Total dissolved solids (mg/l)[1] Percentile[4]			Dissolved oxygen (% saturation)[2] Percentile			Water temperature (degrees centigrade) Percentile			Suspended sediment (mg/l)[3] Percentile		
	15	50	85	15	50	85	15	50	85	15	50	85
1300 Subartic												
M1310 Alaska Range	50	90	120	90	95	100	.0	6.0	13.0	1	3	40
											(100)	(500)[5]
1320 Yukon Forest	43	63	80	95	98	100	.0	3.8	7.5	10	20	40[6]
2100 Warm Continental												
2110 Laurentian Mixed Forest												
2111 Spruce-Fir	62	91	120	79	90	104	.0	10.0	15.5	0	4	14
2112 Northern Hardwoods-Fir	68	104	132	77	87	98	.0	8.0	20.0	2	4	10
2113 Northern Hardwoods	25	29	35	89	97	105	.0	8.0	17.0	1	3	8
2114 Northern Hardwoods-Spruce	16	20	25	86	92	100	.0	4.0	19.0	1	2	5
M2110 Columbia Forest												
M2111 Douglas-fir Forest	70	100	150	85	91	97	3.0	4.0	9.0	10	40	60
M2112 Cedar-Hemlock-Douglas-fir	48	52	54	85	95	105	.0	63.0	11.0	2	5	10
2200 Hot Continental												
2210 Eastern Deciduous Forest												
2211 Mixed Mesophytic	14	16	18	87	93	100	4.5	10.0	16.0	2	4	17
2212 Beech-Maple	206	368	556	80	94	100	4.0	10.5	23.0	2	24	95
2213 Maple-Basswood + Oak Savanna	239	294	313	86	96	110	1.0	9.0	17.0	14	48	734
2214 Appalachia Oak	22	25	29	89	97	105	2.0	6.0	15.0			
2215 Oak Hickory	44	62	156	84	94	105	7.0	15.0	23.0	2	8	40
2300 Subtropical												
2310 Outer Coastal Plain Forest												
2311 Beech-Sweetgum-Magnolia-Pine-Oak	16	23	53	73	83	90	10.0	18.0	24.0	4	19	
2312 Southern Flood Plain	16	23	53	73	83	90	10.0	18.0	24.0	4	19	83
2320 Southeastern Mixed Forest	15	22	34	9*	98	105	9.0	16.0	23.0	3	7	20
2400 Marine												
2410 Willamette-Puget Forest	46	62	75	70	80	90	2.0	12.0	18.0	5	10	20
M2410 Pacific Forest	15	40	75	95	98	100	1.0	5.0	9.0	1	3	40
										(20)	(80)	(400)[5]
M2411 Sitka-Spruce-Cedar-Hemlock	34	48	65	92	95	98	4.0	8.0	11.0	1	2	8
M2412 Redwood Forest	52	87	124	95	98	105	7.0	12.1	18.0	3	26	118
M2413 Cedar-Hemlock-Douglas-fir	25	50	90	85	90	95	3.0	9.0	16.0	4	8	12
M2414 California Mixed Evergreen	50	120	150	93	97	99	8.0	14.5	21.2	6	45	175
M2415 Silver Fir-Douglas-fir	23	46	68	85	90	94	1.4	6.2	10.9	2	5	10
2500 Prairie												
2510 Prairie Parkland												
2511 Oak-Hickory-Bluestem	235	314	370	76	94	128	.0	13.0	22.0	17	55	214
2512 Oak + Bluestem	51	55	58	--	--	--	11.0	20.0	25.0	--	--	--
2520 Prairie Brushland												
2521 Mesquite-Buffalo Grass	240	270	280	83	94	100	12.0	19.0	26.0	2	8	80
2522 Juniper-Oak-Mesquite	244	278	290	83	94	100	11.5	19.0	25.5	2	8	80
2523 Mesquite-Acacia	250	280	295	82	92	100	12.0	19.0	26.0	2	8	80
2530 Tall-grass Prairie												
2531 Bluestem	352	868	1060	70	86	100	.0	9.0	19.5	24	80	199
2532 Wheatgrass-Bluestem-Needlegrass	149	155	161	79	83	90	4.5	9.5	20.0	448	508	650
2533 Bluestem-Grama	72	104	133	54	81	100	5.0	13.0	23.0	--	--	--
2600 Mediterranean												
2610 California Grassland	400	600	800	90	95	100	8.0	18.0	28.0	30	60	90
M2610 Sierran Forest	11	19	20	90	96	102	6.2	13.8	15.5	1	3	5
M2620 California Chaparral	300	600	800	90	94	98	7.2	17.8	24.1	10	20	30
3100 Steepe												
3110 Great Plains Shortgrass Prairie												
3111 Grama-Needlegrass-Wheatgrass	994	2189	3384	53	70	87	1.4	9.7	18.0	10	6000	16186
3112 Wheatgrass-Needlegrass[7]	235	257	269	70	80	87	.0	4.0	12.0	25	47	81
3113 Grama-Buffalo Grass	1491	1610	1730	80	92	104	4.0	13.0	21.0	118	188	258

Table 13.—Concentrations of selected water quality parameters (at three percentiles of the data distributions) from undistributed forest and range watersheds in the United States, by division, province, and section—Continued

Division, province, and section	Total dissolved solids (mg/l)[1] Percentile[4]			Dissolved oxygen (% saturation)[2] Percentile			Water temperature (degrees centigrade) Percentile			Suspended sediment (mg/l)[3] Percentile		
	15	50	85	15	50	85	15	50	85	15	50	85
M3110 Rocky Mountain Forest												
M3111 Grand Fir-Douglass-fir	32	48	57	87	94	99	1.5	8.0	15.5	1	6	22
M3112 Douglas-fir	25	140	400	76	83	110	.0	6.0	12.0	7	25	300
M3113 Ponderosa Pine-Douglas-fir	38	52	60	65	73	78	.0	4.0	11.0	2	4	9
3120 Palouse Grassland	200	250	300	60	70	80	2.0	10.0	17.0	50	500	5000
M3120 Upper Gila Mountains Forest	63	128	173	73	87	114	6.0	11.0	21.0	1	2	20
3130 Intermountain Sagebrush												
3131 Sagebrush-Wheatgrass	85	109	124	9	11	12	2.0	11.0	24.0	4	9	57
3132 Lahontan Saltbush-Greasewood	50	80	100	74	79	84	1.0	8.0	15.0	13	30	177
3133 Great Basin Sagebrush	70	80	100	73	80	90	1.0	8.0	15.0	2	25	1970
3134 Bonneville Saltbush-Greasewood	1000	1400	3200	70	80	90	2.0	9.0	15.0	10	30	2000
3135 Ponderosa Shrub Forest	55	59	66	75	85	95	1.0	14.0	19.0	5.6	17.5	59.5
P3130 Colorado Plateau												
P3131 Juniper-Pinyon Woodland + Sagebrush-Saltbush Mosaic	150	225	350	70	82	100	4.0	13.0	21.0	5	25	500
P3132 Grama-Galleta Steepe + Juniper-Pinyon Woodland	158	228	390	85	95	145	5.0	16.0	23.0	19800	24800	37900
3140 Mexican Highlands Shrub	427	915	1180	95	105	105	15.0	25.0	33.0	14200	68940	111000
A3140 Wyoming Basin												
A3141 Wheatgrass-Needlegrass-Sage	220	495	770	78	87	96	2.0	9.0	17.0	78	850	1622
A3142 Sagebrush-Wheatgrass	190	267	344	71	82	93	2.0	9.0	17.0	1	191	565
3200 Desert												
3210 Chihuahuan Desert												
3211 Grama-Tobosa	1900	2450	2990	100	120	130	8.0	18.0	27.0	12	55	86
3212 Tarbush-Creosote Bush	93	114	132	--	--	--	13.0	21.0	25.0	--	--	--
3220 American (Mojave-Colorado-Sonoran)												
3221 Creosote Bush	509	541	603	70	105	140	13.0	21.0	28.0	7	576	1030
3222 Creosote Bush-Bur Sage	600	700	800	60	70	100	13.0	26.0	32.0	1000	5000	200000

[1]*All solid material that passes through a filter membrane having pores of 0.45 micron in diameter. Measured in milligrams per liter (mg/l).*

[2]*The ratio of the amount of dissolved oxygen present in water at a given temperature to the amount of dissolved oxygen water can hold at that temperature, expressed as a percent.*

[3]*The inorganic particles larger than 0.45 micron in diameter carried in suspension by the water. Measured in milligrams per liter (mg/l).*

[4]*Percentile figures are determined from an analysis of a frequency distribution. The 50th percentile represents the median (midpoint) of the data and a range is selected in which 70% of the data falls between the 15th and 85th percentiles.*

[5]*Figures in parentheses are for streams with a major contribution from glacial melt and are for the same ecoregions as figures immediately preceding.*

[6]*Suspended sediment figures for Yukon Forest do not include that measured in the Yukon River which is a glacial melt river originating in Canada.*

[7]*These figures represent only the Black Hills portion of this ecoregion.*

NOTE—Numbers before the division, province, and section designations refer to lowland ecoregions as described in Bailey (1976) and displayed in USDA (1976). Letters with the numbers, i.e., M1310, P3131, A3142, etc., indicate highland ecoregions in which M = mountains, P = plateau, and A = altiplano (a high plateau or plain).

Source: Environmental Protection Agency. National Water Quality Data Storage and Retrieval Program (STORET), cited in USDA Forest Service (1981).

significant locally if not controlled. Both technology-based and water quality-based approaches are used to control pollution from forest- and rangeland-related point sources.

Nonpoint Sources

As in the case of point-source pollution, nonpoint-source pollution has two abatement approaches: regulatory and non-regulatory. Regulatory controls tend to apply where cause-and-effect relationships can be most easily established, although many exceptions exist. Examples include controls on runoff from mining, construction, and silvicultural activities in states where these are significant industries. Other nonpoint categories such as agricultural runoff are more likely to be subject to non-regulatory, or voluntary, controls, with incentives and technical support provided by a variety of state and federal agencies. Nonpoint pollution controls are often applied on a case-by-case basis and are administered at the local or state level.

The Association of State and Interstate Water Pollution Control Administrators (1985) provides the most complete recent survey on the extent of nonpoint-source pollution in the United States. The Association reported on nonpoint-source programs at the federal, state, and local levels as of 1984. They found 354 programs at the state and local level and 32 programs in 17 federal agencies that manage nonpoint-source-related activities and affect water quality.

The most frequently listed federal programs were those of the Soil Conservation Service, Forest Service, Office of Surface Mining, Bureau of Land Management, and U.S. Army Corps of Engineers. State programs ranged from dredge-and-fill permitting and fish and wildlife management to pesticide applicator licensing and coastal zone/floodplain management. Local programs listed most frequently included those of soil and water conservation districts and planning/zoning commissions, plus those involved with permitting well construction and septic systems and erosion/sediment control.

States reported that 69% of state and locally initiated nonpoint-source programs include some form of regulatory authority. Grants, loans, tax abatement, and other incentives are included in 14% of the state and local programs, with most of these programs directed towards agricultural activities. The states concluded that effective nonpoint-source programs require close cooperation among state, federal, and local governments, along with private interests and the general public.

Economic Impacts of Water Quality Improvements

Water quality improvements resulting from the 1972 Clean Water Act were reported in Chapter 2. Water quality in streams has been upgraded considerably since 1972. Yet progress to date has not been spread uniformly across the countryside. Emphasis since the 1972 legislation has been on cleaning up major point sources of pollution. The result has been that 47% of EPA grant dollars have been spent on 11% of grants, which were allocated to only 1% of the treatment plants nationwide (table 14)(Smit and Chapin, 1983).

Plants having less than 1.05 mgd in capacity account for 79% of treatment plants nationwide, but only 8% of nationwide treatment capacity. In contrast, plants having greater than 50 mgd capacity are only 0.6% of plants but account for 39% of treatment capacity. In funding construction of large plants first, the major point-source problems were addressed first.

There is a substantial backlog of wastewater treatment projects in small communities. The scheduled reduction in the construction grants program funded by EPA means that financial grants to small communities will drop. This construction grants program provided for the federal government to pay 75% of treatment plant construction costs. The new program will provide a federal grant of only 55% and make the communities eligible for low interest loans. For example, if the community finances its 45% of the cost through a loan from the Farmers Home Administration at 5% interest for 40 years, loan payments should result in user charges equivalent to charges needed to retire bonds sold at market rates to fund the 25% community share under the former program (Smit and Chapin 1983). As an additional incentive to small towns, treatment standards for small communities were reduced by the Municipal Wastewater Treatment Grant Amendments of 1981 to allow less-expensive treatment options that would still bring these towns into compliance with the Clean Water Act. These amendments declared that treatment processes such as trickling filters and lagoons met secondary treatment standards established for municipalities.

Feliciano (1982) summarized the economic impact of treatment plant construction grants in terms of jobs. His numbers have been modified here to convert them from a grant-dollar basis to a total-expenditure basis. Each $1 billion in expenditures for wastewater treatment plant construction provides 10,195 person-years of work for building trades, 14,660 person-years of work for industry (manufacturing, transportation and related services and mining), and 1,840 person-years of work for engineers for a total of 26,835 person-years of work. Adjustments made by the Municipal Wastewater Treatment Grant Amendments of 1981 reduced the capital-intensity of treatment plants for small towns, so job impacts of the future construction program combining grants and loans may be somewhat less. Nevertheless, the economic impact is still expected to be substantial. Further, because small towns are more uniformly distributed across the nation, the economic impact of the future program should be spread across the land. Smaller firms will have more opportunities to participate in the construction program.

Table 14.—Distributions of community size, number of grants, and value of grants for wastewater treatment plant construction, 1972 to 1982

Community size	Number of places	Number of grants	Value of Grants
		percent	
Less than 5,000	79	55	12
5,000 to 25,000	16	23	21
25,000 to 100,000	4	11	20
Greater than 100,000	1	11	47

Source: Smit and Chapin (1983)

STATUS OF STATE WATER QUALITY LAWS AFFECTING FORESTRY OPERATIONS

Most modern efforts to maintain or improve water quality in individual states have stemmed from the Clean Water Act. The amendments stressed strong state action and federal oversight to control water pollution. Although many states had enacted some water quality legislation prior to 1972, only a few laws specifically addressed silvicultural pollution of water. Most attention was given to stream blockage with logging debris.

Two sections of the Clean Water Act have direct implications for forestry operations. Section 404 requires a permit for discharging dredge and fill material into navigable waters and adjacent wetlands. Under this authority, the Corps of Engineers may require permits when drainage projects are conducted for certain silvicultural operations in wetlands, such as clear cutting, site preparation, and road and skid trail construction. Additional discussion about the 404 Program is found in the wetlands sections of this chapter and Chapter 8.

Section 208 mandates that individual states develop and implement areawide nonpoint-source pollution management plans subject to approval of EPA. Silvicultural activities are designated as one type of nonpoint-source pollution that plans must address. Thus, most state efforts with respect to water quality in recent years were in conjunction with Section 208. However, despite state activity that resulted from Section 208, many believe that nonpoint-source pollution was still an impediment in achieving national water quality goals. This led to a major revision of the law in the form of the 1987 Water Quality Act. A principal component in the new law, Section 319, contains specific language intended to improve control of nonpoint-source pollution.

Section 319 requires each state to prepare by August 1988 detailed water quality management plans that identify bodies of water not in compliance with water quality standards because of nonpoint-source pollution. Plans are also required to identify categories and individual nonpoint sources that violate water quality, and to describe proposed control mechanisms. Each state must then devise either regulatory or voluntary programs to control nonpoint-source pollution, including that emanating from forestry activities. In implementing voluntary or mandatory nonpoint control mechanisms, states may base compliance on either the use of BMPs or on state water quality standards.

BMPs are optional methods, measures, or practices for preventing or reducing water pollution and include (without limitation) structural controls, operating and maintenance procedures, and activity scheduling and distribution. Water quality standards, on the other hand, are specific water quality criteria, both narrative and numeric, for designated water bodies of a state.

Existing state water quality and related legislation was examined for this report, including how such laws interact with forestry activities and how individual states are currently addressing silvicultural-related nonpoint water pollution. Tables C–1 through C–4 in Appendix C present statutory details for each state, together with a brief discussion of implications of current legislation for silvicultural operations.

Each of the 50 states has in force a general water quality law. Some are more specific than others but all are broad in scope. Each statute authorizes the administering agency to control water pollution by promulgating standards and regulations. Some laws also prescribe a discharge permit system which is usually optional with the administering agency. Only a few of these general laws specifically address forestry operations and only a few distinguish between point and nonpoint sources of water pollution. Virtually all, however, are broad enough in language to encompass by implication nonpoint-source pollution, including that emanating from forestry activities, even though the statutory language fails to mention the terms "forestry or silvicultural" and "nonpoint."

The South.—Most general water quality laws in the South were passed in the 1960s and 1970s. In 11 of 14 southern states, neither the general statute nor regulations promulgated under it address forestry activities. Two states—Tennessee (by statute) and Louisiana (by regulation)—specifically exempt silvicultural operations from the Act's provisions. West Virginia includes forestry under its Act's umbrella except where site-specific silvicultural BMPs are utilized. All southern states except Texas use a voluntary forestry BMP program to control forestry-related nonpoint-source pollution. Texas has no program whatsoever and takes the position that no problems exist in the state. Some southern states have also passed special water-related laws covering stream obstruction, wetland protection, and scenic rivers that impact to some degree on forestry operations in special situations.

The North.—Each northern state has a general water quality law, most of which were enacted prior to 1960. Wisconsin's law was enacted in 1913. This type of statute has generally been in force longer in the North than in other parts of the country where most such laws are much newer. Some northern statutes (or the regulations issued under them) specifically address forestry operations, as do statutes in the West. But other northern states, primarily in the Midwest, have statutes that omit specific references to forestry. These laws, in general, parallel those in the southern states and are broadly enough written to apply by implication to silvicultural nonpoint sources.

Forestry nonpoint-source water pollution in the North is subject to a wide range of control mechanisms ranging from formal regulation in Massachusetts under that state's Forest Practice Act to no program whatsoever in Delaware and Rhode Island. Maine, New York, Vermont and New Hampshire utilize a quasi-regulatory approach with a tie-in to the general water quality law. Maryland, Connecticut, New Jersey, and Pennsylvania approach the situation with a voluntary BMP program. In certain cases, very large forestry harvesting activities in Pennsylvania are subject to state regulation under the general water quality law. Most northern states have also passed a variety of special wetland and shoreline protection laws that contain restrictions on forestry practices in special situations. In addition, there are water-related laws that impact certain forestry operations relating to stream obstruction and scenic rivers statutes.

The West.—All but three general water quality laws in the West were passed in the 1960s and 1970s. Oregon and Utah statutes were enacted in the 1950s and Idaho's in 1947. Eight of 17 laws either specifically address forestry nonpoint pollution control in the basic legislation or do so by regulation or administrative procedure. In California, Idaho, Oregon, Nevada, New Mexico, and Washington, forestry water quality problems are controlled through state forest practice acts and mandatory BMPs promulgated under those laws. In Montana, forestry operations must adhere to BMPs developed by the Department of Public Lands. In Alaska, BMPs written under the authority of the state forest practice act are voluntary—thus if they are not utilized, or are used and fail to prevent violations set forth under the general water quality act, regulatory provisions of the latter can be invoked. In Utah, forestry nonpoint pollution is addressed through state certification of local BMPs as directed by regulations issued under the general water quality statute. Arizona, Hawaii, Colorado, Kansas, Nebraska, North and South Dakota,and Wyoming have no forestry nonpoint programs. A number of western states have enacted special water protection statutes that deal with stream obstruction, scenic rivers, and wetland protection that place limitations on forestry operations in special situations.

Summary

A review of state water quality legislation that affects forestry practices in the East indicates that most laws were not very restrictive to date with the exception of several northern states. However, the opposite situation exists in much of the West. In many situations in the East, however, statutes do have the potential to be more stringently invoked with respect to silvicultural operations. In addition, new state legislation is being considered in a number of eastern states to replace inconsistent, and often conflicting local land use ordinances, many of which address water resource protection. These laws could also result in more pervasive and strict control of silvicultural activities. Passage of the 1987 Water Quality Law with its strong emphasis on state action indicates that nonpoint-source water pollution prevention will continue to be both a national and state priority. New state laws will certainly be passed, and old ones amended, to address in more absolute terms nonpoint-source pollution from silvicultural activities.

WATER QUALITY IMPROVEMENTS SINCE LAST ASSESSMENT

Major advances have been made in improving instream water quality since 1972. Comparison of State reports in EPA (1987) with previous inventory reports demonstrates where and how much water quality has improved. Case studies in the 1987 report show even more impressive results obtained in specific areas.

The Clean Water Act set goals and the nation mobilized to attain them. The 1986 National Water Quality Inventory concludes that industries mobilized to clean up point sources faster than municipalities. In the decade following passage, biochemical oxygen demand loads from municipal plants decreased 46% and industrial loads at least 71% (Association of State and Interstate Water Pollution Control Administrators 1984). Costs of municipal wastewater treatment today are double those of 1972 (in constant dollar terms) and industrial costs are 50% higher. These expenditure patterns portray the additional emphasis water pollution received following passage of the Clean Water Act.

As point sources of pollution have been cleaned up, effects of nonpoint sources have become more apparent. If anything, their effect was underestimated when the original legislation was passed in 1972. Widespread increases in chloride (highway salting), nitrate (fertilizers), and sulfate (coal combustion products) concentrations are thought to be linked to nonpoint-source pollution (Foxworthy and Moody 1986). Sediment from soil erosion is also a major nonpoint-source pollution problem emanating mostly from agricultural areas.

Water quality programs that formerly emphasized control of point-source pollution are shifting to programs emphasizing control of nonpoint sources of pollution, protection of ground-water quality, and cleanup of toxic-waste disposal sites. This shift in emphasis is projected to continue into the next century because these problems are more difficult to address.

SUMMARY

Background water quality levels for undisturbed forests and rangelands represent long-run water quality goals that land managers seek to perpetuate. Before the mid-1960s, offstream uses downstream from forests and rangelands resulted in significant declines in water quality. Dilution of wastes with instream flows was a commonly accepted policy (Wollman and Bonem 1971). The Clean Water Act changed that policy and set goals of returning water to fishable and swimmable levels by 1983 and eliminating discharges causing pollution by 1985. The nation embarked on what has become a successful effort to clean up discharges. Efforts over the past 15 years have largely met the fishable-swimmable goal. Cleanup cost has been considerable—$300 billion for pollution abatement between 1972 and 1984 and $172 billion for capital equipment alone.[8]

It is unlikely that the nation will soon embark on a program of similar magnitude. Any additional cleanup will require larger investments to obtain much smaller increments of improved water quality; successive increments of pollution become more and more costly to remove. Consequently, one cannot take improvements made in water quality since 1972 and project that additional improvements will continue at that rate.

The quality of water supplies available nationwide after 2000 will be somewhat better than current quality, but a major improvement nationwide is not anticipated. The opportunity for the most significant improvements in quality will come from reductions in nonpoint-source pollution. The prevalence of municipalities and industries causing locally significant water quality problems will diminish as smaller point-source discharges are cleaned up.

The quality of water emanating from forested and rangeland watersheds is projected to be higher than quality measured downstream. Maintaining water quality levels that will not foreclose water use options of downstream users will represent the key challenge to forest and range managers in the 21st century.

WETLANDS SUPPLY TRENDS[9]

The use of wetlands—the marshes, tundra, swamps, bogs, and bottomlands that comprise about 5% of the contiguous United States and about 60% of Alaska—is a source of controversy. Some want to convert these areas to other uses while others want them left in their natural state. Some wetlands provide natural ecological services such as floodwater storage, erosion and sedimentation control, nutrient removal to improve water quality and support food chains, and habitat for wildlife and fish. Consequently, wetlands offer varied recreational, educational, and vocational opportunities.

Wetlands are usually characterized by emergent plants growing on soils periodically or normally saturated with water.[10] Wetlands occur along gradually sloping areas between uplands and deep-water environments such as rivers, or form in basins isolated from larger water bodies. Of the 90 million acres of vegetated wetlands in the contiguous U.S., 95% are located in inland freshwater areas. The remainder are coastal saltwater environments. In addition, estimates are that nearly 60% of Alaska—over 200 million acres—is covered by wetlands.[11]

WETLANDS CONVERSION RATES AND ACTIVITIES RESPONSIBLE

Within the past 200 years, 30 to 50% of wetlands in the contiguous U.S. were converted to uses such as agriculture, mining, forestry, oil and gas extraction, and urbanization. According to the most recent federal survey, 11 million acres of wetlands in the lower 48 states were converted (the net change) to other uses between the mid-1950s and mid-1970s. This amount was equivalent to a net loss each year of 550,000 acres, or about 0.5% of remaining wetlands. Eighty percent of actual losses were due to draining and clearing wetlands for agriculture. Although some losses were due to natural events such as erosion, sedimentation, or subsidence, at least 95% of actual wetlands losses between 1960 and 1985 were due to human activities.

The current annual rate of wetlands loss is about 300,000 acres annually. A decline from the 550,000-acre rate of the 1950s to 1970s is due primarily to declining rates of agricultural drainage, and secondarily to government programs that regulate wetlands use. The U.S. Army Corps of Engineers' program under Section 404 of the Clean Water Act regulates many activities that involve disposal of dredge or fill material. Prior to this legislation, much of this material was used to fill wetlands. While coastal wetlands are protected reasonably well by a combination of federal and state regulatory programs, inland wetlands, which comprise 95% of the Nation's wetlands, are poorly protected.

Wetland conversion rates and activities vary significantly throughout the country. For example, conversions in the Lower Mississippi water resource region occurred at rates three times the national average from the mid-1950s to mid-1970s. In contrast, conversion rates along the Atlantic coast (excluding Florida) were only 30% of the national average. Overall, wetland conversions occurred in coastal areas at rates that were 25% less than inland conversion rates during the two-decade period.

From the mid-1950s to mid-1970s, 97% of actual wetlands losses occurred in inland freshwater areas. Agricultural conversions involving drainage, clearing, land leveling, groundwater pumping and surface water diversions were responsible for 80% of the conversions. Of the remainder, 8% resulted from construction of large impoundments and reservoirs, 6% from urbanization, and 6% from activities such as mining, forestry, and road construction. Fifty-three percent of inland wetlands conversions occurred in forested areas that were mainly bottomlands.

Of actual losses to coastal wetlands, 56% resulted from dredging marinas, canals, port developments, and to a lesser extent, from erosion. Urbanization accounted for 22% of the losses and 14% were due to disposal of dredge spoil or beach creation. The balance of the losses were due to natural or human-induced transition from saltwater to freshwater wetlands (6%) and agriculture (2%).

PROJECTED FUTURE LOSSES

Agriculture is the leading cause of wetlands losses (fig. 39 and table 15). If these losses are ignored, losses from all the other land uses balance the gains in wetlands from all land uses. Consequently, our wetlands future is inextricably linked to projected changes in agriculture.

The Appraisal (USDA 1987) concluded that remaining wetlands need protection. Nearly half of remaining nonfederal wetlands and almost all palustrine wetlands in the United States are potentially subject to conversion for agriculture. The 1982 Natural Resource Inventory reported the acreage of wet soils and wetlands that have "potential for conversion" based on similar lands converted in prior years.

About 5.2 million acres of wetlands have high or medium potential for conversion. Wetlands most likely to be drained and converted to agriculture fall into two general categories: small wetland areas, either natural or manmade, that interfere with a farmer's agricultural operations; and relatively large areas in mature hardwood stands where timber values help offset land clearing costs, where land drainage and shaping costs are relatively low, where outlets for drainage water are readily available, and where there is continued profitable land ownership. Although some wetlands were converted directly to agricultural uses, about half were originally forested and entered agriculture use after being cut for timber.

The Food Security Act of 1985 (Public Law 99–447) contains a "swampbuster" provision that makes farmers ineligible for certain USDA programs if they convert wetlands. The Act provides for restrictions or prohibitions on federal commodity payments and loans to farmers who produce crops on newly converted wetlands. The Fish and Wildlife Service (FWS) and SCS have

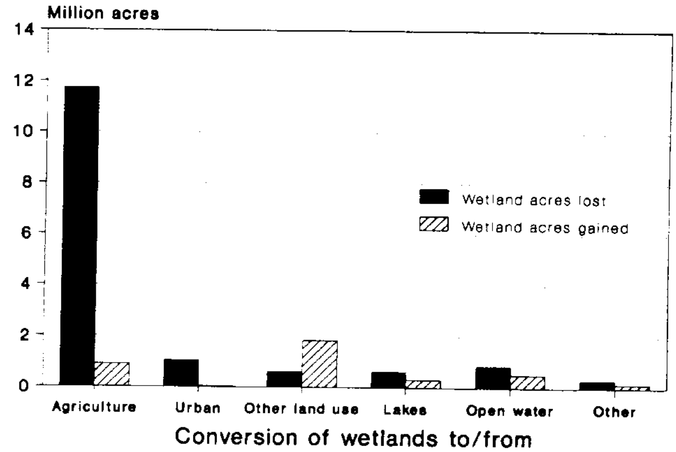


Figure 39.—Trends in the conversion of freshwater and saltwater wetlands, mid-1950s to mid-1970s (OTA 1984).

Table 15—Agricultural conversions of wetlands from the mid-1950s to mid-1970s

How accomplished	Important regions/ wetlands types	Reasons	Trend
Major drainage, flooding	Prairie potholes of Minnesota, North Dakota, South Dakota/ shallow, moderately deep marshes and seasonally flooded flats	Opportunity to gain additional cropland Elimination of nuisance potholes within cropland. Change in farming from diversified crops and livestock to row crops and small grain Increase in tractor horsepower Increases avoidance costs Increase in center-pivot irrigation Climatic variations Absence of financial incentives to maintain wetlands Drainage opportunities from channel projects and rural roads ditches Tax benefits for drainage	Of original, 25% to 30% of acres remain; greatest percentage and acreage drained in Minnesota. However, this is extremely variable within region, varying by 12% to 95%. Continuing conversion. Annual drainage rates estimates range from 0.1 to 5.0%. Almost half remaining wetlands are under protective programs; of these, 90% are permanent forms
Major drainage, flooding, excavation, land-leveling	Nebraska Rainwater Basin/shallow, moderately deep marshes and seasonally flooded flats	Intensify or expand cropland Drainage opportunities through rural road upgrading and improvement Drought incidence Possible federal or state cost-sharing assistance for reuse systems or leveling associated with irrigation Tax benefits for drainage Available farm equipment	Continuing conversion. Remaining are 15% to 25% original acres and 10% to 15% original basins. Protection programs cover 50% to 85% of remaining acreage. Nearly 90% of these are in permanent forms
Ground water pumping, associated land-leveling and filling	Nebraska Sandhills/wet meadows	Conversion of rangeland to cropland Long-term reduction in ground water levels and seasonal ground water variations due to expanding center-pivot irrigation Increase efficiency of center pivot Expand hay production into wetter areas	Accelerating conversion rate in last 10 years. Remaining are 85% to 95% of original acres and more than 95% of original basins
Ground water pumping, surface water diversions	Nebraska-Central Platte Valley/wet meadows	Indirect impact of regional irrigation development Conversion of rangelands to cropland	Of original wet meadows, 30% to 45% remaining
	California-Klamath Basin/emergent marshes	Conversion of rangeland to cropland	Of original acreage, 40% remaining. Continuing conversions on private and managed wetlands. Approximately 50% of remaining wetland and lake areas in national wildlife refuges and state wildlife management areas

Table 15—Agricultural conversions of wetlands from the mid-1950s to mid-1970s—Continued

How accomplished	Important regions/ wetlands types	Reasons	Trend
Normal farming: land-leveling of flood-irrigated areas, shift in crops, shift in planting and harvest schedules	California-Central Valley/emergent marshes	Less water available Increased pumping costs Clean farming practices Pesticide/herbicide use Flood control Irrigation technology	More than 90% converted from 1850 to 1978. Continuing conversions of ricelands to less water-intensive crops. Degradation of habitat on secondary wetland areas. Of remaining acreage, 20% in public ownership)
Drainage, land-leveling	California-Central Valley/emergent marshes	Less water available Higher taxes on nonagricultural lands Increased pumping costs Degradation of habitat on secondary wetland areas	See above description of overall trends of Central Valley. Conversion of private wetlands to agriculture. Reduction of flooded public acreage
Clearing vegetation	Lower Mississippi River Valley/ bottom land hardwoods	Soybeans demand Relative price of timber Drought incidence Flood-control projects	Significant conversion prior to 1937. Forty-four percent reduction, 1937-1977. Forest remaining 0% to more than 60% (1979). Rate of clearing peaked 1967 (except Louisana). Clearing rates related to forest left. Continuing conversion
Clearing vegetation drainage	North and South Carolina/bottom land hardwoods	Relative price of timber Improved drainage equipment Refined use of lime, fertilizer, pesticides Improve seed stocks Agribusiness investment	Increase from 1930's to 1950's from reforestation of abandoned farms. Increasing rate of conversion 1950s to 1970s
Clearing vegetation, drainage	North Carolina/pocosins	Improved drainage equipment	By 1979, 33% totally developed. Of remaining areas, 65% owned by agricultural and forest products industries. Five percent protected from drainage through public ownership or lease
Clearing vegetation, drainage	South Carolina/carolina bays	Large-scale agriculture Forestry	Ninety-five percent altered
Clearing vegetation, drainage	South Florida/cypress	Agricultural and urban uses	Conversions occurred from 1900 to 1973, including 25% of cypress domes and stands and 12% of scrub cypress. Continuing conversions
Lack of drainage, ditch maintenance	New England/wooded wetlands	Agricultural abandonment	Wetlands recreated
Mowing, seeding, fertilizing, grazing	South Florida/wet prairies, sawgrass	Expanded agriculture Transform areas to dry land to prepare for urban development (and avoid regulations associated with fill in wetalands)	Conversion of 45% to 52% of wetlands from 1900 to 1973. Continuing conversions

Source: OTA (1984)

cooperated to define the vegetation and soil types characterizing wetlands eligible for protection under this program.

There are 17 million acres of wetlands having some potential for crop production. Heimlich (1988) concluded that the swampbuster provision will likely hamper conversion on only about one-third of these acres—the 5.2 million acres with medium to high crop production potential. Nearly half of the 5.2 million acres are in the South and 30% are in the North. Wetlands conversion in much of the South Atlantic-Gulf region will likely not be affected by withholding of farm program benefits according to Heimlich's analysis. Additional information on the swampbuster provision is found in Heimlich and Langner (1986).

While the Corps' Section 404 program and swampbuster provisions of the Food Security Act discourage conversion of wetlands, other laws and regulations exist that subsidize wetlands conversions. For example, the federal income tax law (and many states' income tax laws) authorize tax credits for investments, deductions for expenses of operations, and special provisions for resource depletions. Conversion of wetlands has historically been judged an investment with costs eligible for special treatment when income taxes are computed.

Local property taxation administration also favors conversion in some areas. For example, OTA (1984) cited the case of a hunting club in California that owned a large parcel of wetlands. When the recorded land use was changed to recreational land from wetlands, the increased tax burden made it difficult to maintain the club. Financial problems brought on by increased assessed values can lead to sales to developers, making conversion more imminent. Many local governments provide property tax breaks where the assessed value is dependent upon land use; this encourages landowners to keep land in forest cover. Similar local property tax relief would be useful to help preserve wetlands.

OTHER WETLANDS USES AFFECTED BY CONVERSIONS

Wetlands provide food and habitat for many game and non-game animals. For some species, wetlands are essential for survival. For example, waterfowl require wetlands for breeding and nesting. These birds nest primarily in northern freshwater wetlands in the U.S. and Canada in the spring and summer, but use wetlands for feeding and cover in all parts of the country during migration and overwintering. Survival, return, and successful breeding of many species, therefore, depends on a wide variety of wetland types throughout North America. It is no coincidence that major migratory routes, breeding and nesting areas, and overwintering areas correspond with regions of greatest wetland concentrations, and that waterfowl populations have declined along with the decline in wetlands acreage.

For other species, wetlands serve more general needs. Coastal marshes and certain types of inland freshwater wetlands achieve some of the highest rates of plant productivity of any natural ecosystem. This high productivity often supports varied and abundant animal populations within a complex food chain. During the growing season, less than 15% of the plant biomass in saltwater marshes is consumed directly by foraging animals. After plants die, up to 70% of the plant material disintegrates into small particles and is flushed into adjacent water where it becomes a potent food source for estuarine-dependent fish and shellfish.

Several fish species are dependent upon wetlands, as they prefer to spawn in shallow, vegetated water. Wetlands afford abundant food for fingerlings and existing vegetation offers protection from currents, sunlight, and predators.

Wetlands are home to wildlife of economic importance including minks, muskrats, and nutria (furbearers); alligators (hides and meat); and crayfish and assorted fish and shellfish (meat). Other plants and animals could become equally important if proven to be sources of food, chemicals, or extracts.

Other important functions of wetlands include shoreline stabilization, groundwater recharge, and recreation. Vegetated freshwater wetlands significantly reduce shoreline erosion caused by large waves and major coastal riverain flooding. Some wetlands hydrologically connected to groundwater systems provide aquifer recharge through infiltration and percolation of surface water. In general, recharge rates in uplands are typically higher than for wetlands. Finally, because of the habitat wetlands provide for fish and wildlife, they are prime recreation areas for wildlife observation and nature photography, as well as hunting and fishing.

The wildlife and fish assessment that is part of this Assessment provides additional information on wetlands and their importance.

SUMMARY

The historic rate of wetlands conversion of the mid-1950s to mid-1970s (550,000 acres annually) dropped to 300,000 acres in the mid-1980s. Nearly half the land converted during this period was forested palustrine wetlands. The predominant reason for converting wetlands has been to provide additional agricultural acreage.

About 5.2 million acres of wetlands are potentially suitable for conversion to agriculture. Recent changes in agricultural policy will preclude significant additional conversions of these wetlands, particularly forested ones, to agricultural use. The rate of wetlands conversion to agriculture is expected to dip significantly as swampbuster provisions take effect. By the year 2000, conversions are projected to be around 100,000 acres annually. Whether there is any further dip in the conversion rate will depend on whether additional disincentives can be created for conversion to non-agricultural land uses. There remain 11.8 million acres of wetlands only marginally suitable for agriculture that may still move easily into non-agricultural land uses unaffected by the swampbuster provision.

Wetlands support a rich and diversified population of plants and animals, many having economic importance. Further, wetlands provide considerable recreation opportunity and other benefits, such as erosion control. The continuing conversion process chips away at wetlands benefits resulting in losses to society that cannot be adequately compensated.

The acreage of wetlands on federal lands will remain at current levels throughout the planning period due to increased sensitivity to ecological, economic, and social values of wetlands. On private lands, acreage will continue to decrease, but at a slower pace through 2020. The net result by 2020 will be about 94 million acres of wetlands, an area that stays constant to 2040.

NOTES

1. A "stock" resource is one whose supply is fixed or set at the beginning of the planning period. The quantity available cannot be increased, but use can decrease the amount.

2. Managers have no method capable of making significant regional or national increases in water supplies. Cloud seeding, where it has been successful, has only affected specific localities at intermittent intervals.

3. This section is taken largely from Tennant (1975) and first appeared in the water chapter of the 1979 RPA Assessment (USDA Forest Service 1981).

4. USDA (1987) concluded that the trend in damages is increasing at an annual rate of $30.0 million (1984 dollars).

5. This section is drawn largely from USDA Forest Service (1981) and the EPA (1987).

6. STORET is an acronym for the U.S. Environmental Protection Agency's water quality data storage and retrieval program.

7. The numbers in table 13 do not necessarily represent an "average" water quality. Levels of these constituents are a function of the time of day as well as flow characteristics. The quality samples are usually collected during day time and during non-storm periods, so diurnal variation and water quality effects of storm flows are not well represented in this data.

8. EPA (1987, table 5.4). The totals are in 1982 constant dollars.

9. This section is drawn largely from U.S. Congress (1984).

10. This Assessment adopts a wetlands definition following the one employed by the Fish and Wildlife Service of the U.S. Department of the Interior for mapping and land classification. There is a second, and more restrictive, definition of wetlands employed by federal agencies—principally the U.S. Army Corps of Engineers and the U.S. Environmental Protection Agency—for the purpose of regulation. Under the former definition, there were 99 million acres of wetlands in the contiguous U.S. in the mid-1970s. Using the latter definition, there were only 64 million acres of wetlands. For example, under the definition used here, the drier sections of bottomland hardwood sites are included as wetland but the Corps of Engineers does not exercise regulatory control over these areas. The differences in definition led to considerable confusion because the public often views the federal government as monolithic and does not differentiate between the different purposes behind the two definitions.

11. The frozen tundra is another example of a site that meets the Fish and Wildlife Service's definition of wetland—soils that are periodically or normally saturated with water—albeit frozen water. The Corps of Engineers and Environmental Protection agency ignore such sites for purposes of regulating wetlands use.

PLENTIFUL SUPPLIES AND SHORTAGES

The generalized water balance by water resource region was introduced in table 2 to illustrate the current water use situation. The surplus/deficit column indicated how much water is available in the year of mean precipitation for offstream water uses. The water balance was extended in table 12 to account for variations in precipitation between average and two lower levels of precipitation—the 80% level expected to be exceeded 4 years in 5 and the 95% level expected to be exceeded 19 years in 20.

The comparison of projected supplies and demands is presented in this chapter through use of the most complete form of the generalized water balance approach (table 16). Offstream consumptive uses from 1985 to 2040—the demand projections—are incorporated in this table. The surplus/deficit column shows where supplies are expected to be plentiful throughout the next five decades and where shortages are expected.

It is important to note that table 16 presents a comparison where two variables play key roles because they are linked and each is only allowed to be in one of two states. The two variables are rainfall condition and instream flow requirements. Rainfall condition is either "average" (the mean expectation) or "dry" (the 80% level). Instream flow conditions are linked to the rainfall situation. Instream flow providing optimal fish and wildlife habitat is paired with the average rainfall expectation. Instream flow providing good survival habitat is paired with the dry rainfall condition (80% expectation). In essence, this pairing produces surpluses/deficits that bracket a continuum where flows are likely to occur. Thus, it is possible that the surplus in an average rainfall year is less than that in a dry year because of an accompanying shift in instream flow assumptions from optimal to good survival habitat. Moreover, where deficits occur, the implication is that one or more assumptions inherent in the water balance are being violated. The most obvious one is the instream flow requirement. Deficits typically imply that less than the assumed habitat is being provided. For the dry condition, deficits infer that poor survival habitat is provided. The assumption second most likely to be violated is the groundwater overdraft situation. Deficits imply that the overdraft is higher (worse) than estimated.

Deficits identified in table 16 result from a number of factors, including climatological, physiographical, edaphic, economic, technological, and institutional. When an insufficient quantity of water is available for use due to economic, technological, or institutional factors, a *shortage* exists. When an insufficient quantity of water is available for use due to climatological, physiographical, or edaphic factors, a *scarcity* exists. Deficits in table 16 are referred to as shortages throughout the chapter because the prevailing price and institutional frameworks for water use are assumed constant throughout the projection period.

Concern over sufficiency of instream flows for fish and wildlife habitat and recreation will provide the primary impetus for resolving projected water supply deficits.

Table 16.—Generalized water budget for average and dry years, 1985-2040, by water resources region[1]

Water resource region	Rainfall condition[2]	Renewable water supply[3]	Ground-water overdraft[4]	Imports or exports[5]	Reservoir net evaporation[6]	Offstream consumptive use[7] Agriculture	Offstream consumptive use[7] Non-agriculture	Average stream outflow[8]	Instream flow requirement[9]	Surplus or defic.[10]
New England	1985 avg.	77.30	0.00	0.00	0.20	0.06	0.70	76.35	69.00	7.35
	2000 avg.	77.30	0.00	0.00	0.20	0.06	1.05	75.99	69.00	6.99
	2000 dry	62.15	0.00	0.00	0.20	0.07	1.05	60.83	46.40	14.43
	2010 avg.	77.30	0.00	0.00	0.20	0.06	1.18	75.86	69.00	6.86
	2010 dry	62.15	0.00	0.00	0.20	0.07	1.18	60.69	46.40	14.29
	2020 avg.	77.30	0.00	0.00	0.20	0.06	1.29	75.75	69.00	6.75
	2020 dry	62.15	0.00	0.00	0.20	0.08	1.29	60.58	46.40	14.18
	2030 avg.	77.30	0.00	0.00	0.20	0.07	1.40	75.63	69.00	6.63
	2030 dry	62.15	0.00	0.00	0.20	0.08	1.40	61.34	46.40	14.94
	2040 avg.	77.30	0.00	0.00	0.20	0.07	1.50	75.53	69.00	6.53
	2040 dry	62.15	0.00	0.00	0.20	0.08	1.50	60.37	46.40	13.97
Mid-Atlantic	1985 avg.	96.50	0.00	-0.70	0.20	0.31	1.47	93.82	68.84	24.98
	2000 avg.	96.50	0.00	-0.70	0.20	0.36	2.24	93.00	68.84	24.16
	2000 dry	75.03	0.00	-0.70	0.20	0.43	2.24	71.46	57.90	13.56
	2010 avg.	96.50	0.00	-0.70	0.20	0.37	2.55	92.68	68.84	23.84
	2010 dry	75.03	0.00	-0.70	0.20	0.45	2.55	71.13	57.90	13.23
	2020 avg.	96.50	0.00	-0.70	0.20	0.39	2.82	92.39	68.84	23.55
	2020 dry	75.03	0.00	-0.70	0.20	0.46	2.82	70.84	57.90	12.94
	2030 avg.	96.50	0.00	-0.70	0.20	0.40	3.09	92.11	68.84	23.27
	2030 dry	75.03	0.00	-0.70	0.20	0.48	3.09	70.56	57.90	12.66
	2040 avg.	96.50	0.00	-0.70	0.20	0.41	3.38	91.81	68.84	22.97
	2040 dry	75.03	0.00	-0.70	0.20	0.49	3.38	70.26	57.90	12.36
South Atlantic-Gulf	1985 avg.	213.00	0.00	0.00	0.50	2.93	2.32	207.25	188.70	18.55
	2000 avg.	213.00	0.00	0.00	0.50	3.43	3.34	205.73	188.70	17.03
	2000 dry	154.51	0.00	0.00	0.50	4.11	3.34	146.56	127.81	18.75
	2010 avg.	213.00	0.00	0.00	0.50	3.58	3.74	205.18	188.70	16.48
	2010 dry	154.51	0.00	0.00	0.50	4.30	3.74	145.97	127.81	18.16
	2020 avg.	213.00	0.00	0.00	0.50	3.73	4.10	204.67	188.70	15.97
	2020 dry	154.51	0.00	0.00	0.50	4.48	4.10	145.43	127.81	17.62
	2030 avg.	213.00	0.00	0.00	0.50	3.85	4.46	204.19	188.70	15.49
	2030 dry	154.51	0.00	0.00	0.50	4.62	4.46	144.93	127.81	17.12
	2040 avg.	213.00	0.00	0.00	0.50	3.96	4.82	203.72	188.70	15.02
	2040 dry	154.51	0.00	0.00	0.50	4.75	4.82	144.44	127.81	16.63
Great Lakes	1985 avg.	76.80	0.00	-1.30	0.30	0.34	1.88	72.98	63.95	9.03
	2000 avg.	76.80	0.00	-1.30	0.30	0.39	3.11	71.70	63.95	7.75
	2000 dry	61.09	0.00	-1.30	0.30	0.47	3.11	55.91	46.08	9.83
	2010 avg.	76.80	0.00	-1.30	0.30	0.41	3.63	71.16	63.95	7.21
	2010 dry	61.09	0.00	-1.30	0.30	0.49	3.63	55.37	46.08	9.29
	2020 avg.	76.80	0.00	-1.30	0.30	0.43	4.06	70.71	63.95	6.76
	2020 dry	61.09	0.00	-1.30	0.30	0.51	4.06	54.92	46.08	8.84
	2030 avg.	76.80	0.00	-1.30	0.30	0.44	4.56	70.20	63.95	6.25
	2030 dry	61.09	0.00	-1.30	0.30	0.53	4.56	54.40	46.08	8.32
	2040 avg.	76.80	0.00	-1.30	0.30	0.45	5.15	69.60	63.95	5.65
	2040 dry	61.09	0.00	-1.30	0.30	0.54	5.15	53.80	46.08	7.72
Ohio[11]	1985 avg.	140.00	0.00	0.00	0.40	0.19	2.03	137.38	122.00	15.38
	2000 avg.	140.00	0.00	0.00	0.40	0.20	3.25	136.15	122.00	14.15
	2000 dry	107.67	0.00	0.00	0.40	0.24	3.25	103.79	84.00	19.79
	2010 avg.	140.00	0.00	0.00	0.40	0.21	3.77	135.62	122.00	13.62
	2010 dry	107.67	0.00	0.00	0.40	0.25	3.77	103.26	84.00	19.26
	2020 avg.	140.00	0.00	0.00	0.40	0.22	4.20	135.18	122.00	13.18
	2020 dry	107.67	0.00	0.00	0.40	0.26	4.20	102.81	84.00	18.81
	2030 avg.	140.00	0.00	0.00	0.40	0.22	4.71	134.67	122.00	12.67
	2030 dry	107.67	0.00	0.00	0.40	0.27	4.71	102.30	84.00	18.30
	2040 avg.	140.00	0.00	0.00	0.40	0.23	5.29	134.08	122.00	12.08
	2040 dry	107.67	0.00	0.00	0.40	0.27	5.29	101.71	84.00	17.71
Tennessee	1985 avg.	43.30	0.00	0.00	0.00	0.04	0.33	42.93	38.48	4.45
	2000 avg.	43.30	0.00	0.00	0.00	0.04	0.50	42.76	38.48	4.28
	2000 dry	38.14	0.00	0.00	0.00	0.04	0.50	38.14	25.98	12.16
	2010 avg.	43.30	0.00	0.00	0.00	0.04	0.56	42.70	38.48	4.22
	2010 dry	38.14	0.00	0.00	0.00	0.05	0.56	37.54	25.98	11.56
	2020 avg.	43.30	0.00	0.00	0.00	0.04	0.62	42.64	38.48	4.16
	2020 dry	38.14	0.00	0.00	0.00	0.05	0.62	37.47	25.98	11.49
	2030 avg.	43.30	0.00	0.00	0.00	0.04	0.67	42.59	38.48	4.11
	2030 dry	38.14	0.00	0.00	0.00	0.05	0.67	37.42	25.98	11.44
	2040 avg.	43.30	0.00	0.00	0.00	0.04	0.73	42.53	38.48	4.05
	2040 dry	38.14	0.00	0.00	0.00	0.05	0.73	37.36	25.98	11.38
Upper Mississippi[12]	1985 avg.	79.90	0.00	2.00	0.60	0.62	1.21	79.47	69.70	9.77
	2000 avg.	79.90	0.00	2.00	0.60	0.69	1.81	78.80	69.70	9.10
	2000 dry	64.81	0.00	2.00	0.60	0.82	1.81	63.57	47.94	15.63
	2010 avg.	79.90	0.00	2.00	0.60	0.71	2.05	78.54	69.70	8.84
	2010 dry	64.81	0.00	2.00	0.60	0.86	2.05	63.30	47.94	15.36
	2020 avg.	79.90	0.00	2.00	0.60	0.75	2.25	78.30	69.70	8.60
	2020 dry	64.81	0.00	2.00	0.60	0.89	2.25	63.06	47.94	15.12
	2030 avg.	79.90	0.00	2.00	0.60	0.77	2.46	78.07	69.70	8.37
	2030 dry	64.81	0.00	2.00	0.60	0.92	2.46	62.82	47.94	14.88
	2040 avg.	79.90	0.00	2.00	0.60	0.79	2.67	77.84	69.70	8.14
	2040 dry	64.81	0.00	2.00	0.60	0.95	2.67	62.59	47.94	14.65
Lower Mississippi[13]	1985 avg.	470.00	5.80	0.00	6.00	24.99	5.88	377.06	359.00	18.06
	2000 avg.	470.00	5.37	0.00	6.90	29.37	8.98	369.78	359.00	10.78
	2000 dry	315.90	5.37	0.00	6.90	33.83	8.98	275.59	282.00	-6.41
	2010 avg.	470.00	5.08	0.00	7.50	30.69	10.26	366.93	359.00	7.93
	2010 dry	315.90	5.08	0.00	7.50	35.36	10.26	272.05	282.00	-9.95
	2020 avg.	470.00	4.79	0.00	8.10	31.98	11.34	364.26	359.00	5.26
	2020 dry	315.90	4.79	0.00	8.10	36.84	11.34	269.22	282.00	-12.78

Table 16.—Generalized water budget for average and dry years, 1985-2040, by water resources region[1]—Continued

	2030 avg.	470.00	4.50	0.00	8.70	32.99	12.52	355.16	359.00	-3.84
	2030 dry	315.90	4.50	0.00	8.70	38.00	12.52	258.68	282.00	-23.32
	2040 avg.	470.00	4.20	0.00	9.30	33.91	13.79	352.45	359.00	-6.55
	2040 dry	315.90	4.20	0.00	9.30	39.06	13.79	255.81	282.00	-26.19
Souris-Red-Rainy	1985 avg.	7.70	0.00	0.00	0.40	0.08	0.06	7.16	3.67	3.49
	2000 avg.	7.70	0.00	0.00	0.40	0.09	0.08	7.13	3.67	3.46
	2000 dry	4.38	0.00	0.00	0.40	0.11	0.08	3.79	2.31	1.48
	2010 avg.	7.70	0.00	0.00	0.40	0.09	0.09	7.12	3.67	3.45
	2010 dry	4.38	0.00	0.00	0.40	0.11	0.09	3.78	2.31	1.47
	2020 avg.	7.70	0.00	0.00	0.40	0.10	0.10	7.10	3.67	3.43
	2020 dry	4.38	0.00	0.00	0.40	0.11	0.10	3.77	2.31	1.46
	2030 avg.	7.70	0.00	0.00	0.40	0.10	0.10	7.10	3.67	3.43
	2030 dry	4.38	0.00	0.00	0.40	0.12	0.10	3.76	2.31	1.45
	2040 avg.	7.70	0.00	0.00	0.40	0.10	0.11	7.09	3.67	3.42
	2040 dry	4.38	0.00	0.00	0.40	0.12	0.11	3.75	2.31	1.44
Missouri	1985 ave.	67.30	2.20	0.20	3.30	11.96	0.88	53.56	33.96	19.60
	2000 avg.	67.30	2.20	0.17	4.07	14.11	1.26	50.23	33.96	16.27
	2000 dry	51.07	2.20	0.10	4.07	15.53	1.26	32.51	20.12	12.40
	2010 avg.	67.30	2.20	0.14	4.58	14.75	1.42	48.89	33.96	14.93
	2010 dry	51.07	2.20	0.03	4.58	16.23	1.42	31.08	20.12	10.96
	2020 avg.	67.30	2.20	0.12	5.09	15.37	1.55	47.61	33.96	13.65
	2020 dry	51.07	2.20	-0.03	5.09	16.91	1.55	29.69	20.12	9.57
	2030 avg.	67.30	2.20	0.10	5.60	15.86	1.68	46.46	33.96	12.50
	2030 dry	51.07	2.20	-0.10	5.60	17.44	1.68	28.45	20.19	8.26
	2040 avg.	67.30	2.20	0.08	6.11	16.30	1.81	45.36	33.96	11.40
	2040 dry	51.07	2.20	-0.17	6.11	17.93	1.81	27.25	20.19	7.06
Arkansas-White-Red	1985 avg.	63.70	3.60	0.10	1.40	7.43	0.66	57.91	46.17	11.74
	2000 avg.	63.70	3.17	0.13	1.50	8.77	0.95	55.78	46.17	9.61
	2000 dry	39.98	3.17	0.13	1.50	10.52	0.95	30.31	19.11	11.20
	2010 avg.	63.70	2.88	0.15	1.56	9.17	1.07	54.93	46.17	8.76
	2010 dry	39.98	2.88	0.15	1.56	11.00	1.07	29.38	19.11	10.27
	2020 avg.	63.70	2.59	0.17	1.63	9.55	1.18	54.10	46.17	7.93
	2020 dry	39.98	2.59	0.17	1.63	11.46	1.18	28.47	19.11	9.36
	2030 avg.	63.70	2.30	0.20	1.70	9.85	1.28	53.37	46.17	7.20
	2030 dry	39.98	2.30	0.20	1.70	11.82	1.28	27.68	19.11	8.57
	2040 avg.	63.70	2.00	0.22	1.77	10.13	1.38	52.64	46.17	6.47
	2040 dry	39.98	2.00	0.22	1.77	12.16	1.38	26.90	19.11	7.79
Texas-Gulf	1985 avg.	35.90	3.10	0.00	1.80	4.57	1.54	31.09	22.92	8.17
	2000 avg.	35.90	3.10	0.00	1.87	5.38	2.29	29.46	22.92	6.54
	2000 dry	19.77	3.10	0.00	1.87	5.92	2.29	12.80	10.77	2.03
	2010 avg.	35.90	3.10	0.00	1.91	5.62	2.57	28.90	22.92	5.98
	2010 dry	19.77	3.10	0.00	1.91	6.19	2.57	12.21	10.77	1.44
	2020 avg.	35.90	3.10	0.00	1.96	5.86	2.82	28.36	22.92	5.44
	2020 dry	19.77	3.10	0.00	1.96	6.44	2.82	11.65	10.77	0.88
	2030 avg.	35.90	3.10	0.00	2.00	6.04	3.05	27.91	22.92	4.99
	2030 dry	19.77	3.10	0.00	2.00	6.65	3.05	11.18	10.77	0.41
	2040 avg.	35.90	3.10	0.00	2.04	6.21	3.26	27.49	22.92	4.57
	2040 dry	19.77	3.10	0.00	2.04	6.83	3.26	10.74	10.77	-0.03
Rio Grande	1985 avg.	5.00	0.00	0.10	0.80	2.01	0.22	2.07	2.29	-0.22
	2000 avg.	5.00	0.00	0.10	0.80	2.37	0.32	1.61	2.29	-0.68
	2000 dry	4.09	0.00	0.10	0.80	2.61	0.32	0.46	1.50	-1.04
	2010 avg.	5.00	0.00	0.10	0.80	2.48	0.36	1.46	2.29	-0.83
	2010 dry	4.09	0.00	0.10	0.80	2.73	0.36	0.30	1.50	-1.20
	2020 avg.	5.00	0.00	0.10	0.80	2.59	0.39	1.32	2.29	-0.97
	2020 dry	4.09	0.00	0.10	0.80	2.84	0.39	0.16	1.50	-1.34
	2030 avg.	5.00	0.00	0.10	0.80	2.67	0.42	1.21	2.29	-1.08
	2030 dry	4.09	0.00	0.10	0.80	2.93	0.42	0.04	1.50	-1.46
	2040 avg.	5.00	0.00	0.10	0.80	2.74	0.44	1.12	2.29	-1.17
	2040 dry	4.09	0.00	0.10	0.80	3.02	0.44	-0.07	1.50	-1.57
Upper Colorado	1985 avg.	12.30	0.00	-0.60	1.70	2.23	0.17	7.60	7.95	-0.35
	2000 avg.	12.30	0.00	-0.70	1.70	2.64	0.28	6.98	7.95	-0.97
	2000 dry	9.67	0.00	-0.70	1.70	2.91	0.28	4.08	3.69	0.39
	2010 avg.	12.30	0.00	-0.77	1.70	2.77	0.33	6.73	7.95	-1.22
	2010 dry	9.67	0.00	-0.77	1.70	3.04	0.33	3.83	3.69	0.14
	2020 avg.	12.30	0.00	-0.83	1.70	2.88	0.37	6.52	7.95	-1.43
	2020 dry	9.67	0.00	-0.83	1.70	3.17	0.37	3.60	3.69	-0.09
	2030 avg.	12.30	0.00	-0.90	1.70	2.97	0.42	6.31	7.95	-1.64
	2030 dry	9.67	0.00	-0.90	1.70	3.27	0.42	3.38	3.69	-0.31
	2040 avg.	12.30	0.00	-0.97	1.70	3.06	0.47	6.11	7.95	-1.84
	2040 dry	9.67	0.00	-0.97	1.70	3.36	0.47	3.17	3.69	-0.52
Lower Colorado[14]	1985 avg.	11.20	2.10	-3.70	3.60	5.86	0.80	-0.66	6.86	-7.52
	2000 avg.	11.20	2.10	-3.60	3.60	6.94	1.21	-2.05	6.86	-8.91
	2000 dry	8.79	2.10	-3.60	3.60	7.63	1.21	-5.15	3.36	-8.51
	2010 avg.	11.20	2.10	-3.53	3.60	7.25	1.63	-2.72	6.86	-9.58
	2010 dry	8.79	2.10	-3.53	3.60	7.98	1.63	-5.85	3.36	-9.21
	2020 avg.	11.20	2.10	-3.47	3.60	7.56	1.50	-2.82	6.86	-9.68
	2020 dry	8.79	2.10	-3.47	3.60	8.31	1.50	-5.99	3.36	-9.35
	2030 avg.	11.20	2.10	-3.40	3.60	7.80	1.62	-3.12	6.86	-9.98
	2030 dry	8.79	2.10	-3.40	3.60	8.58	1.62	-6.30	3.36	-9.66

Table 16.—Generalized water budget for average and dry years, 1985-2040, by water resources region[1]—Continued

	2040 avg.	11.20	2.10	-3.32	3.60	8.02	1.75	-3.38	6.86	-10.24
	2040 dry	8.79	2.10	-3.32	3.60	8.82	1.75	-6.59	3.36	-9.95
Great Basin	1985 avg.	8.30	0.00	0.00	0.20	3.39	0.23	4.49	3.39	1.10
	2000 avg.	8.30	0.00	0.00	0.20	4.01	0.33	3.76	3.39	0.37
	2000 dry	7.02	0.00	0.00	0.20	4.41	0.33	2.08	2.49	-0.41
	2010 avg.	8.30	0.00	0.00	0.20	4.19	0.36	3.54	3.39	0.15
	2010 dry	7.02	0.00	0.00	0.20	4.61	0.36	1.85	2.49	-0.64
	2020 avg.	8.30	0.00	0.00	0.20	4.37	0.40	3.34	3.39	-0.05
	2020 dry	7.02	0.00	0.00	0.20	4.81	0.40	1.62	2.49	-0.87
	2030 avg.	8.30	0.00	0.00	0.20	4.51	0.42	3.17	3.39	-0.22
	2030 dry	7.02	0.00	0.00	0.20	4.96	0.42	1.45	2.49	-1.04
	2040 avg.	8.30	0.00	0.00	0.20	4.63	0.44	3.03	3.39	-0.36
	2040 dry	7.02	0.00	0.00	0.20	5.10	0.44	1.29	2.49	-1.20
Pacific Northwest	1985 avg.	291.00	0.00	0.00	0.60	12.15	0.59	277.67	214.00	63.67
	2000 avg.	291.00	0.00	0.00	0.60	14.38	0.74	275.29	214.00	61.29
	2000 dry	245.52	0.00	0.00	0.60	17.25	0.74	226.93	174.60	52.33
	2010 avg.	291.00	0.00	0.00	0.60	15.03	0.81	274.56	214.00	60.56
	2010 dry	245.52	0.00	0.00	0.60	18.03	0.81	226.07	174.60	51.47
	2020 avg.	291.00	0.00	0.00	0.60	15.66	0.87	273.87	214.00	59.87
	2020 dry	245.52	0.00	0.00	0.60	18.79	0.87	225.26	174.60	50.66
	2030 avg.	291.00	0.00	0.00	0.60	16.15	0.93	273.32	214.00	59.32
	2030 dry	245.52	0.00	0.00	0.60	19.38	0.93	224.61	174.60	50.01
	2040 avg.	291.00	0.00	0.00	0.60	16.61	0.98	272.82	214.00	58.82
	2040 dry	245.52	0.00	0.00	0.60	19.93	0.98	224.01	174.60	49.41
California	1985 avg.	86.90	1.40	3.70	0.50	19.36	1.70	70.44	32.61	37.83
	2000 avg.	86.90	1.22	3.60	0.50	22.92	2.45	65.85	32.61	33.24
	2000 dry	42.72	1.22	3.60	0.50	25.21	2.45	19.38	26.07	-6.69
	2010 avg.	86.90	1.10	3.53	0.50	23.96	2.72	64.35	32.61	31.74
	2010 dry	42.72	1.10	3.53	0.50	26.36	2.72	17.77	26.07	-8.30
	2020 avg.	86.90	0.98	3.47	0.50	24.96	2.96	62.93	32.61	30.32
	2020 dry	42.72	0.98	3.47	0.50	27.46	2.96	16.26	26.07	-9.81
	2030 avg.	86.90	0.86	3.40	0.50	25.75	3.15	61.77	32.61	29.16
	2030 dry	42.72	0.86	3.40	0.50	28.32	3.15	15.01	26.07	-11.06
	2040 avg.	86.90	0.74	3.32	0.50	26.48	3.29	60.69	32.61	28.08
	2040 dry	42.72	0.74	3.32	0.50	29.13	3.29	13.86	26.07	-12.21
Total contiguous U.S.[15]	1985 avg.	1379.60	12.40	-1.90	15.10	76.03	17.38	1281.59	1043.18	238.41
	2000 avg.	1379.60	11.79	-1.90	16.07	89.69	26.14	1257.60	1043.18	214.42
	2000 dry	1000.98	11.79	-1.90	16.07	102.05	26.14	866.61	784.98	81.63
	2010 avg.	1379.60	11.38	-1.90	16.71	93.75	29.90	1248.71	1043.18	205.53
	2010 dry	1000.98	11.38	-1.90	16.71	106.67	29.90	857.18	784.98	72.20
	2020 avg.	1379.60	10.97	-1.90	17.36	97.68	32.64	1241.00	1043.18	197.82
	2020 dry	1000.98	10.97	-1.90	17.36	111.14	32.64	848.91	784.98	63.93
	2030 avg.	1379.60	10.56	-1.90	18.00	100.75	35.72	1233.79	1031.03	202.76
	2030 dry	1000.98	10.56	-1.90	18.00	114.64	35.71	841.29	784.98	56.31
	2040 avg.	1379.60	10.14	-1.90	18.64	103.59	38.90	1226.70	1043.18	183.52
	2040 dry	1000.98	10.14	-1.90	18.64	117.87	38.90	833.81	784.98	48.83

[1] *The figures in this table differ from those in the Appraisal (USDA 1987, table 16-2) because new projections of offstream consumptive use were prepared for this report based upon regression analyses and more recent water use and demographic data. For example, the 1985 estimates of water use from the Geological Survey were available for this report but not for the Appraisal. Also, the Appraisal was based upon 1982 projections of population and economic growth, this report used 1987 projections.*

[2] *Average condition represents the flows in a "normalized" year, when the amount of annual precipitation is the long-term average (the precipitation that is exceeded 50 percent of the time). The dry condition is the normalized flow when the amount of annual precipitation is exceeded 80 percent of the time.*

[3] *Renewable supply is the precipitation that reaches aquifers or that runs off into surface water supplies. It is estimated by taking measured 1985 instream flows, subtracting other supplies (overdrafts and imports), and adding depletions (consumptive use, net reservoir evaporation, and exports).*

[4] *Groundwater overdrafts are quantities of water withdrawn from aquifers in excess of the recharge volume. These estimates were obtained from Anon. (1984, page 243), cited by Foxworthy and Moody (1986, table 7).*

[5] *Exports are shown in the table as a negative number. The data were taken from Petch (1985), cited by Foxworthy and Moody (1986, table 8).*

[6] *Data for net reservoir evaporation were taken from Foxworthy and Moody (1986, table 7).*

[7] *Consumptive use estimates for agriculture are the sum of numbers in tables A-14 and A-18. Consumptive use estimates for non-agriculture are the sum of numbers from tables A-13, A-15, A-16, and A-17. All the estimates for 2000 to 2040 are new projections prepared for this report. Dry year agricultural use is 20% higher in humid regions, 10% higher in dry regions (Flickinger 1988).*

[8] *Average stream outflow for 1985 is from Graczyk and others (1986). Outflows are computed for 2000 to 2040 from renewable supply.*

[9] *Instream flow requirements for average years are the flows needed for optimal fish and wildlife habitat. Data are from Water Resources Council (1978). Instream flow requirements for good survival habitat in dry years are assumed to be 60% of mean natural flow in the average year for New England, MidAtlantic, South Atlantic-Gulf, Great Lakes, Ohio, Tennessee, Upper and Lower Mississippi and the Pacific Northwest regions. In the other regions, the instream flow requirements for good survival habitat in dry years are assumed to be 30% of mean natural flow in the average year (Flickinger 1987).*

[10] *A surplus exists if the average stream outflow exceeds the instream flow requirement. A deficit exists if the instream flow requirement exceeds the average stream outflow.*

[11] *The estimates for the Ohio water resource region are exclusive of outflows from the Tennessee region.*

[12] *The estimates for the Upper Mississippi water resource region are exclusive of outflows from the Missouri region.*

[13] *The estimates for the Lower Mississippi water resource region represent conditions in all the upstream regions (Ohio, Tennessee, Upper Mississippi, Missouri, and Arkansas-White-Red regions).*

[14] *The estimates for the Lower Colorado water resources region represent conditions in both the Upper and Lower Colorado regions.*

[15] *The total for the contiguous U.S. includes data for the lower 48 States. Information on instream flow requirements was not available for the Hawaii, Alaska, or Caribbean regions.*

Source: After Flickinger (1987, table 28b) and Foxworthy and Moody (1986, table 7).

Although water is relatively scarce in the West as compared to the East, sufficient quantities do exist to meet demands to 2040 if water prices and institutions are allowed to change and bring demands into equilibrium with available supplies. Unfortunately, water institutions and pricing rarely work as effectively as economic theory might suggest. Consequently, shortages result from the failure of institutions to respond adequately to seasonal or long-term changes in the relative scarcity of water. It is probably too much to expect that our water institutions can eliminate scarcities resulting from climatological, physiographical, or edaphic changes in water availability. But institutions can deal more effectively with shortages rooted in prevailing institutional, technological, and economic frameworks.[1]

PLENTIFUL SUPPLIES

Water surpluses exist in all regions east of the Great Plains and the Pacific Northwest through 2040. In most cases, the surplus in an average rainfall year exceeds 10% of instream flow requirements for optimal habitat. In more than half the regions, the surplus exceeds 25% of instream flow requirements. In dry years, surpluses still exist in the Pacific Northwest and in all regions east of the Great Plains except the Lower Mississippi region. Surpluses in dry years still exceed instream flow requirements for good survival habitat by at least 10% through 2040.

The existence of surpluses through 2040 in these regions suggests that there is plenty of water available, on a regional basis, even in abnormally dry years. Surpluses provide a comfortable cushion of flow volume that guarantees continued abundance of both warm and cold water fisheries, assuming of course, that water quality is not limiting.

Surpluses represent regional conditions resulting from expected average annual precipitation if withdrawals or consumptive offstream uses are spread evenly across regions having surpluses. Consequently, even though a surplus is projected for a particular region (table 16), there will still be reaches of rivers and seasons when flows diminish to the point where good survival habitat is threatened.

USDA Forest Service (1981) contains a more detailed analysis of flow depletions than presented in this report. Results of that analysis show that even in many areas which have regional surpluses, there will be certain river drainages or reaches where low flows fall to less than 10% of the mean annual flow for several months each year. Extended periods of flows that low, coupled with quantities of oxygen-demanding wastes formerly discharged into streams in the 1950s and 1960s, resulted in the near-absence of sport fish in many drainages. Even non-sport fish were not prevalent. With a reduction in quantity of oxygen-demanding wastes discharged to these streams as a result of the Clean Water Act, fish populations expanded in many streams to the point where viable sport fish populations have emerged. The point is, however, that even though a surplus exists on an annual basis, water and related resource managers still have significant problems to contend with, albeit on a localized and intermittent basis.

Because ample flows exist in most water resource regions, there is no inconsistency between demand and supply projections. If both projections were plotted on the same axis, they would not intersect. Consequently, the lesser of the two curves, the demand projections, can be viewed as equilibrium projections. The excess supplies are not needed to satisfy current or projected needs. If water were produced and priced like a manufactured product, production output would be reduced to levels demanded over time. But because of the nature of the streamflow "production" process, cutbacks are not possible.

SHORTAGES

Lower Colorado Region

In years of average rainfall, the Lower Colorado water resource region faces significant water deficits. Deficits in an average year are more than instream flow requirement for optimal fish and wildlife habitat. In dry years, deficits are roughly 300% of the instream flow requirement for good survival habitat. Deficits are more than 400% of the regional groundwater overdraft level. Of all U.S. regions, the Lower Colorado has the most severe problems. Projections of recent trends suggest it will continue to have the most significant problems.

Analyses of the water budget for the Lower Colorado region were accomplished in two ways (table 17). The traditional approach is to include effects of supplies and demands from upstream tributary regions, which in this case is the Upper Colorado. A separate analysis excluding tributary regions also exists. The latter analysis illustrates the degree to which upstream regions are responsible for helping create deficits.

In 1985, irrigation consumed 87% of the 6.65 bgd average consumption in the Lower Colorado region (table 17). The deficit in an average year exceeds daily consumption by 865 million gallons per day. By 2040, irrigation consumption will drop to 82% of the 9.76 bgd consumed. Conservation measures likely to be adopted will lessen growth in the deficit over the projection period. Consumption is projected to increase 47% over the projection period while the deficit increased only 36% in the mean year (17% in the dry year).

Supply augmentation measures of the scale needed to eliminate the deficit are not likely to be implemented. Measures available are vegetation management, construction of snow-trapping structures, and weather modification. All are feasible for increasing or changing the season of runoff over a local area. But none has been implemented over a wide enough geographic area to evaluate its ability to make a significant contribution to reducing the projected deficit. The feasibility studies have shown that implementing such measures at the scale needed to eliminate the deficit will create regional environmental impacts on visual amenities and high-

Table 17.—Water consumption (million gallons per day) in the Lower Colorado water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040

Use (including Upper Colorado)	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Irrigation	6,900	6,300	8,700	7,200	6,300	5,830	6,912	7,227	7,529	7,766	7,986
Municipal central supplies	120	164	209	266	431	469	676	746	806	849	874
Industrial self-supplies	37	59	121	217	213	137	222	251	280	310	339
Thermoelectric steam cooling	15	33	58	107	179	156	278	333	376	433	501
Domestic self-supplies	8	7	20	30	44	36	31	32	32	33	33
Livestock watering	19	26	45	61	33	27	27	28	29	30	31
Total	7,099	6,589	9,153	7,881	7,200	6,655	8,147	8,617	9,053	9,420	9,764
Deficit - Mean Year[1]						7,520	8,910	9,580	9,680	9,980	10,240
Deficit - Dry Year[2]							8,510	9,210	9,350	9,660	9,950
Use (excluding Upper Colorado)	**1960**	**1965**	**1970**	**1975**	**1980**	**1985**	**2000**	**2010**	**2020**	**2030**	**2040**
Irrigation	3,395	3,100	4,700	5,700	4,300	3,610	4,280	4,475	4,662	4,808	4,945
Municipal central supplies	110	150	190	240	390	434	626	691	747	786	809
Industrial self-supplies	32	51	100	190	150	115	186	211	235	260	285
Thermoelectric steam cooling	7	15	36	47	49	49	87	105	118	136	157
Domestic self-supplies	6	5	17	27	27	27	23	24	24	25	25
Livestock watering	12	16	28	47	11	14	14	14	15	16	16
Total	3,561	3,337	5,071	6,251	4,927	4,250	5,218	5,520	5,801	6,031	6,237
Deficit - Mean Year[1]						5,110	5,980	6,210	6,430	6,590	6,720
Deficit - Dry Year[2]							5,320	5,570	5,800	5,990	6,130

[1] *The deficit in the mean year assumes the precipitation level that will be exceeded 5 years in 10 and the instream flows needed for optimal fish and wildlife habitat (See notes 2 and 9, table 16).*

[2] *The deficit in the dry year assumes the precipitation level that will be exceeded 8 years in 10 and the instream flows needed for good survival habitat for fish and wildlife (see notes 2 and 9, table 16).*

altitude vegetation far in excess of the impact level heretofore deemed acceptable. Thus, measures to increase supplies are unlikely to make a significant contribution to reducing the deficit. While supply management practices, such as storing runoff in a wet year for use in drier years, do make a significant contribution to satisfying demands, additional reservoir construction on the scale necessary to eliminate the deficit is not likely. Using imports to alleviate the deficit is unlikely given the interbasin agreements in place that regulate flows on the Lower Colorado River.

Groundwater overdrafts are 260% of non-irrigation consumption needs. Overdrafts are a short-term expedient for meeting current demands but eventually will exacerbate the problem. Using additional overdrafts to cure the deficit is not feasible. Consequently, two inescapable conclusions remain. Either we will continue to sacrifice wildlife and fish habitat and recreation potential dependent on instream flows that are at least 30% of the mean annual flow level (good survival habitat) or we must do a better job of curtailing consumption of water by offstream uses.

Instream flows in 1987 are less than 25% of those needed for optimal habitat. Projections of increased demand drive streamflow to less than 10% of optimal by 2000 in an average precipitation year and to negative streamflows in dry years. The latter is possible only by drawing down reservoir storage. By 2040, if recent use trends continue, negative flows will also occur in the mean year.

The magnitude of the deficit and magnitude of conservation measures implied by recent trends in consumption suggest that major new conservation measures will be necessary to cope with an unrelenting increase in deficits. Clearly, strong measures must be taken to deal with the deficit if long-term adverse impacts are to be avoided. Just as clearly, recent trends in increasing demands for water will have to be curtailed to reduce the deficit.

Because irrigation is the largest water consumer in the Lower Colorado region and because this water has the lowest price, it will likely be the use that bears the brunt of demand reduction. Reductions have already begun. Irrigation consumption peaked in 1975 at 5.7 bgd in the region. Since then, consumption has declined by 37% to 3.6 bgd. Further reductions will be necessary to bring supplies and demand into equilibrium. Compared to the 1980 use level, municipal demands have increased 11% to 434 mgd in 1985.

Prices for water are likely to rise as available supplies are rationed by market forces to their highest and best uses. Active markets for water rights have emerged in the states comprising the Lower Colorado region, and especially in Colorado. Institutional adjustments to provide additional freedom in buying and selling water rights are likely to occur to facilitate demand adjustments. Prices will climb as impediments to market functioning are eliminated. Many irrigators will find it quite profitable to liquidate water assets by selling rights to municipal water users. Lease-back arrangements may become a popular method to retire land from irrigated agricultural production.

In summary, water consumption in the Lower Colorado region needs to decline to bring it into long-term equilibrium with available supplies. No other single factor or combination of factors has the potential for significantly reducing the water supply deficit. Prices for water are likely to rise substantially in the Lower Colorado region as shortages continue. Price increases will help bring demand and supply into equilibrium. The ultimate schedule of prices for water cannot be reliably projected, but the long-term equilibrium quantity resulting from price adjustments will probably be close to current supply levels.

Upper Colorado Region

The Upper Colorado region 1985 deficit was 350 mgd (table 18). However, demand projections indicate that deficits will rise to 1.84 bgd by 2040. The situation in this region is interesting because dry year assumptions project surpluses through 2020. The reason is the difference in instream flows necessary for optimal versus good survival habitat for fish and wildlife. The difference between these two instream flow assumptions makes the difference between deficits and surpluses. Projected deficits are between 5 and 30% of average stream outflows.

In the Upper Colorado region, the question whether or not to reduce the deficit depends on the degree to which anglers, hunters, and recreationists are content with less than optimal instream flows. If they are content with minor departures from the optimum, little needs to be done between now and 2020. If, on the other hand, departures from the optimum cause significant reductions in benefits from instream flows, then some moderate demand reduction measures can be taken. For example, if irrigation water usage is held at the 1985 level through 2040, half the projected deficits in the mean year can be eliminated. Remaining deficits would only be 13% of the optimal instream flow. This is probably a tolerable reduction from the optimum because the average rainfall is expected to be exceeded (and wash away the deficit) 5 years in 10.

The equilibrium flow rates will likely lie close to the long-term supply projection. Vegetation management, snow-trapping structures, and weather modification may make a contribution to eliminating a deficit of this magnitude. They are already being practiced in some eastern headwater watersheds in this region.

Rio Grande Region

The Rio Grande region has a current deficit and projected increases in deficits to 2040. In contrast to the Lower Colorado region where the deficit exceeds current and projected future consumption levels, the Rio Grande region deficit is only between 10% (today) and 37% (in 2040) of consumption levels in the average precipitation year (table 19). Deficits in dry years are 39% of projected use in 2000 and 49% in 2040.

Groundwater overdrafts are not used and imports are low at 2% of renewable supply. Neither offer much hope for reducing the deficit. To the west is the Lower Colorado region where interbasin transfers are strictly controlled and increasing exports would encounter insurmountable institutional barriers. The Arkansas-White-Red basin is to the north and east; but the closest drainages to the Rio Grande are not reliable sources of water for exports either. Using additional groundwater to eliminate the deficit is not likely because available aquifers are incapable of withstanding significant increases in withdrawals or short-term overdrafts. Additional reservoir developments of the magnitude needed to eliminate the deficit are not feasible given current conditions.

As in the Lower Colorado region, the greatest potential for reducing the deficit lies in curtailing consumption. If irrigation demands can be held at current levels throughout the projection period, 60% of the deficit can

Table 18.—Water consumption (million gallons per day) in the Upper Colorado water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040

Use	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Irrigation	3,505	3,200	4,000	1,500	2,000	2,220	2,632	2,752	2,867	2,957	3,041
Thermoelectric steam cooling	8	18	22	60	130	107	191	229	258	297	344
Industrial self-supplies	5	8	21	27	63	22	36	40	45	50	54
Municipal central supplies	10	14	19	26	41	35	50	55	60	63	65
Livestock watering	7	10	17	14	22	13	13	13	14	14	15
Domestic self-supplies	2	2	3	3	17	9	8	8	8	8	8
Total	3,538	3,252	4,082	1,630	2,273	2,405	2,929	3,097	3,251	3,389	3,527
Deficit - Mean Year[1]						350	970	1,220	1,430	1,640	1,840
Deficit - Dry Year[2]							(390)[3]	(140)	90	310	520

[1]*The deficit in the mean year assumes the precipitation level that will be exceeded 5 years in 10 and the instream flows needed for optimal fish and wildlife habitat (See notes 2 and 9, table 16).*

[2]*The deficit in the dry year assumes the precipitation level that will be exceeded 8 years in 10 and the instream flows needed for good survival habitat for fish and wildlife (see notes 2 and 9, table 16).*

[3]*Numbers in parentheses are negative deficits, i.e. surpluses.*

Table 19.—Water consumption (million gallons per day) in the Rio Grande water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040

Use	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Irrigation	3,402	3,900	3,000	3,200	2,100	1,970	2,336	2,442	2,544	2,624	2,699
Municipal central supplies	124	110	150	190	140	146	210	232	251	264	272
Industrial self-supplies	31	46	97	55	13	46	75	84	94	104	114
Thermoelectric steam cooling	4	11	17	20	11	13	23	28	31	36	42
Domestic self-supplies	6	7	13	17	18	19	16	16	17	17	17
Livestock watering	13	68	36	37	26	39	39	40	42	43	44
Total	3,581	4,142	3,313	3,519	2,308	2,232	2,698	2,842	2,979	3,088	3,187
Deficit - Mean Year[1]						220	680	830	970	1080	1170
Deficit - Dry Year[2]							1040	1200	1340	1460	1570

[1] *The deficit in the mean year assumes the precipitation level that will be exceeded 5 years in 10 and the instream flows needed for optimal fish and wildlife habitat (See notes 2 and 9, table 16).*

[2] *The deficit in the dry year assumes the precipitation level that will be exceeded 8 years in 10 and the instream flows needed for good survival habitat for fish and wildlife (see notes 2 and 9, table 16).*

be eliminated. Irrigation demand peaked at 3.9 bgd in 1965 and has since declined 49% to the 1985 level of 1.97 bgd. If an additional 16% decline in irrigation use can be attained by 2000, the deficit will disappear in the mean year and in the dry year the deficit would be 360 mgd or 17% of total consumption. Future deficits would likewise be about 6% of use in the mean year and 25% in dry years.

In summary, minor increases in water conservation measures for irrigation, followed by holding the line against further increases in irrigation water usage, will eliminate deficits in the Rio Grande region by 2000 and make deficits manageable for the remainder of the projection period. Projections of recent trends for nonagricultural water usage can be accommodated within this scenario. Equilibrium water usage will progress from 2.23 bgd in 1985 to 2.14 bgd in 2040, which is essentially the constant supply projection.

Great Basin Region

The Great Basin is projected to have surpluses in the average year through 2010, a negligible deficit in 2020 (2% of average stream outflow), and deficits necessitating a response beginning in 2030 (table 20). Significant dry year deficits do not emerge until 2010. In 2040 in a dry year, the projected deficit equals the expected instream flow.

Holding irrigation water usage at 1985 levels would more than eliminate the projected deficits through 2040, even in dry years. In fact, projections indicate that irrigation water usage could be allowed to increase 27% (3.2 bgd) through 2040 and supplies would still be adequate to meet demands in dry years. In this region, managing growth at a lower rate than prevalent since 1960 will suffice to assure adequate water supplies in dry years. The equilibrium between supply and demand will

Table 20.—Water consumption (million gallons per day) in the Great Basin water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040

Use	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Irrigation	8,000	10,000	10,000	9,900	11,000	12,000	14,227	14,875	15,496	15,984	16,439
Municipal central supplies	150	210	260	230	290	219	316	349	377	397	408
Industrial self-supplies	91	83	150	310	350	114	185	209	233	258	282
Thermoelectric steam cooling	0	0	0	9	2	25	45	53	60	69	80
Livestock watering	55	55	47	47	49	150	149	154	161	166	170
Domestic self-supplies	23	75	200	180	200	227	191	196	200	202	204
Total	8,319	10,423	10,657	10,676	11,891	12,735	15,113	15,836	16,528	17,077	17,583
Deficit - Mean Year[1]						(1,110)[3]	(370)	(150)	50	220	360
Deficit - Dry Year[2]							410	640	870	1,040	1,200

[1] *The deficit in the mean year assumes the precipitation level that will be exceeded 5 years in 10 and the instream flows needed for optimal fish and wildlife habitat (See notes 2 and 9, table 16).*

[2] *The deficit in the dry year assumes the precipitation level that will be exceeded 8 years in 10 and the instream flows needed for good survival habitat for fish and wildlife (see notes 2 and 9, table 16).*

[3] *Numbers in parentheses are negative deficits, i.e. surpluses.*

follow demand projections to 2020 when deficits emerge. At that point, the equilibrium projection shifts to the supply line to 2040.

California Region

California has abundant water supplies in average years (table 21). Surpluses in years of average rainfall will exceed total consumption to 2030 and represent 94% of annual consumption in 2040. However, during dry years, significant deficits emerge. The deficit in 2000 during a dry year amounts to 35% of average stream outflow and grows by 2040 to 88% of average stream outflow in dry years.

California is a leader in moving water from locations of plentiful supply to areas where shortages are expected. Aqueducts of heroic length and capacity move water from drainages in the Sierras to the San Joaquin valley and Los Angeles metropolitan areas. Imports from the Lower Colorado region to the Los Angeles metropolitan area also occur. Of the regions, California typifies an area where imbalances between local demands and local supplies have been solved using structural methods. However, additional structural methods are unlikely to completely solve the deficit in dry years. The benefit stream for solving dry-year deficits is too irregular to justify additional structural solutions to the deficit problem given surpluses normally expected at least half the time.

Tradeoffs in California during dry years are similar to those outlined earlier for the Upper Colorado region. The extent to which demands in dry years should be curtailed to preserve good survival habitat for fish and wildlife and other instream water uses is about the same. If agricultural water usage in California can be held to 1985 levels, this action alone will eliminate 42% of the deficit in dry years. Further, this action will reduce the deficit to 51% of the instream flow requirement in dry years. With some additional conservation practices in dry years to reduce water consumption another 20%, limited detrimental impacts to good survival habitat could be tolerated 2 years in 10. Vegetation management, snow-trapping structures, and weather modification may help mitigate detrimental impacts to instream habitats in this region.

The equilibrium projection in California will follow the demand line in the average year. Equilibrium in a dry year will dip somewhat as demands are curtailed in response to more limited supplies of water.

Lower Mississippi Region

Like the California region, the Lower Mississippi region usually has abundant water supplies. In exceptionally dry years (such as the summer of 1988), instream flows can drop low enough to seriously impede navigation.

The Lower Mississippi region has five tributary regions—Ohio, Tennessee, Upper Mississippi, Missouri and Arkansas-White-Red regions. The water balance listed for the Lower Mississippi region includes effects of all tributary regions also (tables 16 and 22). If all regions simultaneously experienced dry-year rainfall, deficits emerge at 2000. Deficits are not large—2% of average stream outflow in 2000 rising to 10% of outflow in 2040. However, deficits in what has historically been thought of as a water-rich region were unexpected.

The two analyses in table 22 illustrate that water users in tributary areas are largely responsible for dry-year deficits in the Lower Mississippi region. Deficits are not projected for any of those regions, but the combined effect in a wide-spread dry year will create an externality on water users in the Lower Mississippi region.

Alleviating problems in dry years will require interstate cooperation. Such institutional cooperation has been rare because problems necessitating cooperation have rarely occurred. The U.S. Army Corps of Engineers has provided structural solutions to interstate flooding and navigation problems in these regions. But navigation and flood control structures can have only limited effect upon alleviating flow deficiencies. With offices and

Table 21.—Water consumption (million gallons per day) in the California water resource region, 1960 to 1985, with projections of consumption and water deficits to 2040

Use	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Irrigation	13,000	16,000	21,000	21,000	23,000	19,200	22,764	23,799	24,794	25,574	26,302
Municipal central supplies	370	1,300	1,400	1,500	1,700	1,342	1,937	2,136	2,308	2,431	2,501
Industrial self-supplies	80	110	170	180	190	198	321	363	405	448	490
Thermoelectric steam cooling	17	18	24	32	41	68	120	143	162	186	215
Domestic self-supplies	120	51	73	76	84	91	77	79	80	81	82
Livestock watering	66	45	50	54	47	157	155	161	168	173	176
Total	13,653	17,524	22,717	22,842	25,062	21,056	25,372	26,681	27,917	28,893	29,767
Deficit - Mean Year[1]						(37,830)[3]	(33,240)	(31,740)	(30,320)	(29,160)	(28,080)
Deficit - Dry Year[2]							6,690	8,300	9,810	11,060	12,210

[1] *The deficit in the mean year assumes the precipitation level that will be exceeded 5 years in 10 and the instream flows needed for optimal fish and wildlife habitat (See notes 2 and 9, table 16).*

[2] *The deficit in the dry year assumes the precipitation level that will be exceeded 8 years in 10 and the instream flows needed for good survival habitat for fish and wildlife (see notes 2 and 9, table 16).*

[3] *Numbers in parentheses are negative deficits, i.e. surpluses.*

Table 22.—Water consumption (million gallons per day) in the Lower Mississippi water resource region, 1960 to 1985, with projections of consumption to 2040

Use (including tributary regions)	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Irrigation	11,066	18,809	20,337	26,179	28,527	23,621	28,005	29,279	30,503	31,463	32,358
Municipal central supplies	898	1,136	1,236	1,380	1,534	1,740	2,510	2,769	2,992	3,151	3,242
Industrial self-supplies	1,206	1,489	1,462	1,710	1,957	1,456	2,360	2,669	2,979	3,291	3,605
Thermoelectric steam cooling	97	157	443	888	1,990	1,955	3,488	4,179	4,716	5,422	6,282
Domestic self-supplies	478	600	621	488	786	740	624	639	652	662	667
Livestock watering	939	1,020	1,065	1,159	1,101	1,373	1,361	1,414	1,477	1,524	1,553
Total	14,684	23,211	25,164	31,804	35,895	30,885	38,349	40,949	43,320	45,513	47,707
Deficit - Mean Year[1]						(18,060)[3]	(10,780)	(7,930)	(5,260)	3,840	6,550
Deficit - Dry Year[2]							6,410	9,950	12,780	23,320	26,190
Use (excluding tributary regions)	**1960**	**1965**	**1970**	**1975**	**1980**	**1985**	**2000**	**2010**	**2020**	**2030**	**2040**
Irrigation	660	1,200	2,200	4,000	4,800	4,400	5,217	5,454	5,682	5,861	6,028
Municipal central supplies	110	200	240	310	400	156	225	248	268	282	291
Industrial self-supplies	380	450	780	810	740	200	324	367	409	452	495
Thermoelectric steam cooling	19	20	190	290	400	325	580	695	784	901	1,044
Domestic self-supplies	52	58	100	68	67	92	77	79	81	82	83
Livestock watering	41	44	55	47	41	348	345	358	374	386	394
Total	1,262	1,972	3,565	5,525	6,448	5,521	6,768	7,201	7,599	7,965	8,334
Deficit - Mean Year[1]						(105,280)	(102,700)	(101,380)	(100,090)	(98,840)	(97,570)
Deficit - Dry Year[2]							(25,600)	(24,280)	(22,990)	(21,740)	(20,470)

[1] *The deficit in the mean year assumes the precipitation level that will be exceeded 5 years in 10 and the instream flows needed for optimal fish and wildlife habitat (See notes 2 and 9, table 16).*

[2] *The deficit in the dry year assumes the precipitation level that will be exceeded 8 years in 10 and the instream flows needed for good survival habitat for fish and wildlife (see notes 2 and 9, table 16).*

[3] *The numbers in parentheses are negative deficits, that is, surpluses.*

contacts in all the states and with membership and leadership roles in most major river basin commissions, the Corps is well positioned institutionally to help address the water deficit externality when it occurs.

SUMMARY

Four common themes emerged from the analyses of surpluses and deficits in the Rio Grande, Upper and Lower Colorado, Great Basin, California, and Lower Mississippi water resource regions.

The first is that the impetus to resolve deficits will come from a desire to mitigate adverse impacts on fish and wildlife habitat, recreation use, and navigation caused by low instream flows. Fishing and water-based recreation are both extremely popular activities. Many bulk agricultural and industrial commodities are transported by barges throughout the mid-west, so maintaining navigation is vital to commerce from the Appalachians to the Rockies. Adequate instream flows are essential for all these uses. If benefits from activities decline, users will demand that responsible public officials take action or litigation will likely follow. Public sentiment is strong to preserve habitat and recreational opportunities and commercial interests strongly endorse maintaining navigation.

The second theme is that irrigation is the predominant consumptive use and accounts for more than three-fourths of all use in each region. Irrigation is also the lowest-value offstream use in all regions. Thus, eliminating deficits will require some reduction in the projected rates of growth in irrigation water usage. Experts recently concluded that irrigated crop production is on the verge of a major shift away from historical trends in acres irrigated and water usage (Department of Agriculture 1987). The Appraisal contains three scenarios projecting cropland and pasture production to 2030. If the intermediate scenario occurs, acreage of irrigated cropland will drop 19 million acres between 1982 and 2030 to 44 million acres. Irrigation water usage will drop commensurately. A significant portion of the decline will occur in the five regions where shortages are projected. Changes in irrigation practices outlined by the Department of Agriculture (1987, Chapter 7) will lead to additional reductions in total irrigation water usage. It appears that reductions in irrigation water usage will make a significant contribution to eliminating water supply deficits over the next 40 to 50 years.

The third theme is that non-structural approaches such as modifications in water rights institutions, freer functioning of water markets, and improved interstate cooperation will play the dominant role in solving water supply deficits. The days of using structural approaches as the dominant way to reducing deficits are past. For example, proposals for new reservoirs are encountering increasing amounts of public opposition in spite of support by local agricultural interests. High-quality dam sites have long since been used. Potential sites remaining have difficulties of one form or another, including geological, environmental, economic, or institutional. Chapter 7 of the Appraisal contains an overview of non-structural changes and their potential for helping alleviate shortages.

The fourth theme is that water yield augmentation by vegetation management, building snow-trapping structures, and weather modification can help remedy small deficits. However, these techniques are unlikely to be employed as the dominant way of eliminating major deficits.

ALTERNATIVE FUTURES

The supply/demand situations outlined in tables 16 to 22 are based on assumptions that changes in consumption from 1960 to 1985 are the best basis for projecting changes in consumption from 1990 to 2040.

Alternative future scenarios of supply and demand were developed for this report and result in changes in surpluses and deficits reported in tables 16 to 22. The approach to specifying alternative futures for water was to consider two alternative rates of change in demand. These are 13% higher demands in 2000 and 20% higher from 2010 to 2040; and 13% lower demands in 2000 and 20% lower from 2010 to 2040. For other resources, supply trend increases 20% above and below the long-term trend were also evaluated. In this report, supply changes were associated with assumptions about effects of potential changes in global climates. These assumptions led to supply reductions of between 5 and 40% depending upon the region. A supply increase is not shown.

DEMAND 20% HIGHER THAN PROJECTED

Alternative futures for demand lead to shifts in surpluses and deficits (table 23). All regions that had surpluses under the baseline Assessment demand assumption (except the Texas-Gulf) continue to have surpluses even if demand is increased 20%. In dry years in the Texas-Gulf region, deficits begin in 2020 and continue to 2040.

Deficits appear earlier in the Great Basin. Under the Assessment baseline projection, deficits appeared in 2000 for the dry year and 2020 for the average rainfall year. If demand is 20% higher than projected, the first deficit appears only a decade from now in 2000 under both rainfall conditions. In addition, deficits are much larger—190% (2040 dry) to 250% (2010 dry).

In California, deficits still do not appear in years of average rainfall even if demand is 20% greater than expected. In dry years, deficits are about 50% larger.

In the Lower Mississippi region, deficits appear a decade earlier in years of average rainfall—2020 versus 2030. In addition, deficits are 145% larger—16.1 bgd versus 6.6 bgd by 2040. In dry years, deficits appear by 2000 if demand is 20% higher. Dry-year deficits are also larger for the higher demand—40% (2040) to 87% (2000).

DEMAND 20% LOWER THAN PROJECTED

Lower demand seems much more likely than increased demand, according to the projected decline in irrigated acreage of 19 million acres in Department of Agriculture (1987). Demand reductions generally postpone the beginning of deficits and reduce their intensity.

In the Rio Grande region where a 220 mgd deficit occurs now in average years, a 20% drop in demand would halve deficits in average rainfall years. In dry years, the reduction in demand reduces deficits to roughly 60% of the level originally projected.

In the Upper Colorado region, reducing demand 20% eliminates deficits in dry years and provides good survival habitat. However, a 20% reduction in demand still is not enough to eliminate deficits and provide optimal habitat in the average-rainfall year. Deficits in the average year are only 60% of those under baseline demands. The demand reduction is still not enough to provide optimal fish and wildlife habitat and optimal instream flows for recreation. On the other hand, deficits that remain are between 15 and 20% of optimal levels for habitat and recreation; low enough that many users may not notice the difference.

The demand drop does not significantly reduce projected deficits in the Lower Colorado region. Deficits still hover around 80% of baseline deficits.

In the Great Basin region, a 20% drop in projected demand would eliminate all deficits in average rainfall years. In the dry years, deficits will amount to 100 mgd or about 8% of instream flows in 2040.

In California, a 20% drop in demand by 2040 would result in the largest absolute regional reduction in consumption, 5.4 bgd. A drop of this magnitude would reduce deficits in dry years to between 3 and 6 bgd, or 15% to 30% of average streamflow. These percentages are still large enough to create problems in a dry year but small enough to be manageable with reservoir storage saved from wetter years.

SUPPLY REDUCTIONS DUE TO GLOBAL CLIMATE CHANGES

A number of researchers and agencies have projected increases in the average annual global air temperature over the next 50 to 150 years. Projected rising temperatures are a function of projected increases in concentrations of atmospheric carbon dioxide and other infrared-active gasses stemming from growth in the combustion of fossil fuels. Projections of temperature increases are based on recently developed atmospheric general circulation models (GCMs). Outputs from state-of-the-art GCMs agree on the degree of hemispheric and global warming. However, Gleick (1986) noted that researchers of climate changes are faced with the dilemma that GCMs capable of providing information on the likely effects of human activities on global climate are unsuited for evaluating the nature and magnitude of important regional effects, especially those involving regional hydrology.

Table 23.—Surpluses and deficits (billion gallons per day) resulting from alternative demand futures, by water resource regions

Water resource region	Rainfall Condition	Surpluses or deficits[1]					
		Normal Expected Supplies; Projected Demands			Supplies Expected if Global Climate Changes; Projected Demands (see note)		
		-20 percent	Normal	+20 percent	-20 Percent	Normal	+20 Percent
New England	1985 avg.	7.83	7.76	7.70	3.63	3.48	3.33
	2000 avg.	7.72	7.63	7.54	3.35	3.13	2.90
	2000 dry	15.17	15.08	14.99	11.54	11.32	11.10
	2010 avg.	7.69	7.58	7.48	3.24	2.99	2.74
	2010 dry	15.14	15.03	14.93	11.44	11.19	10.94
	2020 avg.	7.65	7.54	7.43	3.15	2.88	2.61
	2020 dry	15.10	14.99	14.88	11.35	11.07	10.80
	2030 avg.	7.62	7.50	7.38	3.06	2.77	2.48
	2030 dry	15.07	14.95	14.83	12.13	11.83	11.54
	2040 avg.	7.59	7.47	7.34	2.98	2.66	2.35
	2040 dry	15.04	14.92	14.79	11.18	10.86	10.54
Mid-Atlantic	1985 avg.	25.37	25.03	24.68	20.51	20.15	19.79
	2000 avg.	24.77	24.27	23.77	19.86	19.34	18.82
	2000 dry	14.23	13.74	13.24	10.34	9.81	9.28
	2010 avg.	24.53	23.97	23.41	19.60	19.01	18.43
	2010 dry	14.00	13.44	12.88	10.08	9.48	8.88
	2020 avg.	24.32	23.71	23.10	19.37	18.73	18.09
	2020 dry	13.79	13.18	12.57	9.85	9.19	8.54
	2030 avg.	24.12	23.46	22.80	19.14	18.45	17.75
	2030 dry	13.59	12.93	12.27	9.62	8.91	8.19
	2040 avg.	23.92	23.21	22.50	18.90	18.15	17.39
	2040 dry	13.39	12.68	11.96	9 .38	8.61	7.83
South Atlantic-Gulf	1985 avg.	19.84	18.84	17.85	-1.70	-2.75	-3.80
	2000 avg.	18.73	17.46	16.20	-2.91	-4.27	-5.62
	2000 dry	21.13	19.86	18.60	4.79	3.30	1.81
	2010 avg.	18.27	16.89	15.51	-3.36	-4.82	-6.28
	2010 dry	20.67	19.29	17.91	4.32	2.71	1.11
	2020 avg.	17.86	16.37	14.88	-3.76	-5.33	-6.90
	2020 dry	20.26	18.77	17.28	3.89	2.17	0.46
	2030 avg.	17.46	15.87	14.29	-4.15	-5.81	-7.47
	2030 dry	19.86	18.27	16.69	3.49	1.67	-0.14
	2040 avg.	17.07	15.39	13.71	-4.52	-6.28	-8.03
	2040 dry	19.47	17.79	16.11	3.10	1.18	-0.73
Great Lakes	1985 avg.	10.24	9.99	9.73	5.63	5.19	4.74
	2000 avg.	9.91	9.57	9.24	4.61	3.91	3.21
	2000 dry	12.07	11.74	11.40	7.49	6.78	6.06
	2010 avg.	9.77	9.39	9.02	4.18	3.37	2.56
	2010 dry	11.93	11.56	11.19	7.06	6.24	5.41
	2020 avg.	9.64	9.23	8.83	3.82	2.92	2.02
	2020 dry	11.80	11.40	11.00	6.70	5.79	4.87
	2030 avg.	9.51	9.08	8.64	3.41	2.41	1.41
	2030 dry	11.68	11.24	10.81	6.29	5.27	4.25
	2040 avg.	9.39	8.93	8.46	2.93	1.81	0.69
	2040 dry	11.56	11.09	10.63	5.80	4.67	3.53
Ohio	1985 avg.	16.07	15.69	15.31	8.82	8.38	7.93
	2000 avg.	15.48	14.95	14.41	7.84	7.15	6.46
	2000 dry	21.15	20.62	20.09	15.10	14.40	13.70
	2010 avg.	15.17	14.57	13.96	7.42	6.62	5.83
	2010 dry	20.85	20.24	19.64	14.68	13.87	13.07
	2020 avg.	14.92	14.25	13.58	7.07	6.18	5.30
	2020 dry	20.60	19.93	19.26	14.32	13.43	12.54
	2030 avg.	14.63	13.89	13.15	6.65	5.67	4.68
	2030 dry	20.31	19.56	18.82	13.91	12.91	11.92
	2040 avg.	14.31	13.49	12.66	6.19	5.08	3.98
	2040 dry	19.98	19.16	18.34	13.44	12.33	11.21
Tennessee	1985 avg.	4.51	4.43	4.35	0.20	0.12	0.05
	2000 avg.	4.43	4.33	4.23	0.06	-0.05	-0.15
	2000 dry	11.77	11.67	11.57	8.45	8.35	8.24
	2010 avg.	4.38	4.27	4.16	0.01	-0.11	-0.23
	2010 dry	11.72	11.61	11.50	7.86	7.74	7.62
	2020 avg.	4.33	4.21	4.09	-0.04	-0.17	-0.30
	2020 dry	11.68	11.56	11.43	7.81	7.68	7.55
	2030 avg.	4.29	4.16	4.03	-0.08	-0.22	-0.36
	2030 dry	11.63	11.50	11.37	7.77	7.63	7.48
	2040 avg.	4.25	4.10	3.96	-0.13	-0.28	-0.44
	2040 dry	11.59	11.45	11.30	7.72	7.57	7.41
Upper Mississippi	1985 avg.	10.37	10.06	9.75	6.14	5.77	5.40
	2000 avg.	9.98	9.58	9.17	5.61	5.11	4.61
	2000 dry	16.65	16.25	15.84	12.92	12.39	11.87
	2010 avg.	9.80	9.34	8.89	5.39	4.84	4.29

Table 23.—Surpluses and deficits (billion gallons per day) resulting from alternative demand futures, by water resource regions—Continued

	2010 dry	16.46	16.01	15.56	12.70	12.12	11.54
	2020 avg.	9.64	9.15	8.66	5.21	4.61	4.01
	2020 dry	16.31	15.82	15.33	12.51	11.88	11.25
	2030 avg.	9.47	8.94	8.40	5.02	4.38	3.73
	2030 dry	16.14	15.60	15.07	12.32	11.64	10.97
	2040 avg.	9.28	8.70	8.12	4.84	4.15	3.46
	2040 dry	15.95	15.37	14.79	12.13	11.41	10.69
Lower Mississippi	1985 avg.	83.99	77.29	70.59	-24.87	-31.05	-37.22
	2000 avg.	76.19	67.87	59.55	-30.65	-38.32	-45.99
	2000 dry	-3.92	-12.99	-22.06	-29.92	-38.48	-47.04
	2010 avg.	72.92	64.01	55.10	-32.99	-41.18	-49.37
	2010 dry	-7.32	-17.02	-26.72	-32.90	-42.02	-51.15
	2020 avg.	69.90	60.45	51.00	-35.18	-43.85	-52.51
	2020 dry	-10.47	-20.74	-31.01	-35.21	-44.85	-54.49
	2030 avg.	66.98	57.03	47.08	-43.84	-52.94	-62.05
	2030 dry	-13.49	-24.29	-35.09	-45.29	-55.39	-65.50
	2040 avg.	64.00	53.53	43.06	-46.11	-55.65	-65.19
	2040 dry	-16.58	-27.92	-39.26	-47.69	-58.26	-68.83
Souris-Red-Rainy	1985 avg.	3.54	3.52	3.49	3.14	3.11	3.08
	2000 avg.	3.52	3.49	3.46	3.11	3.08	3.04
	2000 dry	1.56	1.53	1.50	1.30	1.27	1.23
	2010 avg.	3.51	3.48	3.45	3.10	3.06	3.03
	2010 dry	1.55	1.52	1.49	1.29	1.25	1.21
	2020 avg.	3.50	3.47	3.44	3.09	3.05	3.01
	2020 dry	1.54	1.51	1.48	1.28	1.24	1.19
	2030 avg.	3.50	3.47	3.43	3.09	3.05	3.01
	2030 dry	1.54	1.51	1.47	1.28	1.23	1.19
	2040 avg.	3.49	3.46	3.43	3.08	3.03	2.99
	2040 dry	1.53	1.50	1.47	1.27	1.22	1.17
Missouri	1985 avg.	20.67	17.72	14.78	8.70	6.14	3.57
	2000 avg.	17.37	13.80	10.23	5.88	2.81	-0.27
	2000 dry	14.91	11.34	7.78	5.54	2.18	-1.18
	2010 avg.	16.05	12.28	8.52	4.70	1.47	-1.77
	2010 dry	13.55	9.79	6.02	4.27	0.74	-2.79
	2020 avg.	14.79	10.85	6.90	3.57	0.19	-3.20
	2020 dry	12.25	8.31	4.36	3.05	-0.64	-4.33
	2030 avg.	13.64	9.54	5.44	2.55	-0.96	-4.46
	2030 dry	10.98	6.89	2.79	1.87	-1.95	-5.78
	2040 avg.	12.51	8.26	4.01	1.56	-2.06	-5.68
	2040 dry	9.80	5.55	1.30	0.80	-3.15	-7.10
Arkansas-White-Red	1985 avg.	12.76	10.99	9.22	0.62	-1.00	-2.62
	2000 avg.	10.62	8.45	6.27	-1.19	-3.13	-5.07
	2000 dry	13.97	11.79	9.61	5.50	3.20	0.91
	2010 avg.	9.73	7.41	5.09	-1.93	-3.98	-6.02
	2010 dry	13.07	10.75	8.43	4.69	2.28	-0.14
	2020 avg.	8.87	6.42	3.98	-2.66	-4.81	-6.96
	2020 dry	12.22	9.77	7.32	3.89	1.37	-1.16
	2030 avg.	8.07	5.50	2.94	-3.31	-5.54	-7.77
	2030 dry	11.41	8.85	6.28	3.20	0.58	-2.04
	2040 avg.	7.24	4.55	1.87	-3.97	-6.27	-8.57
	2040 dry	10.58	7.90	5.21	2.50	-0.21	-2.91
Texas-Gulf	1985 avg.	9.45	8.24	7.03	-1.37	-2.60	-3.82
	2000 avg.	8.11	6.59	5.06	-2.70	-4.23	-5.76
	2000 dry	4.14	2.61	1.09	-2.26	-3.91	-5.55
	2010 avg.	7.63	5.99	4.36	-3.15	-4.79	-6.43
	2010 dry	3.65	2.01	0.38	-2.74	-4.49	-6.24
	2020 avg.	7.17	5.44	3.70	-3.59	-5.33	-7.06
	2020 dry	3.20	1.46	-0.28	-3.20	-5.05	-6.91
	2030 avg.	6.76	4.92	3.09	-3.96	-5.78	-7.60
	2030 dry	2.78	0.95	-0.88	-3.59	-5.53	-7.46
	2040 avg.	6.34	4.41	2.48	-4.31	-6.20	-8.10
	2040 dry	2.36	0.43	-1.49	-3.94	-5.96	-7.98
Rio Grande	1985 avg.	0.37	-0.04	-0.45	-1.27	-1.72	-2.16
	2000 avg.	0.01	-0.49	-1.00	-1.65	-2.18	-2.72
	2000 dry	-0.11	-0.61	-1.11	-1.68	-2.27	-2.85
	2010 avg.	-0.10	-0.63	-1.15	-1.76	-2.33	-2.90
	2010 dry	-0.22	-0.74	-1.27	-1.81	-2.43	-3.04
	2020 avg.	-0.20	-0.75	-1.30	-1.87	-2.47	-3.06
	2020 dry	-0.32	-0.87	-1.42	-1.92	-2.57	-3.22
	2030 avg.	-0.27	-0.85	-1.42	-1.96	-2.58	-3.19
	2030 dry	-0.39	-0.96	-1.54	-2.02	-2.69	-3.36
	2040 avg.	-0.34	-0.93	-1.52	-2.04	-2.67	-3.31
	2040 dry	-0.46	-1.05	-1.64	-2.10	-2.79	-3.48
Upper Colorado	1985 avg.	0.37	-0.05	-0.46	-4.79	-5.27	-5.75
	2000 avg.	-0.13	-0.64	-1.16	-5.31	-5.89	-6.48
	2000 dry	1.51	0.99	0.47	-2.84	-3.48	-4.11
	2010 avg.	-0.34	-0.89	-1.45	-5.52	-6.14	-6.75
	2010 dry	1.30	0.74	0.19	-3.05	-3.73	-4.40

Table 23.—Surpluses and deficits (billion gallons per day) resulting from alternative demand futures, by water resource regions—Continued

	2020 avg.	-0.52	-1.11	-1.69	-5.70	-6.35	-7.00
	2020 dry	1.11	0.52	-0.06	-3.25	-3.96	-4.66
	2030 avg.	-0.71	-1.33	-1.95	-5.88	-6.56	-7.24
	2030 dry	0.92	0.30	-0.31	-3.44	-4.18	-4.91
	2040 avg.	-0.91	-1.56	-2.20	-6.06	-6.76	-7.47
	2040 dry	0.72	0.08	-0.57	-3.62	-4.39	-5.15
Lower Colorado	1985 avg.	-6.06	-7.36	-8.66	-11.54	-12.88	-14.21
	2000 avg.	-7.19	-8.80	-10.41	-12.64	-14.27	-15.90
	2000 dry	-6.63	-8.37	-10.11	-10.96	-12.73	-14.50
	2010 avg.	-7.51	-9.22	-10.93	-13.16	-14.94	-16.71
	2010 dry	-6.98	-8.83	-10.67	-11.50	-13.43	-15.35
	2020 avg.	-7.82	-9.62	-11.42	-13.23	-15.04	-16.85
	2020 dry	-7.31	-9.26	-11.20	-11.61	-13.57	-15.53
	2030 avg.	-8.06	-9.94	-11.82	-13.46	-15.34	-17.22
	2030 dry	-7.57	-9.60	-11.62	-11.84	-13.88	-15.92
	2040 avg.	-8.28	-10.23	-12.18	-13.65	-15.60	-17.56
	2040 dry	-7.81	-9.92	-12.02	-12.06	-14.17	-16.29
Great Basin	1985 avg.	1.91	1.21	0.51	-0.25	-0.98	-1.70
	2000 avg.	1.26	0.40	-0.46	-0.84	-1.70	-2.57
	2000 dry	0.88	0.02	-0.84	-1.21	-2.16	-3.11
	2010 avg.	1.07	0.16	-0.75	-1.01	-1.92	-2.83
	2010 dry	0.70	-0.21	-1.12	-1.40	-2.40	-3.39
	2020 avg.	0.89	-0.06	-1.01	-1.18	-2.13	-3.08
	2020 dry	0.52	-0.44	-1.39	-1.58	-2.62	-3.66
	2030 avg.	0.75	-0.24	-1.23	-1.31	-2.29	-3.28
	2030 dry	0.38	-0.61	-1.60	-1.73	-2.80	-3.88
	2040 avg.	0.63	-0.39	-1.41	-1.42	-2.44	-3.45
	2040 dry	0.25	-0.77	-1.79	-1.85	-2.96	-4.07
Pacific Northwest	1985 avg.	67.94	65.82	63.71	37.11	34.57	32.02
	2000 avg.	66.22	63.68	61.13	35.21	32.19	29.16
	2000 dry	60.14	57.59	55.05	31.37	27.78	24.18
	2010 avg.	65.71	63.04	60.36	34.63	31.46	28.30
	2010 dry	59.63	56.95	54.28	30.69	26.92	23.15
	2020 avg.	65.22	62.42	59.63	34.08	30.77	27.47
	2020 dry	59.14	56.34	53.55	30.04	26.11	22.17
	2030 avg.	64.83	61.93	59.04	33.64	30.22	26.81
	2030 dry	58.74	55.85	52.96	29.52	25.46	21.40
	2040 avg.	62.58	59.13	55.68	33.23	29.72	26.20
	2040 dry	56.50	53.05	49.59	29.04	24.86	20.68
California	1985 avg.	41.17	36.74	32.31	24.67	20.45	16.24
	2000 avg.	36.98	31.55	26.12	20.93	15.86	10.78
	2000 dry	-0.65	-6.09	-11.52	-9.71	-15.24	-20.77
	2010 avg.	35.73	30.02	24.31	19.70	14.36	9.02
	2010 dry	-1.91	-7.62	-13.33	-11.03	-16.84	-22.66
	2020 avg.	34.55	28.57	22.59	18.53	12.94	7.36
	2020 dry	-3.09	-9.07	-15.05	-12.27	-18.36	-24.44
	2030 avg.	33.60	27.41	21.22	17.56	11.78	6.00
	2030 dry	-4.04	-10.23	-16.42	-13.31	-19.60	-25.90
	2040 avg.	32.74	26.37	19.99	16.66	10.70	4.75
	2040 dry	-4.90	-11.27	-17.65	-14.27	-20.75	-27.23
Total contiguous U.S.	1985 avg.	257.09	238.41	219.73	107.59	88.90	70.22
	2000 avg.	237.58	214.42	191.25	88.08	64.91	41.75
	2000 dry	107.27	81.63	56.00	3.39	-22.25	-47.89
	2010 avg.	230.27	205.53	180.80	80.76	56.03	31.30
	2010 dry	99.51	72.20	44.88	-4.37	-31.69	-59.00
	2020 avg.	223.88	197.82	171.75	74.37	48.31	22.25
	2020 dry	92.69	63.93	35.17	-11.20	-39.96	-68.71
	2030 avg.	230.06	202.76	175.47	80.55	53.26	25.96
	2030 dry	86.38	56.31	26.24	-17.51	-47.58	-77.65
	2040 avg.	212.02	183.52	155.03	62.52	34.02	5.52
	2040 dry	80.18	48.83	17.47	-23.70	-55.06	-86.42

[1] *The surplus or deficit for normal expected supplies and normal projected demand comes from Table 16. The projected demand is presented in Table 16 as the offstream consumptive use for agricultural and non-agricultural uses. To compute the surpluses and deficits in this table, the offstream consumptive uses in Table 16 were decreased and increased by 13% in 2000, growing to 20% by 2040. The surplus or deficit expected if global climate changes uses the same demands as the first three columns but reduces the renewable water supply, table 16, from 5% to 40% depending upon the region.*

Information on regional effects is important for determining appropriate policy responses to climatic changes. Gleick concluded that until realistic surface hydrology responses can be incorporated into GCMs with regional resolution, evaluating regional and local hydrologic effects will only be accomplished by using other methods, such as regional water balance models. Gortch (1988) reviewed four state-of-the-art GCMs and reached the same conclusion; quantitative prediction of anything approaching even a multi-state region is not yet possible.

Observations about the onset of warming in North America have been mixed. Part of the reason is changing urban development patterns in the vicinity of long-term weather observation stations. As areas surrounding observation stations become more developed, pavement and buildings absorb and reradiate more heat than previously. Consequently, recorded temperatures climb. It is not unusual for thermometers in urban settings to register 2° to 3° Celsius (C) or 3.6° to 5.4° Farenheit (F), higher than thermometers in nearby rural areas.

Hilts (1989) reported results of a National Oceanic and Atmospheric Administration (NOAA) study by Karl of temperature records for the contiguous U.S. from 1895 to the present. This study is the most comprehensive one to eliminate the growing effect of increasing urbanization on recorded air temperatures. In looking at U.S. temperatures, NOAA researchers did not find a trend toward warmer average temperatures. The annual average air temperature over the past century was 11.4° C (52.5° F). Annual averages varied between 10.5° and 12.8° C (51° and 55° F), but the difference between the average for the century and the annual average for any one year does not seem to be rising. Examination of average daily highs and lows revealed that highs have remained roughly the same, while lows rose about 0.3° C, especially in the last two decades. This reduction in the daily temperature range is consistent with the kind of response scientists expect from the "greenhouse effect," but it does not prove the effect is occurring. These findings appear to be at odds with the results of Hansen and Lebedeff (1987), who found that global warming has amounted to about 0.5° C. Hansen (1989) noted that the contiguous United States amounts to 2% of global area. Findings reported by Hilts (1989) come from too small a sample of the global surface to provide any definitive conclusions.

Data since 1860 from around the world show that the five warmest years in the history of instrumental measurements are all in the 1980s (1980, 1981, 1983, 1987, and 1988). Hansen (1989) believes this is an indication of the onset of a long-term warming trend. Karl, quoted in Hilts (1989), counters that early instruments and data collection methods gave distorted readings compared to modern techniques. Unanimity on the data, much less the findings, does not exist.

Calculations by Hansen plus other studies in the literature which look ahead 50–150 years report a variety of projected temperature increases ranging from 1° to 9° C. Flaschka et al. (1987) concluded that the most commonly cited projection is an increase of 2° C (4.5° F).

Reports differ on how an increase in hemispheric average annual air temperature of 2° C is likely to affect precipitation, largely because precipitation effects are presumed to vary by latitude and elevation. Consequently, hydrologic analyses are usually made for two precipitation assumptions arising from a 2° C temperature increase. They are a 10% increase in precipitation from current levels and a 10% decline from current levels. Of these precipitation assumptions, the 10% decline is of more interest when analyzing projected surpluses and deficits from a supply-demand perspective. Stockton and Boggess (1979) analyzed climate scenarios involving a 2° C temperature increase and a plus and minus 10% change in mean precipitation for all water resource regions in the U.S. They concluded that a change toward a warmer and drier climate would have impacts nationwide. The most severe effects are west of the 100th Meridian (except for the water-rich Pacific Northwest and the Great Basin, where demand is low and groundwater reserves relatively high). The humid East would not be seriously affected.

Some detailed regional analyses have been performed. For example, Flaschka et al. (1987) created a water balance model for the Great Basin region. They concluded that the most probable change in annual runoff resulting from a 2° C increase and a 10% precipitation decline would be a reduction of 17% to 28%. A 25% decrease in precipitation would reduce runoff 33% to 51%. Revelle and Waggoner (1983) studied the Upper Colorado region and concluded that a 2° C increase and 10% precipitation reduction would reduce annual flows about 40%. This may be a sufficient reduction to require renegotiation of the 1944 treaty between the United States and Mexico on the allocation of flows from the Colorado River. Stockton and Boggess (1983) reported that a similar scenario would cause a 30% reduction in flow for selected sub-basins of the Rio Grand region.

Reductions in runoff of these magnitudes result from projections that temperatures will remain warm enough in autumn so that precipitation which now comes as snow in autumn and early winter will instead come mostly as rain. The aridity of a watershed is a principal factor in determining how runoff will change in response to such changes in the nature of precipitation. When the soil temperature is above 0° C, rainfall will infiltrate the soil and percolate to aquifers. Manabe, an expert on the precipitation factor of GCMs and cited in Rowan (1986), expects more wintertime precipitation in the middle latitudes as a result of global warming. But because temperatures are warmer, more precipitation would fall as rain, resulting in less snowpack and an earlier but smaller springtime runoff. However, at high elevations where temperatures below 0° C are still expected despite global warming, extra precipitation would probably fall as snow and springtime runoff from these drainages would be higher and earlier. Thus, there may be an increased risk of flood damages from runoff.

Effects of global climate change in this report are simulated by percentage reductions in renewable water supplies of between 5% and 40% depending upon the water resource region (table 23). Reductions of 5% were projected for the New England, Mid-Atlantic, Great Lakes, Ohio, Upper Mississippi, and Souris-Red-Rainey regions. Reductions of 10% were projected for South Atlantic-Gulf, Tennessee, Lower Mississippi, and Pacific Northwest regions. Reductions of 20% were projected for the Missouri, Arkansas-White-Red, and California regions. Great Basin supplies were reduced 25%, Texas-Gulf and Rio Grande supplies reduced by 30%, and Upper and Lower Colorado supplies reduced by 40%. These percentage reductions are consistent with reductions summarized in Smith and Tirpak (1988). All reductions were assumed to be in effect by 2000 (table 23).

If global warming induces the supply changes outlined, deficits emerge in several additional southern regions. In the South Atlantic-Gulf and Arkansas-White-Red regions, insufficient flows remain in average rainfall years to provide optimal instream habitat for fish and wildlife under all assumed demand levels. However, adequate survival habitat will remain, even in dry years, until 2020 or 2030. Similar results emerge in the Tennessee region; but deficits are negligible. The Texas-Gulf region will experience much more serious deficits in both average and dry years. Fish and wildlife habitat and other instream uses will definitely be in conflict with off-stream uses in this region, even if demands drop 20% by 2040. Other regions which experience deficits under the current climatic situation will experience more serious deficits if global warming occurs. Environmental effects of projected flow levels are described in more detail in Smith and Tirpak (1988).

The uncertainty attached to climate change forecasts has implications for water resource managers. For example, managers should emphasize preservation of flexibility and robustness when designing, modifying, or rehabilitating structures and operating procedures. Investments in irreversible, inflexible, large scale, or high-cost measures should be avoided. The potential reduction in supplies adds additional impetus to finding new ways to reduce demand. Smith and Tirpak (1988) note that new approaches to managing water resources are not needed as much as the resolve to implement recommendations made repeatedly in water assessments since 1960. Our challenge is to act on the recommendations now in the face of uncertainty.

SUMMARY

Demand reductions are the more likely scenario given a 19-million-acre reduction in irrigated acreage projected in Department of Agriculture (1987). On a national basis, the projected drop in irrigated acreage amounts to a 30% reduction. Because consumptive use for irrigation amounts to 75% of total consumptive use, a 30% drop in acreage equates roughly to a 25% drop in total water consumption. For the 30% drop in irrigated acreage to occur, the assumptions of the Appraisal will need to be fulfilled. Chief among these are gains in crop yields from genetic improvement, gains from adoption of new technologies, and drastic changes in crop price support programs. The interested reader should see the Appraisal for a detailed discussion of assumptions underlying the decline in irrigated acreage.

A reduction in demand of 20% will alleviate deficits in the Lower and Upper Colorado, Rio Grande and California regions and eliminate deficits in the Great Basin. Significant problems will still remain in the Lower Colorado basin and in California towards the end of the projection period even if demand drops 20 percent. Additional measures will be needed to assure reliable, long-term supplies for those areas.

If global climate changes and becomes warmer by an average of 2° C and precipitation declines by 10%, then deficits emerge immediately in southern regions in dry years and by 2020 to 2030 in average rainfall years. If global warming is delayed or the onset is not so sudden as assumed here (full effects felt by 2000), then the emergence of deficits and concomitant effects on fish and wildlife habitat and other instream uses will also be delayed. More definitive statements about the magnitude and timing of regional hydrologic effects in response to global climate change remain more a matter of conjecture than scientific fact, and will remain so until additional data becomes available to validate general circulation models.

The magnitude of anticipated deficits and a lack of credible measures for significantly boosting renewable supplies mean that measures to reduce demand become the focal point. Some measures to reduce demand are already being taken in response to market forces. When not planned, changes imposed by markets can lead to painful adjustments. Planned adjustments are often less painful to society. Now is the time to begin dealing with deficits if we are to avoid the environmental, economic, and social implications of deficits discussed in the next chapter.

NOTES

1. Ken Frederick suggested that the concept of shortages be clarified and contrasted with scarcities.

CHAPTER 6: ECONOMIC, ENVIRONMENTAL, AND SOCIAL IMPLICATIONS OF PROJECTED SUPPLY AND DEMAND

Economic, environmental, and social implications of continuing water use at projected levels are discussed in this chapter. Implications arise from two sources: projected shortages in supply and demographic changes. In the first case, implications help describe consequences of projections. Some readers may have difficulty envisioning how numerical statements of shortages will affect them. The discussion of implications can make the impact of the supply-demand situation more understandable and more personal. In the second case, demographic changes impact supply and demand even where supply shortages are not likely to occur before 2040. For example, population increases will cause increased growth in urban areas. Increased urban development has implications for water resources even though sufficient water supplies may exist.

IMPLICATIONS OF WATER SHORTAGES

The Rio Grande, Upper and Lower Colorado, Great Basin, and California water resource regions are projected to have water shortages of varying degrees by 2040. Water balances presented in Chapter 5 demonstrate that there are three alternative ways to balance water demands and supplies and avoid shortages. These are: 1) reduce offstream demands; 2) increase the level of groundwater pumping; or 3) reduce instream flows and accept degradation of fish and wildlife habitat. In each region, irrigation is the offstream water use responsible for more than two-thirds of water consumption. Irrigation is also the lowest valued offstream use in each region. Consequently, in reducing offstream demands, implications fall most heavily on the agricultural sector of the economy and society.

ECONOMIC IMPLICATIONS

Irrigated acreage in basins projected to experience water shortages amounts to about 5% of the total cropland acreage in the U.S. and about 14% of the total crop value. California contributes two-thirds of this value percentage from two-fifths of the acreage. Most irrigated acres in the other water-short regions produce relatively low-valued crops (Day and Horner 1987).

Implications for California

California produces more fruits, nuts, and vegetables than other regions. Over 200 different crops are grown commercially in the San Joaquin Valley with at least 125 of those contributing significantly to the food supply and economy of the nation. Five San Joaquin Valley counties which are heavily irrigated are among the nation's 10 highest producers of agricultural commodities on a gross value basis (San Joaquin Valley Drainage Program 1987). Water shortages in California, though infrequent, will cause significant price shifts for certain crops in certain seasons (e.g. winter lettuce and table grapes) where California irrigators dominate produce markets. Shortages will also cause significant changes in the quality of produce available.

The combination of price and quality changes may cause consumers to alter consumption patterns, foregoing certain products or purchasing substitutes. If consumers shift purchases, a ripple will be felt throughout the agriculture and food processing industries of California. These industries include fruit and vegetable processing, produce transportation, wholesaling and retailing, poultry and dairy processing, grain milling, cotton ginning, and processing of animal feeds. Thus, any changes in agricultural production will be greatly magnified in the California region.

Implications for the Southern Rocky Mountains

Water shortages in the Upper and Lower Colorado, Rio Grande and Great Basin regions affect crops of lesser value than those in California. Commodities produced under irrigation in these regions include wheat, corn, alfalfa, cotton, and rice. From a national perspective, irrigated outputs from these four basins are a relatively minor contribution to total supply. Consequently, water shortages in these regions will cause mostly local impacts. Producers in other parts of the U.S. where water is not in short supply can expand production to fulfill national market demands.

Hanchar et al. (1987) analyzed changes in irrigated acres and crop production resulting from shifts in exogenous crop production variables between 1976–1980 and 1981–1985. Between these periods, crop production costs increased as a function of increased energy costs. Average irrigated acreage declined in heavily-irrigated Arizona, Texas, and Oklahoma, with the termination of irrigation on some acres. Shifts that occurred between the two periods preview the shifts likely to occur when water shortages emerge in the Lower Colorado and Rio Grande basins. The key factor in this study was energy cost increases. In addition to increasing groundwater pumping costs, energy cost increases made other production inputs such as fertilizer and pesticides more expensive. Irrigators use more of these factor inputs than dry-land farmers.

Hanchar et al. (1987) reported that in Texas, Oklahoma, and Arizona, the area irrigated decreased by 1.9 million acres. In addition, cropping patterns did not change significantly. Grain crops, pasturage, and silage absorbed the bulk of the cuts. The implication of taking most production cuts in livestock feedstuffs is that the regional livestock industry will bear the brunt of any cutback in irrigated acreage.

In New Mexico, the area irrigated increased 78,000 acres or 9% . More importantly, cropping patterns changed significantly. Grain crops, pasturage, and silage showed minimal change. However, cotton acreage rose 7%, oil crops acreage rose 100%, and fruit, nut, and vegetable acreage rose 530% . The obvious shift was to higher-valued crops. California showed a similar shift to irrigating higher-valued crops as pasture and silage acreage dropped about 20% while cotton acreage rose 30% and fruits, nuts and vegetables rose 17%.

To the extent that farmers can shift production to higher-valued crops as irrigation becomes more expensive due to higher water costs or shortages, they can cushion the economic impact of the decline in acreage irrigated. However, the potential of the economy to absorb additional supplies of higher-valued products is not unlimited. To the extent that export markets for these commodities can be developed, farmers can expand beyond limits imposed by demographic changes in the U.S. population.

The Department of Agriculture (1987) projected that irrigated acreage will decline by 19 million acres by 2030. The Appraisal outlined several factors expected to contribute to the decline including advances in technology, increases in crop yields from genetic improvements, higher costs of production in water-short areas, and elimination of price support systems. In areas where water shortages are projected for this Assessment, significant economic impacts on suppliers of farming inputs are expected as irrigated acreage declines.

Several statistics from the Appraisal about irrigated farms illustrate the potential impact for farm suppliers. Compared to the average dry-land farm, the average irrigated farm has 2.5 times more money invested in land and buildings, twice the value in machinery and equipment, 4 times the value of crops, 2.3 times the value in livestock sales, twice the fertilizer requirements and triple the pesticide requirements. Irrigated farms use more than 3 times the energy, 5 times the labor, and 7 times the specialized contract labor. Each acre of irrigated land converted to dry-land farming will cause impacts on bankers, equipment dealers, farm supply businesses, agricultural chemical suppliers, fuel and electricity suppliers, farm laborers, and contractors.

ENVIRONMENTAL IMPLICATIONS

Reducing offstream demands by reducing irrigation in areas projected to experience water shortages will create additional environmental problems primarily related to salinization. The alternatives of increasing groundwater mining or tolerating a reduction in fish and wildlife habitat and recreational use of surface water sources also have environmental consequences.

Salinization

Salinization is a problem in arid and semi-arid areas where precipitation is insufficient to leach salts from the soils. If soil moisture around plant roots contains too much salt, most crops cannot absorb the water and nutrients needed to germinate and grow. Saline (excessive salts, mainly chloride and nitrate) and sodic (excessive sodium) conditions are lowering productivity on 10% of the nation's crop and pasture land, including nearly one-fourth of all irrigated crop and pasture land. Six western water resource regions have salinity and/or sodicity problems on one-third or more of crop and pasture land according to the Appraisal. Notable areas where salinity is increasing are southern California, the lower Gila River basin, Arizona (major tributary to the lower Colorado River), and parts of the Rio Grande basin in southern New Mexico and west Texas. These are all areas where water deficits are projected to increase.

Saline conditions in soil are remedied by applying a sufficiently large amount of water to the soil to leach the salts out of the plant root zone. Salts are either carried to aquifers and to streams or run off overland directly to streams. Salts are not neutralized or bound in any sense, but merely moved off-site, typically in dissolved form. As water shortages emerge as a significant problem in areas where salinization is also a problem, less water will be available for leaching. Less water will also be available in streams to dilute and carry dissolved salts away. Farmers further downstream will have saltier water for their irrigation supply. As water shortages emerge, salinity will increase in importance in the five water resource regions.

Salinity occurs naturally in many western regions. About half of all salinity in the Colorado River at Hoover Dam is attributed to natural sources, and the remainder comes from water use. Of the salinity attributable to water use, three-fourths comes from irrigation (Colorado River Water Quality Office 1986). In headwaters on national forests in north-central Colorado, the salinity concentration of tributaries to the Colorado River is only about 50 parts per million. At Imperial Dam, near the border with Mexico, salinity concentrations fluctuated between 608 parts per million in 1986 after record high flows flushed and filled the major reservoirs on the Colorado River and 826 parts per million in 1982. Without control measures, salinity is projected to increase to more than 1000 parts per million at Imperial Dam by about 2010 (Colorado River Water Quality Office 1986). The Environmental Protection Agency's public drinking water standards limit total dissolved solids (of which salinity is a component) to less than 500 parts per million. Consequently, water withdrawn for municipal use from the lower reaches of the Colorado River must be treated by expensive desalinization processes to render it potable. The need for and cost of doing so will increase as salinity concentrations increase.

Agricultural losses, either as lower yields or higher production and management costs, begin when salinity concentrations in irrigation water reach 700 to 850 parts per million, depending on the soil type and crop. Excessively saline water causes scours, staggers, and occasional blindness in livestock. Excessive salinity in water makes it unfit fish habitat and damages riparian vegetation used for wildlife habitat.

Salinity causes both on-site and off-site damages. Irrigation water return flows carry salinity off-site. The Colorado River Water Quality Office (1986) estimated that off-site damages in the Colorado River Basin alone total $580,000 for every 1-part-per-million increase in salinity concentration at Imperial Dam. About 5% of that damage estimate is a direct cost to agriculture, about 25% is damage to the regional agricultural economy, and the remaining 70% is damage incurred by municipal and industrial users.

Much of the increased salinity in the Lower Colorado region resulted from using irrigation practices requiring large amounts of water, such as overland flow and flood irrigation, in locations with naturally-saline soils. Adoption of water-conserving irrigation practices in response to rising water prices may be an effective means of reducing saline discharges from farmland.[1]

A coordinated program for salinity control in the Colorado River Basin was developed by federal agencies of the Departments of Interior and Agriculture and EPA and agencies of the states comprising the basin. The program treats salinity as a nonpoint source of pollution. Control measures are designed to prevent 1.3 million tons of salt annually from entering and mixing with the river's flow. Similar approaches to those applied in the Colorado River basin can be used in other basins when the interaction of saline soils and water shortages creates problems.

In the San Joaquin Valley of California, related problems with irrigation return flows emerged. Specific salts such as selenium were concentrated in irrigation drainage water and caused significant health impacts to waterfowl. Selenium can bioaccumulate in the food chain, as demonstrated by waterfowl impacts. Further, low levels of selenium are essential for humans, yet slightly higher levels can be toxic. These factors have elevated concerns about the safety of food grown in the San Joaquin Valley. Recent research shows that not enough selenium is being added to the parts of crops destined for human consumption to cause changes in diet (University of California, Davis 1988). However, levels of selenium in some farmland areas in the western San Joaquin Valley are high enough to justify careful monitoring. Further, efforts to solve the saline irrigation return flow problems for the valley, and particularly at Kesterson Reservoir, will be costly because of existing biologically concentrated levels of selenium. High values of agricultural commodities produced in the valley means that considerable expense may be incurred to deal with the problem (San Joaquin Valley Drainage Program 1987). A total of $38.5 million in state and federal funds was spent on the program in fiscal years 1986 and 1987.

Groundwater Mining

Mining of groundwater occurs when the rate of water use exceeds the rate of aquifer recharge. As with other stock resources such as metallic ores, groundwater mining is socially acceptable so long as the rate of extraction is economically efficient and does not cause adverse environmental consequences.

Groundwater levels are currently declining from 6 inches to 5 feet annually beneath 14 million acres of irrigated land in 17 western states where groundwater is the principal irrigation source. Pumping costs are rising, well yields are declining, and pumping efficiencies are decreasing. In these areas, municipalities and rural residents rely on groundwater for domestic and livestock supplies. As groundwater levels have dropped, competition among water uses has emerged.

Sloggett and Dickason (1986) describe the agricultural sectors most affected by recent groundwater level declines. Rice producers in Arkansas and Texas, citrus producers in Florida, and grape producers in California are those most severely impacted by recent groundwater declines. Since the mid-1970s, more than 2 million acres in the Texas High Plains have converted to dry-land farming because of increased irrigation costs associated with pumping groundwater from greater depths. Shifts in crop production, such as converting irrigated cotton, corn, or alfalfa fields to dry-land grain sorghum or wheat production, have affected growers of the same crops in other U.S. regions. As prices rise or fall in national markets in response to decreases or increases in regional and national commodity supplies, some farmers will gain and others will lose.

New irrigation technologies are often touted as the way to extend aquifer life. New technologies improve water delivery efficiencies. For example, newer equipment operates at lower pressures so less water is lost to evaporation between the irrigation nozzle and the ground. However, adoption of new technologies has not always resulted in reduced water consumption. Often, farmers continue to use the same volume of water but irrigate more acres (Sloggett and Dickason 1986). Supalla et al. (1982) studying the Ogallala aquifer area found that increased water efficiency nearly eliminated the increased cost of pumping. Thus, the immediate effect was no change in irrigated acreage.

State and local governments have exerted regulatory control over the groundwater mining issue in some areas. Recent passage of laws and ordinances restricted further irrigation development in about 45% of the irrigated area affected by groundwater mining. Sloggett and Dickason (1986) and Supalla et al. (1982) both concluded that there is no region-wide problem of groundwater mining to 2020. Any problems occurring before then will be localized.

Social implications of groundwater mining are related mainly to prospective ways of augmenting supplies or to the effects of limiting demands. Increasing supplies using interbasin transfers is both politically infeasible and uneconomical in the Great Plains; managing available groundwater is the only option. Interbasin transfers have been more acceptable in the Colorado River basin—both Denver and southern California use them.

Concerning methods of reducing demand, Supalla et al. (1982) found that farmers prefer to have demand management focus on education and information about new research findings. The farmers' preference is to allow pumping costs and crop prices to manage demand.

Other water users prefer demand management that focusses on mandatory restrictions in irrigation water use. Supalla et al. found that mandatory restrictions would cause a 3% reduction in projected economic growth. Average annual growth of 3.65% without mandatory restrictions would fall to 3.59% annual growth with restrictions. These authors also reported that reductions in economic growth of this magnitude were not acceptable to agricultural interests. These differing points of view illustrate some of the social implications of groundwater mining.

Fish and Wildlife Habitat

Discussions on acid deposition and erosion in Chapter 2 outlined the effects of these externalities on wildlife and fish habitat. Excessively acid surface water affects biota low in the food chain and interferes with reproduction and development of fish and wildlife. Erosion results in sediments in streams and also interferes with reproduction and respiration.

Water supply shortages discussed in Chapter 5 will have adverse effects on instream flows and habitat for fish and wildlife and recreation dependent upon adequate flows. The salinity discussion in this chapter mentioned fish and wildlife effects of saline drainage, especially in the San Joaquin Valley.

Flather and Hoekstra (1989) discuss effects of low flows and poor water quality on fish and wildlife in additional detail in their companion report on wildlife and fish.

SOCIAL IMPLICATIONS[2]

Population

Population distribution would be strongly affected by water shortages. While it remains for the 1990 Census to reveal whether or not rural areas are continuing to grow faster than urban ones— a trend first reported in 1980—growth would be limited in those areas lacking either sufficient water supplies or delivery structures. Minimum lot sizes of 10 to 35 acres are used in some western areas to limit development of groundwater for rural livestock and domestic supplies. The Southeast is likely to experience growth rates even higher than current levels as people and industries choose to move where water is plentiful. Additionally, those northeastern and midwestern areas which would no longer experience the population decline that occurred in the 1970s and 1980s would need to provide social and environmental services demanded by a growing population.

Water treatment to assure reliable supplies and wastewater treatment to avoid environmental degradation are two key services affected by shifting population growth trends. Much of the infrastructure for water treatment and delivery in the northeastern and midwestern states is old. The combination of repair, replacement, and expansion will tax capabilities of many municipalities. Many small towns did not participate in the EPA wastewater treatment construction grant program established by the Clean Water Act because their discharges were below minimum levels necessary to qualify. However, towns were not relieved of the burden of meeting the discharge regulations. So in the future, they will be faced with upgrading facilities and adding additional capacity using loans instead of grants.

If more growth occurs, limited financial resources will be stretched to the point where major rate increases are the only way to garner the necessary construction funding.

The population composition would also change if water shortages become prevalent in an area. Fewer people would move into an area with water shortages so the resident population would stabilize according to prevailing characteristics. However, if wealthier, more mobile, younger people move to areas with more secure water supplies and accompanying economic opportunities, communities they leave will experience an increase in the proportion of poor and elderly—groups with fewer relocation options. As the remaining population ages, public services demanded will also shift. Precedents for the kinds of shifts likely to occur are found in cities that relied heavily on iron and steel production from the 1930s to 1950s. Shifts in population composition that occurred as a result of changes in the steel industry are similar to shifts likely to occur if projected water shortages materialize in western agricultural areas.

Attitudes, Beliefs, and Values

These social indicators reflect challenges posed by water shortages. If shortages become prevalent, residents will spend more time and money securing water and an overall decline in quality of life will likely occur. Concurrent declines are expected in the American "can do" attitude as well as individuals' perceptions that they have a degree of control over their future. Municipalities and business water users are expected to respond to shortages by raising water prices and ultimately buying irrigation water rights. The social impact of such transactions is a weakened tie to the land—a major factor in rural agrarian lifestyles, especially on western family farms.

Any social analyses of prospective changes in water use and management should incorporate three basic kinds of information. First, the analyses should recognize that attitudes, beliefs, and values vary by population cohort and background. Second, the analyses should use marketing survey techniques and other sociological instruments to elicit attitudes, beliefs, and values about proposed changes in water use and management by cohort. Third, political polling techniques should be used to evaluate the likelihood that specific cohorts will vote in certain types of elections or take other action, such as seeking injunctions or pursuing litigation. In this way, information on social implications of resource use changes can be gathered and used by decisionmakers when evaluating alternative management strategies. Too often, such analyses are done only after decisions are made; wise stewardship of natural resources suggests they should be done beforehand.

Social Organization

Institutions in communities experiencing water shortages would be affected in a variety of ways. If expected population decreases materialize and competition for water increases, local governments will be required to increase their level of technical and political knowledge of water supply issues such as regulation/enforcement/litigation, and negotiation/consensus-building skills. Gaining knowledge about sophisticated water-related technology and conservation programs and developing the ability explain the necessity for and consequences of the technology and programs to different audiences with a variety of technical backgrounds will also become crucial.

Internal conflict between agencies committed to water quality and those fostering economic growth will increase. Tools of government such as enforcement of regulations and ordinances and eminent domain and annexation would assume greater importance. Officials such as county extension agents may assume positions of leadership in implementing technical and complex changes in resource use.

Local governments would be required to address other challenges caused by water shortages. Growth in the proportion of elderly and poor cited earlier would probably increase demand for social services such as health care and income assistance. Conversely, the amount of tax revenue available to communities to pay for such services will decrease as the younger, more affluent sector moves away. Property tax revenues would go down as farm property values decline due to reduced productivity in dry-land agriculture compared to irrigated agriculture. The lack of sufficient water to attract additional jobs may also lead to reductions in residential property values. Sales tax revenues would also reflect a reduction in the number of homeowners who would ordinarily make major purchases associated with moving into an area. Income tax revenues would also decrease due to the lower number and smaller size of taxable incomes.

Competition among interest groups would also be likely to increase as shortages become more prevalent, encouraging polarization among community members. Examples of groups likely to be affected are recreationists (anglers, boaters, hunters), ranchers, real estate and landscaping concerns, and high-tech industries dependent on water quality. How to satisfy competing demands for water use would be the water managers' challenge.

In many cases, western state and local governments are seeking to diversify local economies by attracting industries that produce no air or water pollution or that depend on clean water for production processes. New industrial developments, lured by tax breaks and relocation assistance, bring new jobs to an area and jobs attract people. Often, new jobs are filled by people from other areas; people whose attitudes, beliefs, and values about resource use are different from those of long-time residents. Clashes that typically emerge over future resource uses in such settings are often "strawmen" for differences in attitudes, beliefs, and values among newer versus older residents. The ballot box and the electorial process are the traditional means of settling many of these disputes. Officials elected under such circumstances should be sensitive to maintaining or rebuilding community cohesion.

Land Use Patterns

If water becomes less available and more expensive, agricultural operations dependent upon irrigation will either change to dry-land farming or cropland will revert to native vegetation. In many areas where water shortages are projected, native vegetation is range grasses or shrubs.

The major reason why agricultural land goes out of production in response to water shortages is that landowners can obtain a higher economic return by putting land and water to another use including leaving it idle.[3] In the 1800s, before the advent of inorganic fertilizers and farming practices that conserved soil, land was farmed until the natural soil fertility was exhausted and then abandoned. For example, cropland abandonment in the South from the 1880s to the 1950s and its subsequent reversion to native vegetation, southern pine forests, was one principal factor behind the rapid expansion in the southern forest products industry following World War II. When cropland moves out of agricultural production, most will likely not return to crop production. The Appraisal projects 160 million acres of cropland will be idled by 2030.

Cropland will also go out of production for reasons other than inadequate returns to farming. Some will shift to urban and suburban uses. Of the agricultural land going to urban and suburban uses, 63% will come from cropland, 18% from pasture, 13% from forest, and 6% from other agricultural land such as orchards. The Appraisal notes that 80% of cropland likely to move to nonagricultural use by 2030 is prime farmland. The reason prime land is most likely to go to urban uses is that settlements often began in the center of fertile areas to provide goods and services to farmers. As these settlements grow, the expansion erodes the prime cropland base.

Much prime agricultural land is river bottom land. Many agricultural settlements began along streams because waterways provided transportation and waterpower used to process crops.

As river bottomland use moves from agriculture to urban uses, water-related impacts result. Periodic flooding of river bottom cropland is what enhanced the fertility of the land, making it prime agricultural land in the first place.

The major implication of expanding urban development on flood plains is that these areas will periodically be flooded and suffer economic damages. The land use implication is that additional flood protection measures will be needed. Structural flood protection measures alter natural stream channels, change ecosystems, and create environmental changes. Non-structural flood protection measures now in vogue often have adverse social consequences. Landowners may perceive that zoning and other non-structural measures are infringing upon their rights and diminishing the land development values. There is no way to avoid implications of one sort or another when expanding development, particularly on flood plains.

If water shortages become more prevalent, so will zoning use as a means of regulating growth. An increase in zoning is liable to prove particularly contentious. To a large extent, the West was settled by people who strongly valued personal freedom. Concepts of homesteading and building wealth from scratch through land resource utilization—appropriating public domain land for use in ranching, farming, mining, logging—created the still-prevalent attitude that government exists mainly to guarantee personal rights. The use of government zoning powers to avoid "the tragedy of the commons" is only now emerging in the West. This development, while common in New England as early as the 1700s, runs counter to the heritage and established social organizations of many small western communities. As resource use conflicts grow, social organizations in the West are likely to evolve in a manner similar to their eastern predecessors. Over time, one would expect the West to become more "liberal" in the sense of the populace agreeing to subordinate personal goals for promotion of the common good.

Another land use impact of water shortages is that water-related recreation will be curtailed due to lack of water. Water access and use points—beaches, riparian camping areas, and boat launching areas—will become more lightly used. Further, recreational quality will probably decline. For example, more mud flats will be exposed and debris on channel bottoms may become a hazard to boaters and water skiers. Use during dry seasons may cease altogether. Concern over conserving remaining water may result in restricting access to key watersheds to avoid damage such as by wildfire or by giardia infestations in water.

The importance of public forests, rangelands, and wetlands on all ownerships will become more apparent as water shortages emerge. Chapter 4 outlined the current trend in wetlands area. Unless this trend is reversed, waterfowl populations will become increasingly endangered. Recreation related to wetlands, particularly fishing for finfish and shellfish and waterfowl hunting, will diminish in quantity and quality—social impacts of considerable importance to anglers and hunters. Support for the continued existence and possible expansion of wetlands will increase.

Summary

Without modification of current rates of growth in water demand, large areas of the West are projected to face water shortages early in the 21st century. These areas need to implement technological and behavioral changes without delay if they are to ensure a continuous water supply without further degradation of fish and wildlife habitat or groundwater mining.

SUMMARY

In this chapter, the environmental, social, and economic implications of the current and projected supply-demand situations for the water resource and water users have been reviewed. Projections developed and compared in Chapters 3, 4, and 5 are based on recent trends in water use and management from 1960 to 1985. The goal was to describe what the water use situation will be in 2040 and its concomitant environmental, social, and economic implications if society does not change recent patterns of water and related land resource use. Major implications are:

- Water shortages will become prevalent in the California, Upper and Lower Colorado, Great Basin, and Rio Grande water resource regions.
- Water shortages will increase the food cost for humans and livestock. Substantial price increases can be expected for products such as vegetables, fruit, and nuts, particularly in dry years. To the extent that production of livestock feed and livestock production cannot be shifted to other U.S. regions, prices of red meat (primarily beef and mutton) and related livestock products (such as wool) will increase. The price of cotton products will also increase if cotton production cannot be shifted from the Southwest to other parts of the U.S.
- Water shortages will disrupt local economies, especially those relying heavily upon irrigated agriculture and the processing, sale, and transportation of crops and products grown under irrigation.
- Water shortages will cause major social impacts on local residents and their communities.
- A continuation of recent trends will lead to groundwater mining.
- A continuation of recent trends will reduce wildlife and fish habitat and other instream uses such as recreation.
- Continuation of recent trends in water use will lead to increased salinity, thus causing additional disruptions in local economies relying upon surface water sources for potable supplies. Salinity will adversely affect farmers depending on irrigation water.
- Continuation of recent trends in wetlands conversion will lead to significant additional reductions in waterfowl populations and reduction in fishing, hunting, and other recreational benefits.
- Expansion of urban areas will increase at the expense of prime agricultural land.

These projections and their implications are only "most likely" in the sense that if society makes no changes in water use patterns, then the projections are most likely to be realized. Many implications of continuing recent water use trends describe a painful transition in lifestyles to 2040, especially in the southern Rocky Mountains and California.

The good news of this Assessment is that we have an opportunity to change the way water has been used in recent years and avoid many of the adverse implications described in this Chapter. Many changes have been made in water use since the 1972 passage of the Clean Water Act. That was strong medicine for our water quality problems but we needed it. More changes in water use are called for; many will call for taking some pretty strong medicine now to avoid major future problems. Whether the nation chooses the distasteful medication now or chooses to tolerate the disease's pain later is uncertain. The painful future consequences of the nation's addiction to cheap water and waste disposal were described in this Chapter; medication and its consequences are described in the following chapters.

NOTES

1. I am indebted to Ken Frederick for suggesting this approach to reducing saline discharges.

2. This section was prepared by Susan Johnson, Sociologist, who is a member of the RPA Staff.

3. Some current agricultural programs pay farmers for idling land previously used for growing certain crops.

CHAPTER 7: OPPORTUNITIES TO IMPROVE THE MANAGEMENT OF WATER AND RELATED FOREST AND RANGELAND RESOURCES

The objective of this chapter is to highlight the most significant opportunities available for improving the management of water and related land resources. Implications of water shortages discussed in Chapter 5 provide many opportunities for altering annual crop production practices to avoid adverse environmental, social, and economic impacts. Opportunities whose primary application is to crop and pasture land have not been addressed here. In this chapter, the focus is narrowed to matters of interest to forest and range managers.

Opportunities presented are all high-priority; the order of presentation here does not reflect a ranking. Opportunities were selected without regard to who should implement them. Some are opportunities for both private groups and public agencies. Some opportunities requiring government involvement are opportunities for federal, state, or local agencies. The common thread is that the opportunities all pertain to forests and range management. The opportunities to be discussed are:

- Ensuring suitable flows for instream water uses emphasizing fish and wildlife habitat and recreation;
- Improving watershed condition with special emphases on maintaining water quality, managing the timing of runoff, improving riparian areas, and enhancing soil productivity;
- Encouraging use of non-structural watershed improvement measures to avoid flood damages;
- Implementing nonpoint-source pollution abatement approaches for silvicultural and range management activities; and
- Reversing the trend of losing wetlands.

ENSURING SUITABLE FLOWS

The water budget analyses of Chapters 4 and 5 reveal that when deficits occur in the Lower and Upper Colorado, California, Great Basin, and Rio Grande water resource regions, projected low flows will be insufficient to provide good survival habitat for fish, wildlife, or recreation. Population dynamics for most fish and wildlife species are such that having poor survival habitat for an extended period an average of one year in five is too frequent to provide sustained high-quality fishing and wildlife-related experiences.

Projections indicate that the situation will worsen in proportion to increases in demands for offstream surface water use. In regions where water shortages are projected, many rivers originate on public lands, thus public land managers have opportunities to pursue management practices that augment instream flows. Through administrative procedures, managers can help ensure protection of minimum instream flows. These opportunities can be realized by manipulating vegetation to augment low flows and protecting instream uses through administrative controls and state water rights procedures.

OPPORTUNITIES TO MANIPULATE VEGETATION TO AUGMENT LOW FLOWS

Research demonstrates that timber harvesting patterns and frequencies can be planned to increase water yield from some sites. Most increases come from the fact that timber harvesting reduces evapotranspiration. A second benefit is that if cutting patterns are properly planned, residual stands will trap and concentrate drifting snow in partially-cut areas much as snow fences are used to trap snow and keep it off roadways. Cutting intensity can be designed so that effective trapping occurs and enough shade is provided to retard melting in early summer. Thus, the snowmelt period is extended and high springtime peak flows are reduced. The main effect of this practice is make more meltwater usable.

Troendle (1983) concluded that with prudent management of high-altitude subalpine forests in the Rocky Mountains, an increase of 0.1 to 0.25 acre-foot per acre in water yield can be realized. By altering the forest's aerodynamics and energy budget, timber harvest alters the accumulation and melt characteristics of the snowpack. These impacts are partially translated into flow changes. Eliminating vegetation reduces evapotranspiration losses which also translate into increased flows. Because vegetation recovers after cutting and its evapotranspiration increases, only one-fourth to one-third of the acreage under this kind of management will produce increased yields due to reductions in evapotranspiration at any one time. The potential for increasing water yield is greater in the northern than in the southern Rocky Mountains, but areas in the Upper Colorado and Great Basins are amenable to these vegetation management practices.

Douglas (1983) concluded that water yield from well-stocked northeastern forests could be increased from 0.3 to 1.0 acre-feet per acre the first year after clear cutting. As the forest grows back, water yield drops logarithmically back to base levels. Increased yield duration averages 1.9 years for each 0.1 acre-foot of increase. There are two problems with applying these research findings. First, diversity of landownership and ownership objectives makes capturing the full potential increase nearly impossible because of difficulty in coordinating cutting patterns. Second, many stands in the northeast are understocked and they have less potential increase in water yield because they are not currently at maximum evapotranspiration. Douglas concluded that the greatest potential for increasing water yield is on municipal or utility watersheds. Even here, timber sale revenues will often dictate cutting patterns rather than increased value of the extra water produced. In short,

Cutting patterns and orientation can affect snowmelt. This 66-foot wide clearcut strip runs east-west. By early April, all snow has melted on the north edge while 25 inches remain on the south side.

Douglas concluded that we know how to increase water yield in the northeast but until shortages occur, there is no incentive to implement research findings.

If sufficient reservoir storage existed to contain all springtime runoff, it would not matter when snow melted. All meltwater could be captured. It could then be metered into streams during dry periods to maintain adequate low flows and good survival habitat. Sufficient storage does not exist, however, and sites for building additional reservoirs are scarce and rarely feasible either from environmental or economic efficiency perspectives. Thus, structural solutions to problems of maintaining adequate low flows do not appear promising. Vegetation management practices, on the other hand, offer some promise for lengthening the runoff period and shortening periods of low flows which create problems for instream water uses.

OPPORTUNITIES TO ENSURE WATER NEEDED TO SUPPORT INSTREAM USES

In some states where the appropriation doctrine is used, stream water is oversubscribed in drier years when not enough water is available to meet all users needs. Instream water uses are not recognized as a beneficial use for water appropriation in many states; where they are recognized, they are defined as junior to other uses. In such situations, instream water uses are foregone to satisfy other uses. Thus, there is little opportunity to ensure instream flow rates which provide, at a minimum, good survival habitat and recreation.

Residents of western states have begun to recognize the importance of maintaining instream flows and benefits created. Institutions are beginning to respond to public sentiment on these issues. The current situation is a dynamic one; change is underway. However, many more opportunities remain to be captured beyond those already obtained by recent changes. There is strong support from anglers, hunters, and recreationists for increasing and enhancing fishing, wildlife, and instream recreation experiences. The land manager has an opportunity to use the support of groups advocating maintenance of suitable flows to help influence how instream flows are protected. Partnerships thus established often provide opportunities for addressing other land management issues.

IMPROVING WATERSHED CONDITION

Fundamental concepts of watershed condition and its relationship to water quality and quantity were outlined in Chapter 2. The percentage of watersheds in the lowest condition class, those needing major capital improvements to regain productivity and produce top-quality water, varies between 13% (South) and 25% (North). Watersheds in this Investment Emphasis class typically have vegetation and soils that have experienced significant disturbance. Often, vegetation is sparse or lacking and much of the soil surface is exposed to the direct impact of precipitation. In such situations, runoff water quality is rarely up to the level displayed in Table 13.

Water supply utilities, whether public or private, have long emphasized maintaining high-quality supplies. In areas where the riparian doctrine of water use is in force and surface waters are the supply, utilities have sought to acquire land adjacent to streams and reservoirs and restrict trespass. The objective has been to minimize the potential for water contamination. Utilities viewed this approach as less expensive than installing water treatment processes to purify the water.

In areas where the appropriation doctrine of water use is in force, municipal water utilities have taken their place in the queue of water users. Over time, and especially west of the Great Plains, utilities have become less confident of having adequate supplies. Further, increasing amounts of dissolved salts and nutrients in surface waters reduce its potability in many places. Therefore, western utilities are beginning to compete for water, often seeking to purchase more-senior rights from agricultural interests. The utilities' goal is to divert water nearer its source which means the supply will be of more reliable quantity and higher quality. It matters not whether utilities are operating under the riparian or appropriation doctrines, there is increasing emphasis on securing and maintaining high-quality surface waters.

INCREASED EMPHASIS ON MAINTAINING WATER QUALITY

Land management consequence of utilities' search for reliable, high-quality surface water supplies is that utilities will become much more interested in watershed management activities upstream. In coming years, utilities will exercise critical scrutiny over those activities that disturb ecosystems and increase salts, sediments, or other pollutants moving into streams. If there is an increasing trend in those activities in watersheds producing potable supplies, then utilities are expected to become vigorous participants in the planning, review, and environmental analysis process of watershed managers. In such circumstances, utilities and other water users dependent on high-quality water will become effective advocates for mitigating ecological disturbances. In addition, there will be interest in rehabilitating areas where previous disturbances are contributing to in-stream water quality degradation.

INCREASED EMPHASIS ON MANAGING THE TIMING OF RUNOFF

Vegetation management activities discussed as a way of ensuring suitable flows, represent one of three opportunities for managing runoff timing. In addition to using timber harvesting patterns to trap snow, snow fencing can be erected to concentrate blowing snow in drifts and prolong melting into early summer. Snow fencing, on a scale much greater than the woven wooden lath typically erected along roads in the East, is particularly useful for trapping snow in cirques above timberline and on high-altitude rangeland.

Weather modification, primarily cloud seeding, can be used to increase snowfall on watersheds. Used in conjunction with vegetation management and large-scale fencing, opportunities exist to store considerable amounts of snow in drifts to prolong melt.

Currently, snow melt occurs in the headwaters of water-short regions in April to early June. Storage reservoirs fill early with meltwater. Because snowmelt occurs when crop irrigation needs are low, water that cannot be stored moves downstream underused. In July and August when irrigation and other offstream and instream water needs are high and instream flows have declined, water stored in reservoirs is released to help meet needs. The objective of trapping snow and delaying snowmelt is to extend meltwater runoff into early summer to help meet emerging summertime water needs. The result is that the beginning of reservoir drawdown can be delayed, thus making more water available in late summer and early fall when instream flows and needs are greatest.

It has not been determined if enough snowfall can be trapped to prolong melting into July and make a significant contribution to regional instream flows. The challenge to watershed managers is to determine if these three approaches—vegetation management, snow-trapping structures, and weather modification—can be combined to significantly influence the timing of water availability.

INCREASED EMPHASIS ON IMPROVING RIPARIAN AREAS

Riparian areas—the strip of land and vegetation bordering a stream or lake—are the last line of defense against pollutants reaching streams and lakes. These areas are also the primary buffer between land management activities and adverse effects on fish, wildlife, and other organisms that are a part of the aquatic ecosystems.

Riparian vegetation often shades streams and keeps water temperatures cooler and more amenable to fish and other aquatic organisms. This vegetation also provides cover for wildlife. Recent research demonstrates beneficial effects of allowing riparian vegetation debris to modify stream channel configurations and augment cover and structure normally provided by rocks and boulders. Riparian vegetation also slows precipitation runoff, thereby reducing peak flows during high flow periods. Although riparian vegetation consumes water, the benefits it provides far outweigh the value of the water it uses.

Emphasis on maintaining water quality will also manifest itself in an increasing concern over safeguarding riparian areas. Mechanized equipment use, heavy livestock grazing, or other activities that disturb riparian vegetation will be increasingly viewed as unacceptable resource management. Active programs to assist the recovery of riparian vegetation damaged by trespass or overuse are needed in many watersheds in the Investment Emphasis condition category.

OPPORTUNITIES TO ENHANCE SOIL PRODUCTIVITY

Soil productivity refers to a soil's ability to produce vegetation. The concept of soil productivity includes all chemical, biological, and physical aspects of a soil that affect its ability to sustain vegetation production over time.

Many factors discussed in Chapters 2 to 6 influence soil productivity. For example, erosion results from physical practices such as soil disturbance or vegetation removal that lead to topsoil moving off-site. Sediments carry nutrients away, thus reducing the site's ability to sustain vegetation at previous levels. Acid deposition affects soil chemistry by making aluminum ions more mobile and altering nutrient relationships, both of which lead to reductions in soil productivity.

When treating watersheds in the Investment Emphasis class, opportunities exist to affect more than the physical aspects of the site, such as halting erosion. Treatments should be designed that also consider the chemical and biological aspects of soil productivity. Chemical considerations include restoring nutrient balances such as by fertilization or inclusion of legumes in revegetation plans. Biological considerations include maintaining and enhancing biological diversity by restoring a mixture of native species instead of using only monocultures or exotic varieties. Site analyses for planning watershed recovery investments need to examine all aspects of soil productivity so the root cause of the problem can be cured instead of only treating symptoms.

SUMMARY

Increasing emphasis on maintaining high water quality, reliable stream flows, and diversity in fish and wildlife populations presents a significant opportunity to build a consensus for improving watershed condition. Improvements needed include rehabilitating watersheds and riparian areas, restoring soil productivity, and reducing adverse water quality impacts. Consensus will take the form of increased demand to restore adequate vegetation to watersheds, especially riparian areas, and to hold sediments and nutrients in place.

Adherence to nonpoint-source pollution regulations and use of Best Management Practices will be supported by water users as a way of encouraging rehabilitation and restoration of problem watersheds. Even though cities served by water utilities may be geographically distant from watersheds needing work, strong support of city governments and utilities for improving watershed conditions will be experienced. Forest and rangeland managers should recognize that this consensus is emerging and plan proactive ways of using the opportunity to help achieve rehabilitation and restoration goals.

Where watersheds are in middle-class or Special Emphasis condition, integrated resource management is the primary vehicle for facilitating additional watershed rehabilitation or preventing additional degradation of sensitive watersheds. The opportunity afforded by increased attention to maintaining water quality and altering runoff timing also provides additional support for managing these areas. For example, use of interdisciplinary teams to develop environmental assessments and prepare management prescriptions for watersheds in the Special Emphasis class will be a primary vehicle for maintaining and improving watershed condition. Included in this is an increased emphasis on seeking coordinated multi-disciplinary approaches to managing riparian areas. Special attention will be needed to address the resource characteristics making the watershed especially sensitive to use.

Watershed researchers can use these opportunities to create support for developing and testing innovative ways of protecting watersheds and riparian areas from degradation, and for accommodating multiple uses. Involving watershed researchers in resource planning and taking advantage of their findings to mitigate adverse impacts will become increasingly important.

Contributions of watershed specialists toward making other resource uses feasible by mitigating detrimental watershed impacts have often been overlooked in the past. The increased attention that will be devoted to maintaining water quality and riparian areas will result in more accurate accountability for successes in watershed rehabilitation, restoration, and management.

NONSTRUCTURAL FLOOD DAMAGE REDUCTION

Society has three general ways of responding to flood damages. One is to provide direct economic relief to those suffering losses. The Federal Emergency Management Agency (FEMA) coordinates government responses to flood disasters. Grants and low-interest loans to residents as well as direct recovery measures to restore infrastructure (e.g. roads, bridges, electricity, sanitation) are examples of the services delivered by FEMA. A second response is to build structural measures designed to control flood waters. These include dams, dikes, levees, floodwalls, diversion structures, and channel alterations. The third way of responding to flood damages is to use nonstructural measures to reduce flood peaks and the potential for flood waters to damage investments. Forest and rangeland managers have opportunities to participate in the latter approach through watershed management.

FLOOD DAMAGES IN RURAL AREAS

The bulk of flood damages—60% to 70%—occur in rural areas, largely to agricultural investments. Although urbanization is increasing, rural damages are still projected to account for half of annual damages in the next century. Most damage is to crops and improvements on flood plains with fertile soils. As agricultural land use shifts occur, these sites will be among those where crop production will become more concentrated. Flood plains are also often used for grazing. Improvements subject to flood damage include fences and structures, such as watering facilities and shelters. In mountainous terrain, stream bottoms are common locations for roads and utility lines. These too are susceptible to flood damages, even when properly designed and constructed.

Another method of curtailing flood damages is limiting construction and other flood plain developments. Flood plain zoning was introduced several decades ago along with the federal flood insurance program as a method of regulating flood plain encroachment. While the insurance program has been successful, the zoning program has been less so. When the government is willing to provide low-cost insurance, landowners are content to continue developing flood plains.

OPPORTUNITIES TO REDUCE FLOOD DAMAGES

Floods occur when precipitation is heavy and infiltration rates are less than precipitation rates. Thus, rainfall runs rapidly over the soil surface and into streams. Because forest and rangeland managers have little control over precipitation patterns, frequency, or intensity, focus of flood damage reduction efforts must be on the two key points of maintaining soil infiltration rates and providing ways to slow overland flow of runoff to streams.

Maintaining Soil Infiltration Rates

Generally, the way to maintain soil infiltration rates is to keep vegetation healthy. The principal way precipitation overwhelms infiltration capacity is by droplet impact compacting the soil surface. Machine, hoof, or foot traffic across a site can create the same effect. Keeping vegetation growing on a site cushions traffic effects and provides the point of initial impact for rain droplets, reducing soil surface compaction. Accumulations of organic debris such as forest litter serve the same purpose.

Opportunities exist to manage land to maintain vegetation and litter and protect the soil surface. Wildfire prevention, detection, and suppression conserve vegetation and litter and thereby reduce flood damages. Rapid watershed rehabilitation and restoration following wildfires is needed. Fertilizing and seeding with quick-sprouting grasses have been employed successfully to reduce flood damages after fires. Opportunities to employ such techniques will continue. Additional opportunities exist to develop new and better soil protection techniques, such as hydrophilic mulches that protect the soil surface and hold water for vegetation being reestablished. Another technique is production of seedlings in containers. Container-grown seedlings can speed the process of replanting burned-over sites because they can be grown faster than is possible in conventional bare-root seedling nurseries.

Opportunities exist to develop new methods of managing watershed vegetation to maintain soil infiltration rates. Many techniques have already been borrowed from agricultural research and soil conservation practices such as planting trees on the contour instead of straight up and down hills. The opportunity now exists to develop forestry and range applications of more recent agricultural research findings. For example, "conservation tillage" or "no-till" farming is just coming into vogue. These practices no longer employ site preparation techniques common in the 1950 such as deep moldboard plowing or disking and harrowing.

Slowing Overland Runoff to Reduce Flood Peaks

Inevitably, precipitation events occur that overwhelm soil infiltration capacity. These may be severe events such as locally heavy thunderstorms that create flash floods or events of longer duration that saturate soils so thoroughly that infiltration and percolation rates slow down. In urban areas, sanitary engineers have grappled with related stormwater runoff problems for a number of years. Innovations that have become popular in the last decade include altering construction project design to incorporate temporary stormwater detention structures. Detention facilities (e.g. lips around parking lots or roof drains) collect stormwater and retard its entry into sewers, thereby reducing peak flows to sewage treatment plants. In agriculture, strip-cropping is an example. Strips of forage or field crops are alternated with strips of row crops planted on the contour. Runoff from row crops such as corn is impeded in flowing through field crops such as alfalfa. The opportunity exists to develop ways of applying these stormwater management concepts in forestry and rangeland settings.

There are opportunities to manage riparian areas to slow overland runoff. Not only will water flow be slowed, but reduction in velocity will allow sheet or rill erosion sediment to settle out of the water. Many kinds of vegetation can be used to slow overland runoff. Grasses are favored because of their dense root systems, but other kinds of vegetation can be employed. For example, when performing site preparation, strips of brush might be left on the contour to slow runoff until forest or range vegetation is reestablished.

Other land management opportunities to reduce or retard runoff include piling logging debris on the contour and using a bedding harrow or fireplow on the contour to intercept runoff. When laying out roads and trails, they should be angled across slopes following contours instead of going straight up or down slopes. Where that is not possible, water bars and culverts can be designed to divert and control water. When road or trail locations follow stream bottoms, special care must be taken to avoid damage to riparian areas.

Many flood damages occur when debris is carried downstream with floodwater. Land managers need to take steps to reduce the possibility of timber harvest debris reaching streams. Slash may reach streams, especially where valleys are narrow with steep walls and main haul roads are in a valley. It is often natural to locate landings next to roads and landings are sites where slash tends to accumulate. Managers need to take advantage of slash disposal opportunities further up slope to prevent organic debris from reaching steams. Bridges, livestock fencing, and structures are susceptible to damage from tree tops and limbs carried by floodwater. Many quasi-regulatory programs for controlling nonpoint-source pollution are targeted toward reducing debris in streams for this reason.

Summary

Many activities are standard practices for mitigating off-site effects of resource use. Many activities serve more than one purpose such as reducing nonpoint-source pollution. Opportunities to use these practices will continue to grow as the value of agricultural production and suburban development increases in flood plains. The challenge is to consistently and reliably apply the practices at every opportunity.

SILVICULTURAL NONPOINT-SOURCE POLLUTION ABATEMENT

The smaller areal extent of forest management activities, less intensive site preparation, infrequent harvests, and lower frequency of pesticide and nutrient applications in a given year all result in silviculture generating a much smaller volume of total nonpoint source pollutants than does agriculture. Although silvicultural activities do not appear to cause problems as pervasive as those caused by agriculture or as severe as those caused by mining, they can still lead to localized water quality problems in places where activities are not well managed. Where localized problems occur, an opportunity exists to use nonpoint-source abatement approaches as a remedy. States identifying silvicultural nonpoint-source pollution as a widespread problem affecting 50% or more of their waters are Maine, Vermont, North Carolina, Alaska, Idaho, Oregon, and Washington (Myers et al. 1985).

Range management activities were combined with pasture management in nonpoint-source reports (Myers et al. 1985). Range projects involve the same kinds of activities as forestry. For example, fertilizer and pesticide applications to range provoke many of the same concerns as fertilizer and pesticide applications to forests. Overharvesting of range forage by livestock can lead to runoff and erosion problems similar to forest problems. Range cover type conversions and reseeding operations often involve burning or a combination of burning and chemical or mechanical treatments which expose bare soil to erosion. These actions occur on rangelands at frequencies approximating their use on forests. Consequently, range management activities are viewed much more like silvicultural than agricultural activities. Many of the same opportunities for reducing nonpoint-source pollution exist for range management as for silviculture, as do the vehicles for capturing them.

CURRENT APPROACHES TO IMPLEMENTING ABATEMENT PROCEDURES

Programs to reduce nonpoint pollution from silvicultural activities rely on a voluntary compliance approach in 29 states, a regulatory approach in 5 states (Alaska, California, Idaho, Oregon and Washington) and a quasi-regulatory approach in 6 states (Hawaii, Maine, Massachusetts, New York, New Hampshire, Pennsylvania) (EPA 1984b). Regulatory approaches control activities by using forest practices acts. Quasi-regulatory approaches use laws passed for ancillary purposes such as sediment and erosion control. In western states where the forest industry has substantial land holdings and is very active, regulatory or quasi-regulatory approaches are favored. In states with a plethora of small parcels, voluntary, educational, and sometimes incentive-oriented approaches are aimed at private landowners.

OPPORTUNITIES TO CONTROL SILVICULTURAL NONPOINT-SOURCE POLLUTION

Major nonpoint-source pollutants from silvicultural activities are sediment, chemicals from pesticide applications, and organic debris (EPA 1984b). Principal sources are roads, logging activities, preparation of sites for revegetation, and aerial spraying. Management practices to control these pollutants are well known and well understood. Types of best management practices (BMPs) likely to prove most effective include:

- Better pre-harvest planning;
- Better planning, design, and construction of roads;
- Less soil-disturbing techniques for harvesting, storage, and hauling procedures;
- Closure and revegetation of temporary roads and landings not needed after harvest; and
- Careful application of fertilizers and pesticides.

As in agriculture, adoption of some BMPs will be within the means and self-interest of the landowner and timber operator. For example, proper planning, design, and construction of logging roads intended for long-term use will lower operation and maintenance costs. In other cases, however, adoption of BMPs will not be in the economic self-interest of operators. Needs for specialized equipment may put some BMPs beyond the means of the small landowner or operator. Finally, certain BMPs may be unattractive because they result in reduced income. For example, leaving unharvested timber in riparian zones costs the landowner money in the short-run but benefits accrue to society.

Nonpoint-source problems are fundamentally land management problems. Thus, adopting BMPs that can also save money presents an opportunity to land managers. Opportunities also exist to develop demonstration areas and to show private landowners and land managers how to secure financial benefits.

Demonstration areas also present opportunities for disseminating information and educating landowners about related issues such as the importance of water quality, the benefits of preserving fish and wildlife habitat, and how to safely conduct harvesting and regeneration operations. Some landowners may need technical or financial assistance to implement abatement procedures during regeneration or intermediate stand treatments. Where abatement procedures cost the landowner money, opportunities exist for the federal government to share the cost through programs such as the Forestry Incentives Program. The landowner also has an opportunity to claim costs of abatement procedures associated with regeneration as eligible costs under the Reforestation Income Tax Credit. EPA (1984b) concluded that agencies with programs that involve the land manager or that affect the relationship between the state and the land manager are key to implementation of nonpoint-source controls for agriculture, silviculture, construction and mining.

REVERSING THE TREND IN LOSS OF WETLANDS

Eighty percent of the wetlands lost between the mid-1950s and mid-1970s was attributed to agricultural conversions. Wetlands are lost to agriculture through two primary activities: direct conversions by draining and/or clearing; and indirect conversions associated with normal agricultural activities. Although direct conversions are responsible for the most lost acreage, indirect conversions may be a major factor in some regions (Office of Technology Assessment 1984). Examples of direct conversion include drainage to expand crop acreage in the prairie-pothole region and clearing and draining bottomland hardwood forests for soybean or rice production. Examples of indirect conversions include the general lowering of the water table resulting from irrigation or altering water management practices so irrigation discharges are no longer available to maintain wetlands.

A number of reasons have been advanced to explain continued conversion of wetlands (Office of Technology Assessment 1984):

1. Elimination of the nuisance and costs of farming around wetlands within cropland;
2. The opportunity to gain relatively productive cropland for the cost of drainage;
3. Changes in farming from a diversified crop-livestock combination to increasing emphasis on row-crop and small-grain production;
4. Rapid increase in tractor horsepower which increases avoidance costs and facilitates drainage of potholes by providing the power to operate drainage equipment (this allows the landowner to drain land at low cost);
5. Continued increase in the use of center pivot irrigation systems that are incompatible with wetlands;
6. Short-term farm income variability which provides investment capital for drainage during periods of high income and increases incentives to expand cropland area;
7. Absence of private returns from maintaining wetlands without government programs; and
8. Low returns from government incentives to preserve wetlands relative to profits from conversion.

In the last two years, two major changes in legislation, recent projections in the Appraisal (USDA 1987), a report by a distinguished public forum, and the new North American Waterfowl Management Plan have combined to change the expectations associated with most of the above reasons. The changed expectations create an opportunity to conserve or restore wetlands thereby altering the trend toward further reductions in wetland acreage.

Legislative changes to conserve wetlands.—The Food Security Act of 1985 contained a "swampbuster" provision that disqualifies farmers who convert wetlands to agricultural use from participating in other USDA farm commodity programs. In addition to the *prima facie* effect of this provision, it also established the principle of "cross-compliance" as a major factor in administering resource management programs. Cross-compliance means that an action is enforced by establishing performance of the action as a criterion for qualifying for some other government benefit. The key is that two actions or programs need not be directly related, but that they affect the same people. In the swampbuster case, continued receipt of crop subsidy payments is contingent upon not converting more wetlands to agriculture. Now that the principle of cross-compliance has been accepted in the resource management area, it presents a host of additional opportunities for influencing private landowners' resource management decisions such as adoption of BMPs for nonpoint-source pollution abatement.

Appraisal projections provide opportunities to conserve wetlands.—The intermediate projections of the Appraisal are founded on several assumptions that run counter to the above reasons for wetlands conversion to agriculture. For example, assumptions about increasing yields due to genetic improvement will mean that equivalent net returns can be obtained by farming fewer acres. Fencerow-to-fencerow planting using all available space will no longer be necessary, so wetlands need not be converted to increase output and income. The net result of the 2030 projections is a 19-million-acre reduction in irrigated acreage. This implies a reduced need for new center pivot irrigation systems, and a 120-million-acre reduction in land farmed.[1] Both reduce the need to bring available wetlands under cultivation. One way to help capture new opportunities to conserve forest and rangeland wetlands is to increase research efforts that will help make technological and policy assumptions in the Appraisal come to fruition.

Public opinion favors wetlands conservation.—A bipartisan panel of state and federal officials, business representatives, and conservationists—the National Wetlands Policy Forum—issued a report in November 1987 containing more than 100 recommendations for protecting wetlands. The group endorsed "no net loss" as an interim goal. This means that no more wetland should be drained or developed than is created or restored. The long-term goal endorsed by the Forum is increasing the wetlands inventory (Peterson 1988).

The Forum concluded that efforts to conserve wetlands were ineffective because of inadequate laws, confusing regulations, and economic incentives that encourage development rather than protection. The panel recommended major legislative changes to give EPA and states more authority over wetlands. It also urged Congress to eliminate federal "inducements" for wetlands destruction such as investments in roads and airports that encourage development on nearby wetlands. The Forum also proposed that tax incentives and programs be created for private landowners who agree to conserve or restore wetlands (Peterson 1988).

The 20-member Forum included three state governors; representatives of the U.S. Army Corps of Engineers, Interior and Agriculture departments; and private groups representing farmers, conservationists, developers, and the oil industry. The panel endorsed the interim and long-term goals and suggested legislative and regulatory changes reflecting a newly emerging public consensus on wetlands conservation and restoration.

A key factor in capturing an opportunity to redirect public policy is timing. When broad-based public support for change emerges—as it did in the early 1970s for doing something about water pollution—public advocates must be prepared to move quickly to take advantage of momentum generated by public support. The National Wetlands Policy Forum report indicates that broad-based public support for wetlands conservation and restoration is building. The time to capture opportunities to change public policies and favor increased wetlands conservation and restoration appears near.

The North American Waterfowl Management Plan.—Waterfowl experts in Canada and the U.S. have developed a plan, endorsed by both governments, that establishes a framework for increasing waterfowl populations back to 1970 levels. Its primary objective is to provide enough habitat to sustain at least 62 million breeding birds and a fall flight of over 100 million birds by the year 2000. The estimated price tag is $1.5 billion (Rude 1988).

Six "Key Priority Habitat Ranges" were identified: Prairie Potholes and Parklands, Lower Mississippi Valley, the Gulf Coast, California's Central Valley, Great Lakes-St. Lawrence Lowlands, and the Atlantic Coast. This plan calls for protection and enhancement of 6 million acres of wetlands ecosystems, which in some cases also include nearby uplands.

The plan will be implemented primarily at the regional and local levels by representatives of various agencies and organizations working with landowners in partnerships coordinated by the U.S. Fish and Wildlife Service and Canadian Wildlife Service. Tools available for protecting habitat include acquisition, easements, incentives, and technical assistance to improve land use practices. Private groups, such as Ducks Unlimited, have a leadership role, especially since the financial burden is to fall primarily on the private sector. This plan is the largest single effort ever undertaken to protect wetlands and waterfowl.

SUMMARY

Clearly, there are opportunities for changing watershed management practices on all ownerships and on all sizes of ownerships. Many principles and methods have already been developed; their consistent application is needed. Some landowners have not applied recommended principles and methods; additional education and technical and financial assistance are needed.

Some opportunities need further research and recent research findings need additional work to develop practical solutions to problems. Additional research and development work is needed. Only through coordinated efforts of all public and private parties can the use of water and related resources reach their full potential.

NOTES

1. Actual reduction in acres farmed from 1982 to 2030 amounts to 160 million acres, 40 million of which are projected to be enrolled in the Conservation Reserve Program established under the Food Security Act of 1985.

CHAPTER 8: OBSTACLES TO IMPROVING THE MANAGEMENT OF WATER AND RELATED FOREST AND RANGELAND RESOURCES

Significant obstacles to improving management of water and related land resources are highlighted in this chapter. Obstacles presented are not in any order of priority. Each contributes to not being able to capture opportunities presented in Chapter 7. Some obstacles identified can be altered by changing resource management policies; others will require new regulations or legislation. Some alternatives to surmounting these obstacles are identified and methods of implementation are suggested.

The obstacles are:

1. Water prices do not reflect true costs to society of supplying water for agricultural use. Devising an acceptable transition from subsidized agricultural production to production where farmers' costs more nearly reflect social costs of inputs such as water will be extremely difficult because the transition threatens major changes in agrarian lifestyles and the agricultural economy.
2. Water institutions are giving high priorities to offstream uses to the detriment of instream uses such as fish and wildlife habitat and recreation.
3. Information that accurately assesses current watershed and stream channel conditions and capabilities on all ownerships is not consolidated. Further, information available is often not displayed to managers in ways useful to evaluate management impacts or plan rehabilitation of watersheds which are in the worst condition.
4. Private landowners lack incentives to implement BMPs to reduce nonpoint-source pollution.
5. Income and property tax laws and regulations encourage wetlands conversion. There are few incentives to encourage private landowners to manage wetlands for wildlife and recreation benefits.
6. Large-scale water yield augmentation entails significant environmental and social risks.

WATER PRICES IN TRANSITION

The projections of water shortages in Chapter 5, implications of shortages discussed in Chapter 6, and opportunities for making changes outlined in Chapter 7 all point to a need for changes in current water resource allocations. A major obstacle to making the changes in an economically efficient manner is that water prices often do not accurately reflect the marginal social benefit of providing or using water. This leads to a misallocation of resources from society's perspective. This needs to be redressed if crop production is to become economically efficient on a national basis and water shortages are to be avoided.

Economic development of the West was water-driven. Between its formation in 1902 and the present, the Bureau of Reclamation has spent $8.7 billion constructing irrigation projects across the West. Today, longstanding ways of distributing water are being challenged. Also, there is plenty of evidence that consumption restrictions and higher prices will occur unless new ways can be found to manage existing supplies (Shapiro et al. 1988). Colby et al. (1988) reviewed state legislation and regulations related to water markets and transfers. In regions where shortages are projected, they concluded that markets have emerged and are functioning reasonably well. The obstacle to resolution of the contentions documented by Shapiro et al. (1988) stems largely from water price imbalances among uses. Correction of the price imbalances threatens to alter the agrarian lifestyle favored by many farmers and other agricultural interests.

During the middle half of this century, and particularly in the 1950s and 1960s, the government strongly encouraged farmers to increase crop production. Public policies were employed to stimulate production and western farmers were offered water from Bureau of Reclamation projects at prices that were substantially subsidized by the federal government. Further, if farmers produced more crops in aggregate than society demanded, the government bought the surplus at very near market prices. According to a recent Interior Department report, 38% of western farmland getting water from federally sponsored irrigation projects is used to grow crops that are eligible for federal subsidies because they are in oversupply (Shapiro et al. 1988). Because of irrigation subsidies, crops needing substantial amounts of water, such as hay and alfalfa for cattle feed, cotton, and rice, are being grown under irrigation in water-short areas when they could be grown in other parts of the U.S. at lower total social cost (when the government irrigation water subsidies are factored out).

Times are changing, and so are government policies. In this era of large federal government deficits, federal water resource managers and congressional decisionmakers are re-examining fiscal priorities to determine if continued subsidization of irrigation projects and surplus crops is socially desirable. For example, the House Appropriations Committee provided no funding for new irrigation projects in the 1989 budget. The Appraisal assumptions include cessation of farm commodity programs for purchasing surplus crops and a reduction of 19 million acres (32%) in irrigated cropland by 2030.

These kinds of actions foretell a major change in the agricultural sector of the U.S. economy; one that will not only affect farmers, but ripple through farm suppliers, manufacturers, distributors, and retailers of farm implements, irrigation hardware, fertilizer, and agricultural chemicals, down to consumers of farm products. All will experience some effects of the adjustment; farmers in regions where water shortages are imminent have already begun to experience changes. Irrigated acreage has dropped 1.9 million acres from its peak.

This is a classic economic case where what is good for a region or locality differs from what is beneficial from the national perspective. If we could ignore local concerns and do what is optimal for society as a whole, water and crop subsidies would be eliminated and the agricultural economy would struggle to adjust to new socially optimal crop production patterns. However, local concerns cannot be ignored.

It is difficult to deal with pending water shortages in an economically efficient manner from a national perspective. The major obstacle is lack of a politically acceptable transition from the current situation where crop production is subsidized to the new situation projected in the Appraisal. Here, subsidies are substantially reduced or gone. Until such a transition is developed, groundwater mining will continue at rates above long-term acceptable levels and instream uses of water will be under-supplied.

INSTREAM USES HAVE LOW PRIORITY

The water budgets of Chapters 5 illustrate that of the four key variables affecting water balance—precipitation rates, instream flow levels, rate of groundwater pumping, and rate of offstream consumption—only the latter three are under the manager's control. The manager takes precipitation that nature provides and chooses levels of two of the latter three variables. Once the levels of two are chosen, the level of the third variable provides the balance.

In many states, water managers chose the rate of groundwater pumping and the rate of offstream consumption and let the instream flow levels provide the balance. The consequence is that instream flow levels are highly variable and may not always meet the flow requirements for optimal, or even good, survival habitat outlined by Tennant (1975). In dry years, groundwater pumping proceeds at the maximum rate and offstream use slackens a bit but instream flows drop considerably. Some streams in the southern Great Plains, New Mexico, and Arizona dry up completely. In wet years, groundwater pumping slackens somewhat and reservoir refilling occurs to prepare for the next dry year. Instream flows rise and balance the equation, but, like the runt in a litter, only after all other uses are satisfied. Consequently, offstream uses create externalities affecting fish and wildlife populations and recreation activities. This priority of operations is also reflected in priorities for water uses. In Arizona, for example, the priority of water use has been established as follows: (1) domestic and municipal supply, (2) irrigation and stock water, (3) mining and power generation, (4) recreation, wildlife, and fisheries; and (5) artificial groundwater recharge (Colby et al. 1988). Offstream uses first, then instream uses, and finally something to recharge overdrawn aquifers.

A CLASH OF PRIORITIES IS THE OBSTACLE

Since the 1979 Assessment, there has been a surge in public interest in fishing and water-based recreation. The effects of cleaning up rivers and streams to make them fishable and swimmable again in response to the Clean Water Act has provoked increased interest in water-

Participation in fishing and water-based recreation has skyrocketed since passage of the Clean Water Act. It will be impossible to resolve future deficits and meet increased demands for these instream uses without changing water rights laws.

based recreation. Fishing participation continues to increase rapidly, according to the 1985 National Survey of Fishing, Hunting, and Wildlife Associated Recreation (Fisher 1988). Other water-related recreation activities also have enjoyed increases in participation.[1] Near urban areas and especially in warm climates, summertime water-based recreation is booming. The question is, how will projected increases in demand for instream water-based recreation be served by declining instream flows? The obstacle to meeting increased demands is the low priority given to instream flows compared to offstream water uses.

Whether or not social preferences among water uses have changed needs to be determined. The political process is one way of gauging changes. However, it is often difficult to get a clear reading of social consensus on a particular issue from the political process because elections are rarely decided on a single issue and because elections occur relatively infrequently. Markets are an alternative to elections for gauging social consensus. In markets, people vote with dollars and they vote frequently—each transaction instead of each election is another datum.

The "Nature Conservancy" approach.—Where the prior appropriation doctrine of water rights is used and markets for water rights are functioning, one method of gauging the consensus for increasing instream flows for recreation is to let the market function freely. Let interest groups purchase water rights and dedicate these rights to instream water uses. This approach is a water-based parallel of land purchases the Nature Conservancy has practiced for years.

The Nature Conservancy acquires property, often at fair market prices, and dedicates these holdings to management for recreational and preservation purposes. The Nature Conservancy manages some of the lands purchased, but also creates partnerships with public agencies to manage property purchased to meet Conservancy goals. The Conservancy has often functioned as a third party in purchases where a public agency wants to acquire a private holding. The Conservancy buys rights when a land management agency does not have funding for that purpose. In a subsequent year after receiving appropriations, the agency purchases the property from the Conservancy and dedicates it to recreation and preservation purposes.

Water markets emerging in the West are managing water rights more and more like real property. One way of providing more water for instream uses is to modify water rights laws and regulations to allow water purchases for dedicating the water to instream uses. Modifications should explicitly declare maintenance and improvement of fish and wildlife habitat and water-based recreation to be beneficial water uses. In addition, most state water laws declare that water must be used (offstream) or rights are forfeited. Where water is reserved for instream use, that water is reserved in the name of the state. Protections need to be added to water laws to assure that water purchased by groups will not be subject to re-appropriation by offstream users who want to put it to a "higher" or "more beneficial" use. Also, instream water rights should be allowed to be in the name of a party other than a state.

The "Multiple-Use" approach.—Reservoir operators in the Appalachian Mountains are receiving increasing numbers of requests for water releases to make certain recreation activities possible. The Corps of Engineers has been a leader in timing reservoir releases to meet the needs of recreational water users. For example, special reservoir releases from Francis Walter Dam, built primarily for flood control on the Lehigh River in northeastern Pennsylvania, are made for 12 to 18 hours on weekends to create whitewater rafting opportunities. The schedule of releases is advertised well in advance so outfitters and private raft owners can make recreation plans. On the Savage River in western Maryland, national and international kayaking and canoeing competitions are held with special reservoir releases. Similar reservoir operating schedules were implemented in Tennessee and north Georgia for rafting on the Ocoee and other rivers.

In establishing reservoir operation schedules such as these, environmental assessments should be conducted to evaluate effects of short-term variations in flows. In some areas where fish and other aquatic organisms are suffering from poor survival habitat, flow variations of this sort may not have significant additional adverse effects.

SUMMARY

A reconsideration of water use priorities is inevitable. Crop production is changing in response to market signals and public policies. Per-acre crop production potential is increasing faster than demand—that's the implicit Appraisal assumption behind the projected 120-million-acre decline in acreage farmed between now and 2030. As crop production changes in quantity and geographic distribution, so will consumption of inputs to crop production such as water. As water use in agriculture changes, so will all other uses of water. Fish, wildlife, and recreation should be freed from constraints that relegate them to lower status than offstream water uses. Thus, when water use changes occur, water markets can function freely to attain a social optimum.

WATERSHED CONDITION ASSESSMENTS REQUIRE BETTER INFORMATION

Watershed condition is a concept discussed in general terms for years. However, only recently has the concept been translated into a practical definition usable in land management (Chapters 2 and 7). Three condition classes were identified that link management goals and the land's current condition and capability to meet the goals.

Two major management uses of watershed condition classification serve to evaluate the amount of erosion likely to be created by use and to assign priorities for watershed rehabilitation and restoration project planning. Before land managers can use watershed condition classifications for these purposes, however, current land condition and capability information must be available. Stream channel types and conditions should also be described. Only then can site impacts from use be evaluated and planning priorities be assigned.

The obstacle to using watershed condition classifications in land management evaluation and planning is that information on current land condition and capability and stream channel types and conditions is not available for all areas.

RESOURCE INVENTORY DATA MUST BE CLEARLY PRESENTED

The U.S. Department of Agriculture conducts several different inventories that provide useful information to resource managers. Some inventories provide information on a regional basis. The Natural Resources Inventory (NRI) is conducted by SCS every five years. It provides a snapshot of land uses and related information focused primarily on crop and forage production. The Forest Service conducts resource inventories of forest and rangeland across the U.S. Inventory cycles range from 10 to 15 years, depending on the region. Mid-cycle updates are based on subsamples. The focus here is on vegetation cover types and production levels. These inventories provide useful information for this Assessment and the Appraisal, but data is too general for use by land managers contemplating specific projects in particular watersheds.

Incomplete data coverage.—The National Cooperative Soil Survey (NCSS), led by SCS, conducts soil surveys that provide watershed managers with much useful information on soil types, textures, and other essential information. Federal agencies, such as the USDA Forest Service, conduct soil surveys and related land resource inventories on public lands by following NCSS standards. Although soil surveys have been conducted since the beginning of the 20th century, complete coverage has not been attained. Because the focus of soil surveys has been on crop and pasture lands, gaps in coverage fall most heavily on private forests and rangeland.

Where land cover types have been changing from crops and pasture to forests such as occurred in the South in the early part of this century, soil survey coverage of forest land is better than in other regions. Nevertheless, a lack of complete coverage of counties where forests or range predominate is a hindrance to implementing and using watershed condition classification.

Unconsolidated data.—Land capabilities and current situations on many sites have been evaluated by field personnel of various federal, state, and local agencies. For example, SCS District Conservationists and county extension agents know current situations and capabilities of the lands and streams in their areas. On each national forest, a Watershed Improvement Needs inventory is periodically conducted. The major problem with the practice of performing capability and situation evaluations on a decentralized basis is that it is difficult to present a consolidated summary of information for the entire watershed. Consequently, land managers have incomplete data for assigning project priorities. Decision-makers have only partial information for balancing watershed improvement needs against other resource management needs when allocating budgets.

A major reason for this inability to consolidate data on a watershed basis is the patchwork-quilt distribution of land ownership within a watershed. One or two locations creating problems in a watershed that is otherwise in satisfactory shape can adversely affect water quality and constrain use of the total flow coming from a watershed. Differences in land ownership and associated differences in the mission of agencies serving different types of landowners create an obstacle to evaluating impacts, setting priorities, and attaining water quality goals on a watershed-wide basis.

The first step toward surmounting this obstacle is to find ways to consolidate, standardize, and display data already collected for different land ownerships by different agencies at different levels of government. The objective is to lay a foundation of data needed to coordinate solutions to watershed problems and build partnerships among landowners and those agencies offering technical and financial assistance to implement solutions.

Geographic Information Systems (GIS) may help in this process. The key is finding a way to standardize data collected by different entities for related purposes over parts of watersheds and putting this into a single overlay for the entire watershed. Until this becomes possible, it will remain difficult for managers to evaluate cumulative effects and assign priorities. GIS will not make existing information better. But it will make data more usable by providing a mechanism for storing and displaying consolidated data. Having the mechanism provides an impetus to consolidate data already collected by different agencies.

Significant strides have been made in the past two decades in using aerial photography and remote sensing to map overstory vegetation. Advances have also been made in using these techniques to distinguish among some soil characteristics such as moisture because of their influence on light reflectivity. For example, the extent of wetlands along stream channels or reservoirs can be mapped using photography or remote sensing. Preparing maps this way reduces cost and amounts of field labor. Instead of collecting all data needed to prepare maps, maps already prepared based on photography and telemetry need only to be verified. Similarly, some differentiation among forest cover types has been achieved based on leaf reflectivity.

Aerial photography and remote sensing provide complete geographic coverage of the U.S. Geographic resolution is approaching acceptable levels for GIS proposed by state and federal resource management agencies. These methods of data collection are not capable of providing all the details on mid-story and understory vegetation or on soil and stream channel characteristics needed by watershed managers for a condition classification system.

The consequence of not having consolidated data for all landownerships is that decisions on watershed rehabilitation and restoration priorities will be made based only on ownerships for which information exists. Because coverage is incomplete, it cannot be determined if expenditures targeted on the areas with known problems will provide the largest possible improvement in overall watershed and water quality.

Soil survey work.—Additional work is needed to gather complete soils and stream channel information on forests and rangeland. For example, about 80% of the soils inventory on national forest is completed. The inventory should be completed without delay. It should emphasize information necessary to make management decisions concerning soil, site, and water productivity and impacts of site use. Additional work is also needed on how to summarize and display the information collected. This should go beyond building GIS overlays so that it can contribute to management decisions.

This work is only getting started. Watershed managers and decision makers need to play a stronger role in this effort. There is a need to articulate the kinds of decisions expected based on watershed condition classifications and data. Then, data analysis and presentation procedures must be developed or updated to meet needs—no small task.

More work is needed to test the validity of information already collected. Validation is likely to be a difficult research task. Validation presupposes that a clear cause-and-effect relationship has been developed between the soil, site, or vegetation characteristics and project- or activity-related impacts, such as erosion or water flow regimes, that watershed managers hope to evaluate. If these relationships have not been developed through research, they should be, as they are a necessary precondition to developing inventory sampling and data validation procedures.

A primary beneficiary of better watershed-level information will be nonpoint-source pollution control and erosion modelling work. Because sediment is the primary nonpoint pollutant from forests and rangeland in terms of volume, watershed condition information related to soil type, texture, and erodibility are key needs. A multi-agency task force of U.S. Department of Agriculture experts has begun work on the Water Erosion Prediction Project (WEPP). WEPP's goal is to improve prediction of surface erosion and sediment yield and their on- and off-site impacts. It is hoped that the WEPP model will replace the Universal Soil Loss Equation developed in the 1950s for predicting forest and rangeland erosion and impacts. The WEPP framework includes elements for surface erosion, sedimentation-slope relationships, off-site damage, channel routing and stability, mass failure rates, and watershed condition. Data discussed in this section is needed to project these WEPP elements. WEPP information needs to be integrated with data analysis, consolidation, and display tasks already discussed.

LACK OF INCENTIVES TO USE BMPs

Nonpoint-source pollution has emerged as a major problem in many areas now that major point sources have been cleaned up. Sediment is the major nonpoint-source pollutant from forests and rangeland. Undisturbed, mature forests generate very low annual sediment loads of less than 0.5 tons per acre. Disturbances are caused by most typical management activities, each of which has a different potential for causing nonpoint-source pollution. Road construction, harvesting, fire, and preparing for regeneration are the primary activities causing nonpoint-source pollution.

Average erosion rates for well-managed logging activities may be fairly low, perhaps only an additional ton per acre per year. However, erosion rates of 10 to 15 tons per acre per year are not uncommon for harvesting activities. Intensive mechanical site preparation before tree planting can generate sediment at rates exceeding 100 tons per acre per year (Dissmeyer and Stump 1978). In the past decade, managers have become more aware of adverse effects that some mechanized activities such as root-raking can have on soil productivity and sediment loss. Many of these practices are not as widely used today as a decade ago.

BMPs ARE KNOWN

Research has successfully identified major causes of sediment production. Practical procedures to reduce sediment production and mitigate sediment damages have been developed. WEPP is producing predictive models that will help managers evaluate the likelihood of environmental damage to a specific site from various activities. Thus, silvicultural and range-related BMPs are known and the ability to predict effects is being developed.

Why are some landowners not using BMPs when engaged in soil-disturbing activities? There are three reasons for this. The first is that erosion is an externality and the market provides little or no incentive to use BMPs. The second is that employing BMPs is often not in the economic self-interest of a landowner. The third reason is that knowledge about BMPs has not been effectively transferred to all landowners.

Erosion is an externality.—Erosion as an externality was discussed in Chapter 2. Sediment typically imposes few short-run costs on a landowner; operating savings may even occur if no attention is paid to sediment generation. For example, two and three decades ago, if a skidder could be driven back and forth across a stream without bogging down, it was. By continually crossing the stream, the costs of installing culverts or building a bridge were saved. Fish habitat destroyed or the cost of added water treatment by downstream municipalities did not show up on the landowner's ledger. Thus, the landowner was not paying full costs of his land management decisions.

Libby (1985) noted that there is no incentive for an individual to personally bear the cost of producing benefits for others. Motivated by the Clean Water Act, state governments are now intervening in the market and establishing legislation and regulations to levy civil and criminal penalties for creating nonpoint-source pollution. Incentives are being created that force those creating the problem to bear fiscal responsibility for sediment production.

Using BMPs costs money.—In spite of laws and regulations, some landowners are not using BMPs. Myers et al. (1985) noted that adoption of only some BMPs is in the self-interest of landowners and equipment operators. For example, using BMPs to construct proper logging roads intended for long-term use can produce savings both in terms of lower road maintenance costs as well as in lower repair rates for vehicles using the road. In most cases, however, using BMPs is not in the economic self-interest of the owner or operator.

There are two ways to alter the situation where using BMPs costs the landowner more than is provided in benefits. The incentive approach uses financial payments to make it more profitable for landowners to use BMPs. Cost-sharing and income tax credits are the two current vehicles available. To encourage more widespread use of BMPs, funding levels for incentives should be increased. Not only should more landowners be able to participate, but the economic benefit per landowner should also be increased.

To use the enforcement approach, costs of not employing BMPs should be increased. There are two elements to this approach—a penalty for getting caught not using BMPs and the likelihood of prosecution. Both elements enter the landowner's decision whether to pay the added costs of using BMPs. Increasing the aggressiveness of enforcement increases the likelihood of getting caught and helps ensure that a financial penalty is likely. Increasing financial penalties is one alternative. Increased enforcement usually costs the government money and goodwill, whereas increasing fines for lack of compliance results in financial returns to government.

Now that cross-compliance has been adopted as a mechanism for levying penalties in the agriculture land use sector, it may also prove an effective means of securing use of BMPs in silviculture and range management areas. Eligibility for forestry incentive payments should be contingent upon using BMPs.

Whether to use the incentives or enforcement or a combination of the two is a decision involving aspects of public administration, public policy, and politics. For example, regulatory programs are popular in the West where numbers of forest landowners are relatively few and the size of holdings makes BMPs more affordable. Incentive programs are more popular in the South with a large number of forest landowners and small average size of individual holdings. There BMP costs are more difficult for an individual to absorb, plus costs of enforcing regulations among a large number of small landowners is administratively and politically difficult.

Landowners lack knowledge.—Forest and range landowners tend to perform soil-disturbing activities at infrequent intervals. Many forest landowners harvest timber only every 10 to 15 years; for some, once in a lifetime. In addition, many landowners undertake timber harvesting or range rehabilitation without obtaining assistance from either private consultants or public servants. Consequently, the uninformed landowner does not take necessary steps to avoid nonpoint-source pollution in project planning and project supervision.

Sorenson (1985) reported that information programs for nonpoint-source pollution abatement were in a pioneering stage and that much remained to be learned. His experience in Wisconsin with one of the earliest programs provided the following insights:

- Identifying specific objectives of the information program is a key element. While the ultimate objective is reducing nonpoint-source pollution, identifying more detailed objectives for information program elements is essential.
- There is usually more than one audience and each has different needs. The community in general is usually one audience separate and distinct from the specific landowner creating pollution problems.
- It usually takes more funding and time than planned to develop an effective program whose success can be evaluated in terms of on-the-ground results.
- Any information and education program will be a cooperative effort among federal, state, and local agencies. Preparing written agreements outlining the role of each cooperator, updated every few years, will assure that gaps and overlaps in outreach efforts are minimized.
- A variety of activities to reach everyone in target audiences should be planned.
- Evaluation is an important, albeit difficult, part of the information and education program. Finding out what works and what does not is the only way to make programs more effective. Deciding on the measures of success is often a most difficult aspect of conducting a program evaluation. Consultants can be of assistance in this phase.

Because agricultural activities are a much larger component of the nonpoint-source pollution problem than silvicultural activities, information and education programs targeted at agricultural audiences are being developed in some states. Agencies concerned about silvicultural nonpoint-source pollution may be able to cooperate with those having ongoing agricultural information and education programs. Alternatively, agencies concerned with silvicultural nonpoint-source pollution will be able to learn from experiences of those serving the agricultural community if a separate silvicultural program is warranted.

SUMMARY

Wilson (1985) discussed provisions of the Oregon Forest Practices Law and how it is implemented to reduce silvicultural nonpoint-source pollution. His description demonstrates the importance of information and education efforts and how they can be combined with rules and enforcement procedures into an integrated program to maintain forest productivity. State agencies are the logical institutional units to coordinate programs to implement BMPs. Federal agencies need to provide financial and technical assistance to help states design programs. Federal agencies also should be ready

to help deliver assistance to landowners during program implementation. A coordinated institutional approach gives private landowners incentives needed to use BMPs and help state-run programs achieve consistency with national nonpoint-source pollution abatement goals.

CURRENT LAWS ENCOURAGE WETLANDS CONVERSION

There are two major categories of tax incentives to convert wetlands to "higher and better" uses such as crop production and urban developments. These are income tax laws and regulations and property tax laws and regulations. The income tax code operates primarily at the federal level. State income tax laws often contain the same provisions encouraging wetlands conversion as does the federal code. Property tax laws are commonly enacted at the state level and enforced at the local level.

INCOME TAX INCENTIVES

The income tax code provides deductions for all types of general development activities and is the most significant federal incentive for farmers to clear and drain wetlands. The result is that a significant portion of wetlands conversion costs are shifted to the taxpayer. The dollar value of tax incentives is higher at higher income levels. The Office of Technology Assessment (1984) listed four major incentives to wetlands conversion. 1986 changes in the income tax code altered two of them. The four incentives mentioned are:

1. First-year tax deductions of up to 25% of gross farm income are allowed for draining expenses. Expenses in excess of this limit may be deducted in subsequent years.
2. Tax deductions are allowed for depreciation on all capital investments necessary for draining or clearing activities.
3. Tax deductions are allowed for a portion of interest payments related to draining and clearing. The 1986 changes in the income tax code provide for gradual phasing out of this deduction, unless interest is on a home equity loan.
4. Investment tax credits equal to 10% of drainage tile installation costs are allowed. The 1986 changes in the income tax code eliminated this tax credit.

PROPERTY TAX INCENTIVES

Property taxation encourages wetlands conversion through assessed valuation of a parcel. Wetlands are not commonly used for income-producing purposes, hence assessed value is low. When wetlands are converted to a use producing income, assessed value is usually increased. When the assessed valuation increment is big enough that the tax increase makes the income-production process no longer financially attractive, landowners are put in the position of either discontinuing the activity or selling the land.

Property assessment guidelines are commonly quite broad and general. In the hierarchy of uses, land used for business purposes is often assessed a higher value than land used for private purposes. Assessment guidelines also make it easier to raise assessed value than to lower it.

Here is a generic example of how property tax administration has often encouraged wetlands conversion. A farmer has wetlands on his property. Assessment guidelines do not provide for unproductive areas in fence rows and similar land to be subtracted from producing acres when the assessment is conducted. The assessor rules that wetlands shall be treated as fence rows. So the farmer is required to pay several hundred dollars in taxes each year on land that produces no income. In the occasional bountiful year, the farmer takes advantage of income tax rules and spends some added income on draining a portion of the wetlands. Over time, the entire area is drained and converted to production of income. Repeated thousands of times annually across the U.S., the net result is losing several hundred thousand acres of wetlands per year.

REDUCING THE INCENTIVES

There are both direct and indirect approaches to reducing incentives to convert wetlands. Direct approaches involve changing tax codes and property assessment guidelines. Indirect approaches are like cross-compliance; let the tax incentive remain but add a penalty that reduces usefulness of the incentive or increase payments providing a counterincentive to the tax incentive.

Direct Approaches

Change the income tax code.—The direct approach of changing the income tax code to disqualify wetlands conversions has not been used. Legislation declaring that the cost of converting wetlands is ineligible for deduction or amortization is the kind of precise remedy that has a reasonable chance of passage. The key is whether a political consensus could be mustered to show that preserving wetlands is socially desirable. Alternatively, a provision establishing a new tax credit for retaining and restoring wetlands, much like the forestation or reforestation tax credit, would also work. The approach would be to compensate landowners for the additional tax burden borne by keeping wetlands in place. The political efficacy of this approach is judged to be much less than the former proposal.

The 1986 changes to the federal income tax code consolidated income brackets into three broad brackets and lowered marginal tax rates for higher incomes. The net result is that lower marginal tax rates reduce benefits of converting wetlands to other uses because deductions are no longer worth as much to the taxpayer. Another provision in the 1986 changes reduced the deductibility of consumer loan interest unless the loan is tied to property equity. This may have some effect on a farmer's willingness to borrow money to drain wetlands. The investment tax credit formerly available for installation of drainage tiles was abolished by changes in the law.

Change the property tax code.—The direct approach to changing property taxation regulations hinges on modifying assessment valuation guidelines. Changing laws and guidelines state-by-state takes time. It took several decades for the current use valuation principle to become widely applied to forestry. This principle is that property shall be assessed as forest land if uses such as forestry are deemed desirable. To qualify for the lower assessed value as forest land, trees must be kept on the land regardless of other potential values such as cropland or industrial development.

The first step in securing use valuation for wetlands is to attain consensus that such lands are socially desirable and get that preference written into law. The second step is to modify assessment valuation guidelines so that surveys recognize wetlands and assess their value accordingly.

Indirect Approaches

The indirect approach has been the preferred approach to date. The swampbuster provision of the Food Security Act of 1985 is the latest provision. It reduces conversion by denying eligibility for federal farm benefits to those growing agricultural crops on wetlands whose conversion began after December 23, 1985. It is important to note that this provision neither protects wetlands nor prohibits drainage or modification. It is too early to tell what effect this provision is having on the wetlands conversion rate. Recent market conditions for agricultural commodities making conversion unprofitable and the swampbuster provision may slow conversion (Feierabend and Zelazny 1987). If converted wetlands are not used to grow crops subsidized by the government, no penalty ensues. The effectiveness of swampbuster will not be tested until crop prices recover and it once again becomes profitable to convert wetlands to boost crop production.

The 1977 amendments to the Clean Water Act provided language giving the Corps of Engineers rulemaking discretion to include wetlands within the Section 404 program.[2] The Section 404 program gave the Corps responsibility for regulating discharge or disposal of dredged or fill material. The Corps views its primary function in carrying out the law as protecting water quality. Although wetlands values are considered in reviewing project permits, the Corps does not believe that Section 404 was designed specifically to protect wetlands (Office of Technology Assessment 1984).

The 404 program provides a major avenue for federal involvement in regulating activities that use wetlands. However, it was not designed to stop wetlands conversion. The 404 program only regulates the discharge of dredged or fill material onto wetlands. Projects involving drainage, clearing, or flooding of wetlands are not explicitly covered in the legislation, hence are not regulated directly by the Corps. Thus, instead of preventing wetlands conversion, the thrust of the program is to prevent water quality degradation from activities affecting wetlands. The consequence is that some wetlands conversions have been avoided, but the extent is difficult to estimate. Office of Technology Assessment (1984) concluded that without more direct government involvement, conversion of most inland wetlands is likely to continue unabated. It appears that the swampbuster provision of the Food Security Act of 1985 was a congressional response to the above conclusion.

The 404 program provided some disincentive to convert wetlands. In 1981, acreage affected by requested permits totalled about 100,000 acres. As ultimately approved by the Corps, acreage affected totalled about 50,000 (Office of Technology Assessment 1984). Of approximately 11,000 permits received annually, about 3% are denied, about 14% are withdrawn by applicants, about 33% are modified significantly, and the remainder are approved without significant modifications.

Other federal agencies, such as the FWS can participate in the permit review process, but EPA has veto power over permit approvals. The National Marine Fisheries Service of the Department of Commerce estimated that the 404 program, in combination with state programs, reduced coastal wetlands conversion by 75 to 80% in 1981. EPA has used its veto power less than a dozen times between 1977 and 1984 (Feierabend and Zelazny 1987).

There are four principal nonregulatory programs that help protect wetlands. Most of these involve land acquisition and are designed to protect wetlands from drainage and destruction through purchase or lease. The 1929 Migratory Bird Conservation Act authorized federal acquisition of land for migratory waterfowl refuges. The 1934 Duck Stamp Act established funding for the Migratory Bird Conservation Act through sales of federal migratory bird hunting stamps called "duck stamps" to all hunters aged 16 and older. Funds collected are used to acquire habitat for migratory waterfowl, including wetlands and related uplands areas used for nesting and cover. Since enacted, the duck stamp program has generated nearly $313 million, used to acquire more than 2.3 million acres (Feierabend and Zelazny 1987).

The Wetlands Loan Act of 1961 was intended to accelerate federal acquisition of migratory waterfowl habitat. The law, extended through 1988, authorized additional federal appropriations as a loan against future revenues from duck stamp sales. As of 1985, more than $190 million had been appropriated for acquiring additional habitat.

The Land and Water Conservation Fund was established in 1964 and also provides money for land acquisition financed by receipts from offshore oil and gas revenues. Legislation establishing the fund authorized Congress to appropriate up to $900 million annually. Annual appropriations have always been a fraction of the authorized level. As amended by the Emergency Wetlands Resources Act of 1986, the fund can also be used to acquire wetlands. The act also requires states to include acquisition of wetlands as part of their statewide comprehensive outdoor recreation plans. The 1986 act also increased the level of funding going into the Migratory Bird Conservation Account.

The Water Bank Program, administered by the Agricultural Stabilization and Conservation Service, authorized $10 million per year for 10-year leases of waterfowl habitat from private landowners. Few funds have been appropriated for this program in recent years. As of April 1987, the program had funded 4,615 leases, protecting 153,073 acres of wetlands and 332,861 acres of adjacent uplands (Feierabend and Zelazny 1987).

SUMMARY

The slow grinding of the political process is a factor in implementing tax code changes or expanding indirect approaches for halting wetlands conversion. The process will not accelerate unless a political consensus emerges indicating that additional federal help is needed to conserve wetlands. It may be easier to secure the needed consensus at the state level to obtain changes in state legislation.

Nonregulatory vehicles available have proven effective in conserving wetlands. With additional appropriations, more could be done without significantly expanding the bureaucracy needed to implement programs.

IMPACTS OF LARGE-SCALE WATER YIELD AUGMENTATION

The three water yield augmentation measures identified as management opportunities in Chapter 7 are vegetation management, snow trapping structures, and weather modification primarily through cloud seeding. The efficacy of each of these measures for increasing water yields has been demonstrated in pilot tests. They have never been implemented on the scale necessary to have significant impact. Environmental and social impacts of large-scale use of these measures constitute the major obstacle to employing them in a coordinated way on a regional basis.

The cumulative nature of impacts generated to make a significant contribution to regional water yields makes them important. Employing measures in a single watershed is insufficient. Most watersheds in the Upper Colorado region must be managed for water yield if projected water shortages in the Upper and Lower Colorado regions are to be alleviated. Consequently, the implicit tradeoff being considered is to mitigate major impacts in the social structure of agricultural communities along the middle and lower portions of the Colorado River basin by making major alterations to the environmental and social character of forest and rangeland management in the headwaters of Colorado River tributaries. This section looks at impacts likely to occur in the headwaters to provide a better foundation for evaluating the role of water yield augmentation in alleviating projected shortages.

ENVIRONMENTAL IMPACTS

Implementing the three augmentation measures over wide areas will create significant environmental impacts. The focus here is on the two major impacts—a significant increase in timber cutting[3] and stream channel integrity.

Timber Cutting

Vegetation management relies upon a reduction in evapotranspiration as a major vehicle to obtain water yield increases. Cutting timber in correct patterns can improve the ability of an area to trap snow and delay snowmelt into early summer. However, this does little to increase total regional flows.

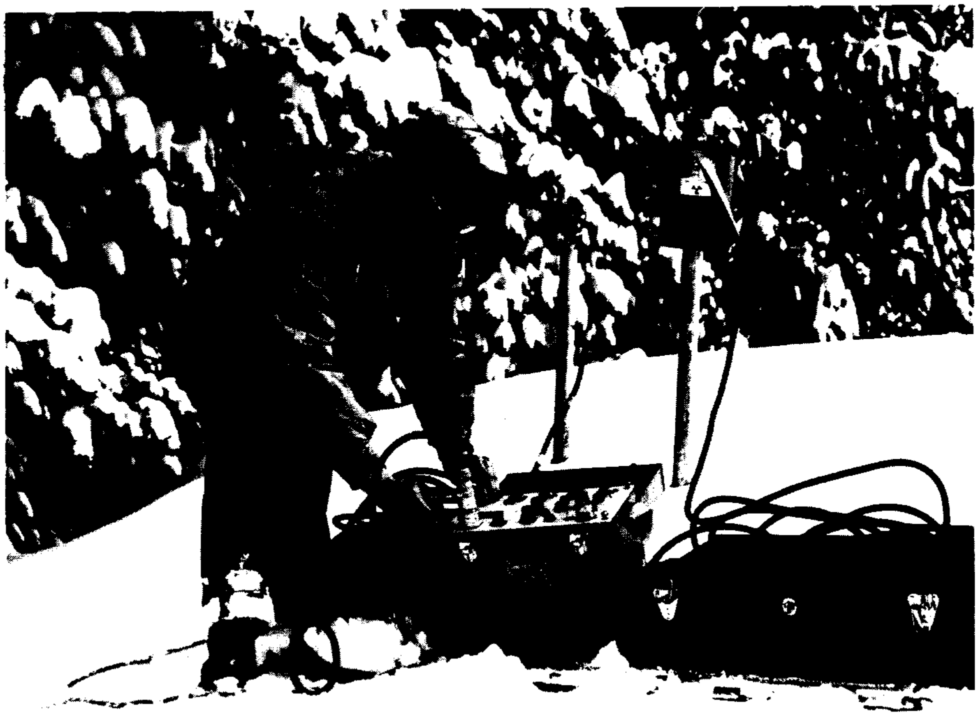
Some level of clear cutting will be necessary to provide patchy cover necessary to trap blowing snow. Thinning will also be needed to regulate the amount of shade and timing of snowmelt. At altitudes where cutting is needed, soils tend to be more fragile and unstable than at lower elevations. Consequently, any cutting that increases the amount of water in the soil increases the hazard of landslides. The likelihood of increased numbers of landslides must be considered when evaluating feasibility of a major regional commitment to water yield augmentation and during project-level planning such as for road and timber-cutting layouts. If soils were consistently stable or consistently unstable, it would be easy to deal with whether more landslides will occur. But the fact is that soil stability in high-elevation watersheds tends to be quite variable. Thus, planning and decision-making are all the more difficult.

After timber cutting, ecological succession begins. Water yields usually remain high until trees are reestablished and their crowns close. Delaying crown closure will pay benefits by keeping water yields elevated.

Fire and herbicides are the most common practices used to retard ecological succession. For example, chaparral needs to be burned every 12 to 15 years to keep water yields high. Although fire is relatively inexpensive, the difficulty of using it on slopes is retaining enough vegetation on the site to keep the soil anchored. This usually requires cool, low-intensity burn. Such fires can easily overrun the prescription boundaries.

Herbicides and application rates can be chosen to selectively kill some plants but not others. For example, products are available that will kill broadleaved plants but only stunt grasses. These herbicides are quite popular in right-of-way maintenance beneath utility lines and along highways. A single herbicide treatment each year has reduced the mowing frequency in highway medians by more than half, yet the grass remains effective in preventing erosion. Thus, using herbicides can reduce the likelihood of sediments polluting water supplies.

A benefit from using vegetation management to augment water yields is the creation of a more diverse vegetation structure. Clearings will be interspersed with areas thinned and where no cutting has occurred large amounts of edge will be created. Thus, the area will pro-



Although researchers have demonstrated the feasibility of trapping increased amounts of snow and delaying melting in experimental watersheds, the environmental and social impacts from widespread application of these techniques present an obstacle to using them.

vide habitat for a wider variety of wildlife. Adequate cover for concealment and protection from heat and cold will also remain. Larger numbers and a wider variety of wildlife are expected from a more diverse vegetation structure.

The objective of the cutting patterns is to alter the wind flow so that snow falling in cutover areas is blown into and trapped by thinned stands. The clearcut patches will create changes in wind patterns up to several hundred feet above the ground. Currents will be changed and eddies will form. The consequence will be increased hazard of windthrow damage. Trees along the edge between cut and thinned areas on the upwind side will be most susceptible to swirling gusts. Early season snowfalls before the ground is frozen or late spring storms where snow is wet and heavy create the greatest risk of windthrow.

Finally, vegetation management to augment water yields is expensive, especially if the timber cut cannot be sold. Many watersheds along the Colorado River are public land. Given recent Forest Service budget levels, it is not possible to fund vegetation management on the scale described. New partnerships must be created whereby beneficiaries of additional water would help pay to create and maintain flows from national forests.

Stream Channels

Stream channels have evolved due to historical patterns of precipitation and runoff. When major increases in precipitation and runoff occur, higher flows will create environmental impacts. If snowmelt timing is not extended, flood peaks will rise as will water velocity. Higher peak flows will increase flood damages to residents along valley bottoms. Higher flow rates mean that the water has more energy to carry sediment. Increased bottom scour and bank erosion is the result and leads to increased sediment damages downstream.

The purpose of timber cutting is to extend snowmelt duration so flows are higher and extend longer into the summer. The major impact on stream channel integrity will come if winter and early spring weather varies significantly from its long-term average. If wintertime precipitation is abnormally heavy and if the spring thaw is abnormally rapid, then flows will rise rapidly to a peak well above the norm and water velocities will be high. Even the best timber cutting patterns cannot overcome abnormally warm air temperatures. Weather modification plans must take into account stream channel capacities in the event of a sudden warmup. Weather modification should not add more snow to a basin than stream channels can handle.

Despite research, weather modification remains an inexact process. Seeding has been used in recent years to augment snowfall for skiing. But difficulty in controlling where the snow falls has reduced the acceptability of the technique. Snow often continues to fall well past the target area. For purposes of water yield augmentation, targeting is less of a problem as all melt water goes down the same major stream.[4]

Other Environmental Impacts

Research demonstrates that snow trapping structures can be used above timberline. Alpine and tundra ecosystems are much more fragile than ecosystems below timberline. The impact on vegetation from constructing fencing 15 to 20 feet tall can be severe. Fencing must be anchored solidly to withstand severe winds and constructed of materials that will withstand the elements. Considerable maintenance activity may be required that further impacts the surrounding vegetation. When all factors are considered, fencing will probably not become as popular for solving regional water shortages as vegetation management and weather modification. However, fencing will continue to play a prominent role locally in keeping snow off highways, in range management, and for filling isolated depressions for stock and wildlife watering.

Sites undergoing vegetation management to increase water yield need more attention than conventional timber management. Crews will be working on sites every few years. Although such schedules are acceptable in the South for managing southern pine, it is not known if a more intensive management schedule including activities such as burning or herbicide applications every several years will be acceptable in the Rocky Mountains.

SOCIAL IMPACTS

Vegetation management, weather modification, and snow fencing create social and political impacts. Certain impacts are tangible in the sense that they can be mitigated or compensated with dollars from regions that use the added water. Other impacts occur, however, where neither mitigation nor compensation may be feasible.

Large-scale vegetation management will cause visual impacts. Unless cutting pattern design is done with skill and sensitivity, mid- and long-distance mountain views will be adversely affected. Irregular shapes that blend with terrain features are least objectionable. Computer programs exist that enable landscape architects to design cutting patterns and model how views will appear after cutting. Whether views will be socially acceptable is unknown. Structures used above timberline may create additional visual impacts.

Weather modification creates additional snow in both rural and developed areas alike. Public reaction to current weather modification practices is mixed. Concerns were expressed about the ability of roof structures of residential dwellings to carry additional snow loads. More snow requires greater local government expenditures to keep roads cleared. Economic costs such as these need to be considered when partnerships are formed to provide interbasin transfers of water. Social impacts include living with more snow in winter and for a longer time period.

Additional water provided from public lands is subject to appropriation. Forest Service policy is to provide water for other political entities to distribute. Competition among political jurisdictions and interest groups to appropriate increased flows of water will be keen. Conflicts among competing uses are likely to emerge. Additional reservoirs will be needed to capture additional water from increased yield. Reservoir construction will generate additional environmental, social, and economic impacts.

One unanswered question is who will pay the costs of vegetation management, weather modification, and associated water developments? In early decades of this century, the federal government would have played a major role each step of the way. Recently, federal participation in water resource developments has declined. Partnerships between local, state, and federal governments are now needed, with local and state interests sharing a much bigger portion of extra costs. The partnerships are yet to be formed. The social and political compacts needed to reach a consensus on how to deal with projected shortages do not exist. Whether the linkages can be forged, at what cost, and who will pay remain to be seen.

SUMMARY

This chapter has focused upon the six obstacles having the most severe and direct consequences on forests and rangelands and associated wetlands. Obstacles to managing water resources and related lands other than forests and range were not explored here, although many exist. Removing some of the obstacles discussed here, such as making water markets freer or giving instream uses higher priority, will undoubtedly have effects on other uses and obstacles.

The goal of this chapter and the preceding one was to stimulate thought about how to manage water and related lands. To realize opportunities and overcome obstacles will require changes in recent trends of water and land resource allocations and in institutions that manage the resources. Whether we as a nation choose to continue recent trends and endure the likely implications outlined in Chapter 6, or pursue a different future, perhaps realizing some of the opportunities and removing some of the obstacles presented in the last two chapters, requires conscious decisions on the part of society and land managers. One vehicle to involve society in considering these decisions is to outline potential changes in government programs for managing water and related land resources. Then, through discussion of proposed program changes, managers and members of society can interact and begin to build a consensus about management directions.

The 1990 RPA Program will discuss potential strategies for managing water and related land resources on national forests, for assisting states in watershed management, and for conducting research in these areas. To build a linkage to the program, the final chapter discusses the implications of the findings in this water assessment for current and future Forest Service programs.

NOTES

1. See the Flather and Hoekstra (1989) and Cordell (1989), companion technical documents supporting the 1989 RPA Assessment for additional information in increases in fishing and water-related recreation participation rates.

2. A 1975 decision by the U.S. District Court for the District of Columbia, in *Natural Resources Defense Council versus Calloway* broadened the scope of the original 404 program from the Corps' traditional definition of navigable waters (emanating from the 1899 Rivers and Harbors Act) to "all waters of the United States." The issue of the Corps' jurisdiction was hotly debated, but left unchanged in a close vote, when the 1977 amendments to the Clean Water Act were passed.

3. Timber cutting is used here instead of timber harvest, because harvest implies that the trees cut are a merchantable product, when in fact, they may have little or no market value. Merchantability is affected by may things, including tree diameter, species, and the location of the stand in relation to the nearest mill. Increasing the water yield from the site, not obtaining returns from harvesting timber, is the primary land management objective.

4. In Colorado, much of the water used to supply residents east of the Front Range, who live in the Missouri and Arkansas-White-Red regions, comes across the Continental Divide from the Upper Colorado region. These trans-region diversions are ignored in the referenced sentence.

CHAPTER 9: IMPLICATIONS FOR WATER AND RELATED FOREST AND RANGE MANAGEMENT PROGRAMS

The economic, environmental, and social implications in Chapter 6, the opportunities outlined in Chapter 7, and the obstacles discussed in Chapter 8 suggest ways that water and land management programs can alter the future situation projected in Chapters 3, 4, and 5. Many changes have implications for programs of other federal agencies, state agencies, and local organizations. Although some implications will be mentioned in this chapter, the main focus is on implications for Forest Service programs.

Forest Service program implications of the water assessment findings are presented as answers to six questions. These questions provide a structured way of exploring the impact of assessment findings on how the Forest Service manages national forests, provides assistance to states and private landowners, and conducts research. Similar questions are being asked in the other assessment technical reports as a way of strengthening the link between assessment findings and the 1990 RPA Program.

QUESTION 1: WHAT SHOULD THE FEDERAL GOVERNMENT DO TO EASE POTENTIAL SHORTAGES OF WATER AND OTHER WATERSHED RESOURCES?

Potential shortages arise because of a projected gap between future supplies and future demands. If the government does not intervene in the market, the economy will function and prices rise until demand and supply are equal. Rising prices may reduce demand and may provide incentives to boost supplies.

In some cases, allowing prices to rise high enough to equilibrate demand and supply results in price increases judged socially inequitable. Then, government could intervene in the market to curb demand by implementing rationing, or increase supplies by sharing costs of forest regeneration. In addition, government actions may be used to redistribute impacts. Rationing allocates the resource without regard to a user's ability to pay.

THE FEDERAL ROLE

All three levels of government—federal, state, and local—have borne responsibilities for easing water shortages. The traditional federal government response to shortages has been to increase supplies, not to restrict demand. The federal government has intervened to help develop water resources using dams and conveyance structures and has played a role in the expansion of irrigation through decisions about water prices from federal projects.

The Forest Service has been involved in water development projects by providing permits for locating dams and diversion and conveyance structures on national forests. When measures affecting demand are needed, states have played the lead role. Controlling water use and water rights are areas that have historically been state responsibilities. Demand management has traditionally focused on managing the queue of users to assure that everyone gets a fair share.

Arriving at the socially preferred mix of demand and supply management presents an institutional challenge because determining the mix requires state and federal agencies to achieve a joint consensus on their respective roles. State agencies have traditionally undertaken demand management actions while federal agencies have responsibilities for supply management. Further, each federal agency involved in supply management typically has a narrow functional mandate. For example, the Forest Service lacks dam-building authority. The institutional challenge is not only to arrive at a socially-preferred division of responsibilities between the state and federal levels of government but also to decide the extent to which specific federal agencies should be involved. Similar institutional challenges have been met in the past by chartering regional commissions. Examples are the Appalachian Regional Commission and the Delaware River Basin Commission. This approach to institutional coordination was popular in the 1960s and early 1970s. Following the demise of the Water Resources Council in 1982, no group at the federal level has provided coordination among federal agencies with roles in planning and development of water and related land resources.

Projected water shortages in the West and limited capability to combat shortages by building more storage and conveyance structures suggests that a new examination be made of options to manage water and related land resources. One approach to obtain the institutional coordination needed would be for Congress to charter additional regional river basin commissions and reinvigorate those that currently exist west of the 100th Meridian. Commissions could be charged with responsibilities to develop and oversee implementation of regional plans to minimize shortages and resulting adverse effects. Another approach would be for Congress to authorize new "Level A" studies of river basins with projected shortages and use this planning process to explore public preferences for dealing with projected shortages. Whatever approach is taken to decide on the preferred mix of demand and supply management practices, the specific missions and roles of various government agencies must be taken into account.

Vegetation management, weather modification, and construction of snow fencing can all help augment water yield from public forests and rangeland. These practices have proven feasible in studies on experimental watersheds and have been used on a limited scale on national forests in Colorado and California to support ski developments. Expanding the use of these measures to the scale needed to increase supplies substantially and ease water shortages may create significant environmental and social impacts due to the cumulative effects of using measures on a multi-state basis. In many cases, implementing these measures on the scale needed may be judged too costly.

Major water shortages are projected for the Lower Colorado water resource region. Lesser shortages are predicted for the Upper Colorado, California, Great Basin, and Rio Grande water resource regions. If recent water use trends continue, the Forest Service needs to consider the following questions:

— To what extent should the Forest Service adopt a policy of implementing vegetation management, weather modification, and/or snow fencing construction to help alleviate shortages?

— What contribution should the Forest Service make toward easing water shortages using these measures compared to other supply and demand management measures? What does that imply for the application intensity of such measures and for the scope of geographic coverage?

— How quickly can or should the Forest Service proceed with implementation?

Concurrently with Forest Service consideration of these questions, other federal agencies also need to examine their role in easing projected water shortages.

THE ROLE OF OTHER GOVERNMENT AGENCIES

The major non-price tool available for easing future water shortages is water conservation. Conservation has no widely-accepted definition. In this section, conservation means "use less water". In other reports, water conservation is defined as using the same amount of water more efficiently such as growing more crops with the same volume of water. If crop shortages were the problem, then defining water conservation as improving water use efficiency would help ease the shortage. However, *water* shortages are the main concern. People in the five regions where shortages are projected must conserve more water than the current trend in water use indicates.

The question is what can other government agencies do to help residents conserve water? A second question is whether the federal government has regulatory power to implement water conservation. States have historically had the legal responsibility to regulate water use. In recent years, however, there has been considerable expansion of federal regulatory power into what have traditionally been the states' bailiwick. Most of this intrusion has been justified, constitutionally speaking, through an expansion of authority under the commerce clause.

Few parallels exist at the federal level where conservation practices have been successfully employed. The oil crisis of the early 1970s is the most recent example of major federal initiatives to promote conservation. A variety of tools were used including setting energy efficiency standards for automobile and appliance manufacturers, giving income tax credits for energy-saving home improvements and increasing funding for mass transit and car-pooling. Although gasoline rationing coupons were printed, rationing was never imposed. It is difficult to imagine how federally-mandated conservation measures similar to those used during the oil crisis would be imposed for water, especially because projected water shortages are not nationwide.

State and local governments, on the other hand, have often taken the lead in promoting conservation on a regional and local basis. Taxes have often been used to increase prices and promote conservation. Non-price methods have also been used. During the oil shortage, gasoline station hours were regulated and 10 gallons was established as the maximum purchase in many areas. In some localities, vehicle license plate numbers were used to implement rationing—if the last digit on the plate was odd, gasoline could only be purchased on odd-numbered days of the month. Similar regulations have been used during temporary water shortages due to droughts. For example, car washes were closed or hours of operation restricted. Citizens with odd-numbered addresses could water lawns only on odd-numbered days. Similar regulations exist in many areas. To implement them, a designated official usually issues a formal declaration that a water emergency exists. Then, regulations go into effect for an indefinite period until the emergency passes.

In contrast to measures designed to deal with droughts on a temporary or seasonal basis, dealing with projected water shortages will require more permanent measures. The measures cited above deal with the symptom of the problem, not the root cause.

THE REAL PROBLEM IS WATER PRICES

Water conservation measures employed so far deal with physical shortages. However, physical shortages are only a symptom of the real problem in the five water resource regions. The major problem creating water shortages is that water used for irrigation is under-valued in the marketplace. It is available at a lower, subsidized price than what it is really worth.

Federal irrigation water development projects were originally designed to sell water at a price covering project costs. But federal government policy has kept prices low, so receipts for water sold are covering only a small portion of project costs. It is a well-known economic fact that items available free or below cost will get greater use than if fair market prices were charged. Water priced below supply costs is the major reason why irrigation comprises 80% of water consumption and why shortages are projected in these five regions.

Institutional barriers have also been erected that prevent a freer market for water from emerging; or where one has emerged, constraints have been imposed that keep the market from functioning efficiently. The barriers and constraints typically hinder the sale of water and water rights to non-agricultural users who are willing to pay fair market price. For example, in some western states water rights cannot be separated from the real estate where they are used for irrigation. Thus, municipalities that need water to meet the needs of expanding populations and diversifying economies are forced to buy farm real estate to obtain the rights to the water needed.

RECENT GAINS IN PRODUCTIVITY DECREASE RELIANCE ON IRRIGATION

A century ago, federal and state governments embarked on a path of using agriculture to motivate development of the West. The burgeoning population of the U.S. needed agricultural products, railroads were available to deliver crops to distant eastern markets, and irrigation was the technology available in the early 1900s to improve crop productivity. A stimulus to spread development quickly over a wide area was needed. Water development projects provided it. Today, irrigation is used on over 60 million acres but its use appears to have peaked. Nearly 2 million acres have been withdrawn from irrigation since 1980. In parts of the southern Great Plains and Rocky Mountains, it has become too costly to pump groundwater for irrigation. Net returns from dry-land farming equal, and often exceed, net returns from irrigated production in those areas.

Future gains in crop productivity will come more from advances in genetics and biotechnology than from increasing irrigation. New crop varieties have been developed for dry-land farming in semi-arid areas and for saline soils. The Appraisal projects continued increases in agricultural productivity from genetics and biotechnology to 2030. New ways of boosting productivity can be combined with irrigation to meet society's crop needs on fewer acres. New technologies can also be used as substitutes for irrigation. Gains from new methods are the underlying reason why the Appraisal projection of agricultural acreage required to meet society's needs in 2030 is 160 million acres less than today. Irrigated acreage projected is 19 million acres, or one-third, less than today.

Farmers can keep yields and farm income steady using new methods; however, changes will occur in farming and irrigation practices. Changes will affect both farmers and the farm economy because of decreased farm capital invested in irrigation equipment and field leveling, a reduction in sales of products associated with irrigation, and a potential change in asset value of irrigation rights. In theory, farmers should not allow capital already invested to stand in the way of changing to more efficient operations. However, this is not easy. More importantly, many state water rights laws contain provisions that water must be used or rights will be lost. Also, water rights cannot be sold without selling the land formerly irrigated. Such provisions make a decision to abandon irrigation very difficult because either farm size must be reduced or a valuable asset—the water right—will be lost without compensation.

As new methods of improving agricultural productivity are implemented and the recent trend in increasing irrigated acreage drops, the potential exists to make a major structural change in recent water use trends in the five water-short regions. This structural change could reduce the likelihood that shortages will emerge. As pointed out in Chapter 5, if irrigation water usage can be held at 1985 levels, shortages will disappear in the Rio Grande, Upper Colorado, and Great Basins. In California, holding irrigation water use at 1985 levels reduces the deficit enough that conservation in other uses will remedy the problem. The major impact of holding irrigation water usage at current levels is that irrigation will no longer be the primary impetus for growth in the agricultural economy in these regions; it will instead become a constraint. In the Lower Colorado basin, holding irrigation water usage at 1985 levels will not eliminate most shortages.

FREER WATER MARKETS WILL HELP

What is the most efficient way of keeping irrigation water usage at current levels in the Rio Grande, Upper Colorado, Great Basin, and California regions? Also, what is the most efficient method of reducing irrigation water usage in the Lower Colorado region?

The nation's economic system is predicated on allowing the market to function and induce changes in resource allocations. Seeking a market solution should be the first priority. Because irrigation water is the lowest-valued offstream water use, a freely-functioning and reasonably competitive market should help water move from irrigation to higher-valued offstream uses. It is too early to determine if changing to fair market pricing for water and lifting market constraints will be sufficient government intervention to ease projected shortages in the former four regions. Changing to fair market pricing will probably not induce sufficient change in irrigation water use in the Lower Colorado region to eliminate the projected shortage. Widespread and strong water conservation measures may also be necessary.

Without changes in water pricing and institutional arrangements, the projected shortages will probably occur. Current institutional frameworks that tie water rights to real estate and that mandate using water or losing the right to it provide the farmer with few options and little flexibility. These frameworks are protectionist and designed to stimulate expansion in demand—the opposite of what is needed to ease shortages. The current crop-surplus situation and Appraisal acreage projections hardly merit further expansion of crop production on the basis of economics. Non-price actions can be taken to help avoid shortages, but the effect will be to further constrain free market functioning. Farmers need flexibility to respond to clear market signals for crops and water in ways that best fit their short- and long-term operations. Being able to buy and sell water in competitive markets could provide the additional flexibility needed. For example, being able to sell water rights separate from land may enable some farmers to liquify one of their farm's major assets yet still remain a viable enterprise using new crops and varieties better suited to semi-arid, dry-land farming. To help free markets for water, state and federal agencies need to consider the following policy issues:

— Should water markets be decontrolled to ease projected water shortages? Should water rights be separated from real estate so water and land can be sold independently?

— How far should water prices be allowed to rise and what will be the remaining imbalance between demand and supply at that price? Can non-price actions be taken to close the remaining gap? What will be the impacts of alternative courses of action on current and potential future water users?

— To what extent should cross-compliance measures be used to promote water conservation? Should subsidy payments be made on crops grown with subsidized water? Should receipt of crop subsidy payments be tied to an approved water conservation plan?

SOCIAL PREFERENCES ABOUT WATER USE PRIORITIES ARE CHANGING

The major impetus for easing water shortages is to assure sufficient water to meet society's needs. Historically, the first approach often tried in such situations was to increase supplies rather than face the reality that resources may be limited. Some water interests may still advocate such an approach through modification of vegetation, redistribution of high mountain snowpack, and weather modification. These approaches are attempts to retain established water use structures and institutions. However, as society and the economy have become more urbanized, the voting population has become progressively less sensitive to agricultural issues and concerns. Urban/suburban voters are demonstrating concern about the environment in terms more relevant to their lifestyles—they want fish and wildlife populations and recreation opportunities preserved. Consequently, if water shortages become more prevalent and affect urban/suburban lifestyles in terms of having less water-based recreation and fewer places to go fishing, political support will grow at the state level for changing the doctrine of prior appropriation. The priority of beneficial uses will change to non-agricultural uses. The question no longer is *will* the shift in water rights emphasis occur, but *when* and *how fast*.

Government programs to ease shortages that seek to perpetuate the status quo of appropriations priorities will increasingly come in conflict with social preferences. The trend in voter preferences suggests that suburban/urban interests are forcing changes in water use priorities. The effect is that irrigation will probably cease to enjoy its current water use priority. Evidence of this change is being observed. The Census of Agriculture shows areas where the decline of agricultural irrigation is largest. These are the areas where urban growth is fastest. Clearly, urban interests are forcing water use changes.

In the southern Rocky Mountain region, a water rights market appears to be emerging. Involvement by state water agencies varies—some encourage open market functioning while others strongly defend the existing water rights holder. Regardless of state agency involvement, water rights are generally shifting from agricultural to municipal and industrial use. Instream water uses are being recognized more and more in state courts.

REVERSING TRENDS IN WETLANDS LOSSES

The federal government has passed a number of laws over the past 50 years to encourage wetlands preservation. The Migratory Bird Hunting and Conservation Stamp program provided millions of dollars for wetlands conservation. Other incentive programs were also passed. The latest wetlands census indicates these programs have been unable to stem the tide; 300,000 acres of wetlands continue to be lost annually. The Food Security Act's swampbuster provision is another example. If someone not engaged in agriculture wants to convert wetlands to a non-agricultural use, the provision will not deter conversion. To reverse the trend in wetlands losses, incentive programs need to be strengthened. Plainly put, more money needs to be made available to conserve wetlands—a difficult task given the nation's current fiscal situation. A step that will not cost the government money is to change income tax provisions encouraging wetlands conversion, as outlined in Chapter 8.

State and local governments also can do more. Many local property tax administration policies contribute to wetlands conversions. In other jurisdictions, policies have begun to change. For example, "current use" valuation provisions are used in some areas to protect and encourage continuation of certain land uses such as forestry or crop production. Current use provisions assess land value based upon current use and not the highest-and-best use of the land. As long as landowners engage in forest management, for example, they retain the assessed value of forest land in spite of the potential land use for some higher-valued purpose. Similar provisions are being enacted for farmland near rapidly growing urban areas. If current-use valuation provisions were extended to wetlands which normally generate less income per acre than cropland, this would have a significant effect upon reversing the trend in wetlands losses.

QUESTION 2:

WHAT SHOULD BE THE MISSION OF THE NATIONAL FORESTS IN PRODUCTION OF WATER AND OTHER WATERSHED RESOURCES?

The discussion of question 1 highlighted policy issues about water yield augmentation.

Because 80% of the West's water emanates from national forests, the Forest Service will continue to play a role in diversion, storage, and development of water resources. These objectives will probably be emphasized to a greater extent in the remainder of this century than augmenting water yields from forest land.

Maintaining high-quality water in streams originating in or passing through national forests will become a top Forest Service priority.

MAINTAINING AND IMPROVING WATER QUALITY

There will be increasing concern about the Forest Service's ability to maintain high-quality water in streams originating in and passing through national forests. As concerns mount about skyrocketing costs of removing pollutants, emphasis will increasingly be placed on keeping water pure. Controlling sediment, the biggest nonpoint-source pollution threat from silvicultural and range management activities, will be a high priority. Implementing BMPs is the conventional approach to controlling erosion and protecting water quality. The Federal Facilities Compliance Program is placing renewed emphasis on cleaning up point- and nonpoint-source pollution from federal facilities. Rehabilitation and restoration of eroding watersheds is a major concern. The fate of chemicals (fertilizers and pesticides) applied to forests and rangelands is also a concern.

A shift in ownership of senior water rights is underway in the West. In many states, especially those where shortages are likely to emerge, municipalities are acquiring more senior rights from irrigators. Municipalities prefer to pay costs of diverting and transporting clean water rather than paying for treating water to render it potable. Once senior rights are secured, municipalities will become vocal proponents of maintaining high water quality. Thus, local governments are going to play an increasingly prominent role in reviewing land management decisions for water quality and quantity impacts. Further, these local governments may be located some distance from the national forest, so working relationships may need to be built where close ties have not existed in the past.

ENSURING SUITABLE INSTREAM FLOWS

Ensuring suitable instream flows for fish and wildlife habitat and for recreation has emerged as an issue and will become increasingly important in the coming decades. The shift in social priorities for water use will elevate concern about instream flows.

Serving instream flow needs will require close cooperation with state agencies dealing with water development, natural resources, fish, and wildlife. New memoranda of understanding may be needed to formalize cooperation. Partnerships with interest groups could be explored as a way of solidifying support for ensuring suitable flows. Obtaining interest group participation in building and maintaining fish habitat improvements is one example of help interest groups can provide.

MANAGING RIPARIAN AREAS

Riparian areas are at the interface between land areas and streams. These areas represent the last line of defense against sediment and other pollutants reaching streams and also play a significant role in providing habitat for fish and wildlife and in regulating runoff. Demands placed on riparian areas to help reduce nonpoint-source pollution will gain importance. Their use in regulating runoff also helps mitigate damages from minor floods. Management of riparian areas will become more intensive.

Integrated resource management will become more important over time. Watershed condition information will play an important role in bringing integrated resource management into broader use. Riparian areas will be located where integrated resource management is practiced most intensively. Thus, on many national forests, riparian areas are where integrated management will be practiced initially.

LONG-TERM MONITORING AND EVALUATION SITES

An important tool for solving complex ecological problems such as determining effects of acid deposition and ozone on forests and rangelands is having long-term trend data available. An important component of collecting long-term trend information is identifying sensitive areas and collecting data needed to understand ecosystem functioning. Without background information on how the ecosystem functioned before pollution, it is very difficult to determine effects of the pollutants after they begin to influence the ecosystems.

The most important obstacle to overcome in establishing long-term monitoring and evaluation sites is that it takes many years before the payoff. While essential baseline data is being collected and costs are incurred, benefits are still some years away. It is often tempting to postpone or cancel data collection, especially when budgets tighten. Postponement may be viewed as wise budgeting, but could have large social costs. Data may lose its ability to contribute toward solving major environmental problems.

The Forest Service makes periodic investments in human resources by providing training and varied assignments to prepare employees for management challenges. Making investments in beginning long-term data records now can also help prepare for solving more challenging questions in the future.

Establishing long-term monitoring and evaluation sites is more than a research task. National forest managers need information on long-term ecological trends to help prepare plans. Long-term trend data is essential for constructing a feedback loop for managers by indicating how they can learn from decisions and experience. Long-term trend information will also make possible cumulative effects evaluations over time. To make these analyses possible, planning for monitoring programs should be sensitive to two key elements: managers should decide on specific objectives for the monitoring process; and a statistically valid experimental design should be planned that responds to the objectives. Only then will long-term data collected be helpful in maintaining a quality environment.

Because of isolation from urban areas, parts of national forests are often left untouched by some pollutants affecting developed and populated areas. Wildernesses are important because they provide sites where baseline water quality information can be collected. However, locations outside formally-designated wilderness exist where vegetation management can provide the most important long-term data on environmental effects of watershed and water quality management. Long-term monitoring and evaluation programs can provide improved management information for land ownerships.

QUESTION 3: SHOULD POLICIES FOR MANAGEMENT OF NATIONAL FOREST WATERSHEDS VARY AMONG REGIONS?

The key objectives of national forest management—maintaining water quality; ensuring suitable flows in streams for fish, wildlife, and recreation; managing riparian areas; augmenting water yields—require consistent nationwide policies. But the targets and levels attained for each objective may differ considerably among Forest Service Regions, even though each is complying with the same policies.

East and West differences in water uses and water rights institutions are factors that justify varying policies among Regions. In the economic arena, conditions for optimality are often a function of prevailing institutional arrangements. What is most efficient under one scenario may be infeasible under a different scenario.

General policies that span differences in institutional frameworks allow for implementation within the varied contexts of local institutional arrangements. Policies should be consistent nationwide. Regions should have flexibility in developing objectives and implementing arrangements to deal with local institutions. For example, fish and wildlife species differ among Regions and require different practices to secure suitable minimum flows and flow levels. Yet all Regions can adhere to a consistent national policy about promoting habitat and managing riparian areas. Regions are the key organizational level for translating national policies and objectives into activities tailored to regional situations and institutions.

The concept of cumulative effects is becoming more important in national forest management. The idea is that while some effects may be innocuous on a local basis or for an individual project, the sum of all effects is unacceptably high when considered on a watershed, regional, or national basis or for all projects. Nonpoint-source pollution is an item whose cumulative effects have become very important for watershed managers. Regions could assume a lead role in establishing tolerable levels of cumulative effects for sediment generation and then monitor the situations on national forests to assure that the cumulative effect is within limits.

QUESTION 4: HOW SHOULD MULTIPLE-USE RELATE TO WATER AND WATERSHED MANAGEMENT ON NATIONAL FORESTS?

Multiple-use is an important concept for watershed management even though the term has become politicized in recent years. The importance of multiple-use from a watershed standpoint relates to the historical approach taken by water supply firms and municipalities. This approach is to declare water supply watersheds off limits for public use and most vegetation management practices. If the public is excluded and vegetation remains undisturbed, water quality will remain high and risk of contamination and associated treatment costs will be low. This approach to obtaining potable supplies from watersheds originated at the turn of the century before chlorination and filtration were used. The cause of contamination was understood; how to clean it up was not and preventing contamination was stressed. Although municipal supplies are routinely disinfected today, some organisms such as *giardia* bacteria are remarkably resistent to chlorination and preventing contamination remains a public health challenge.

As senior water rights are acquired by municipalities, this historical approach will be recommended to public land managers as a way of guaranteeing high quality water supplies. For example, management guidelines are more restrictive for the watershed where Boulder, Colorado obtains its water supplies than are management guidelines for the nearby Indian Peaks Wilderness.

It is very important for the Forest Service to demonstrate that other resources on watersheds can be managed while still maintaining high-quality water. Areas should be identified where management activities such as recreation, grazing, or timber harvesting pose high risks to water quality. Unless greater sensitivity is demonstrated in integrating resource management to protect pristine water supplies, management options will become increasingly constrained as municipalities acquire larger numbers of senior water rights. If this happens, multiple-use will become an anachronism for watershed managers.

QUESTION 5: WHAT IS THE FOREST SERVICE MISSION IN PRODUCING WATER AND OTHER WATERSHED RESOURCES ON NONINDUSTRIAL PRIVATE LANDS?

There are three ways the Forest Service can provide assistance in the production of water and related watershed resources on nonindustrial private lands: improving water quality, restoring and protecting riparian habitat, and helping to reduce flood damages.[1] All three kinds of assistance will lead to improvements in watershed conditions.

IMPROVING WATER QUALITY

Private forests are key in the fight to reduce nonpoint-source pollution. Chapter 8 pointed out that lack of financial incentives and knowledge were two major obstacles to private landowners using BMPs for pollution control. BMPs are often not in the financial interest of landowners; however BMPs for silvicultural activities are generally known.

Financial assistance programs are in place. They are, however, inadequate to meet the needs of nonpoint-source pollution control. Cleaning up nonpoint-source pollution has emerged as a larger, more difficult, and more costly task than imagined when the Clean Water Act was passed. Additional funds could be provided for the forestry portion of the Agricultural Conservation Program and for water quality aspects of timber production under the Forestry Incentives Program (FIP). More funding is needed under both programs to attract wider participation by landowners. More money per landowner is also needed to cover additional expenses of BMPs. More assistance is needed to make landowners aware of the reforestation income tax credit and how they can use that provision to help pay for water quality protection and improvement.

Not only is financial and technical assistance needed to employ BMPs as part of current timber harvesting and regeneration activities, but assistance is also needed to restore and rehabilitate abused areas. For example, strip mines worked in the early part of this century and long since abandoned still emit sediment and other pollutants. Research demonstrates that planting abandoned strip mines to mixtures of trees and legumes is an effective way to rehabilitate the land, rebuild soil productivity, reduce nonpoint-source pollution, and restore productive watershed conditions. Assistance is needed to help cure problems created by past land uses.

Technical assistance is also needed for landowners switching from agricultural to forestry or range management to reduce agricultural nonpoint-source pollution. The Conservation Reserve Program is providing impetus for farmers with erodible land to switch from agricultural crops to trees or grass. In return for keeping land in trees or grass for a decade, the landowner receives annual payments from the Department of Agriculture.

Landowners need help weighing the merits of removing erodible land from crop production and in choosing between trees or grass as permanent cover. While receiving Conservation Reserve payments, the landowner cannot cut timber or harvest forage from enrolled lands. The landowner can, however, lease the land for hunting. In addition to providing technical assistance on timber production, assistance could be provided on how to increase wildlife populations and thereby hunting lease rates. The more income landowners obtain from not growing crops, the lower the incentive to convert land back to agriculture. This also lowers the chance that the land will contribute to erosion problems in the future.

RESTORING AND PROTECTING RIPARIAN AREAS

Many private landowners are unaware of the importance of riparian areas in preventing nonpoint-source pollution, reducing flood flows, and maintaining productive watersheds. Additional support is needed for using BMPs and the Conservation Reserve Program to establish streamside management zones on private lands. Information and education programs are needed that provide management information on how to integrate resource management and accompanying benefits.

REDUCING DOWNSTREAM FLOOD DAMAGES

Watershed rehabilitation efforts on private lands can increase rainfall infiltration rates and moisture-holding capacity of soils, thereby improving watershed condition. Both actions help retard runoff. If runoff is slowed, peak flows are reduced and less sediment is carried off-site. Trees are especially effective in promoting infiltration and slowing runoff.

Fire protection assistance is needed to keep vegetation growing on important watersheds. Watershed importance is determined by the magnitude of off-site damages that sediments and flood water could cause if vegetation were destroyed. The proliferation of dwellings on headwater flood plains is increasing the potential damage from flooding and fire. Maintaining vegetation on watersheds that would otherwise have rapid runoff is an important part of flood damage reduction efforts. When fire damages the vegetation, the emergency watershed program can provide assistance for quick revegetation.

Reversing the trend in wetlands conversions is also an important part of reducing flood damages. Wetlands provide temporary storage of flood water and slow flood water velocity. Preventing conversion of wetlands is a major reason for the swampbuster provision of the Food Security Act of 1985.

The impetus for conversion is often inability to obtain income from wetlands. Technical and financial assistance is needed so landowners can earn returns from not converting wetlands to other uses. Technical assistance should include not only silvicultural assistance, but also managing land for wildlife.

QUESTION 6:

WHAT IS THE MISSION OF FOREST SERVICE RESEARCH PROGRAMS IN PRODUCING NEW INFORMATION AND TECHNOLOGY NEEDED FOR WATERSHED AND WATER QUALITY MANAGEMENT?

The implications, opportunities, and obstacles outlined in this report identify two interrelated missions for watershed and water quality management research.

CUMULATIVE EFFECTS

Cumulative effects are an important research area for the Forest Service. Small disturbances distributed across a watershed may appear innocuous, yet their cumulative effect on downstream water uses may be substantial.

Disturbances distributed spatially across a watershed are important. For example, small timber harvest areas may each produce sediment. They may be so well scattered that they are not objectionable on visual grounds or in terms of the sediment generated at each harvesting location. The road network that connects them, however, may have a greater adverse effect upon the cumulative erosion in the watershed than all harvest sites put together.

Disturbances may also result from events distributed over time. Uneven-aged timber management is often advocated as less visually offensive than clearcutting. From a sediment generating perspective, frequent cutting and skidding may generate more sediment over time than clearcutting and artificial regeneration. For example, continual small harvests can generate enough sediment to cause lower respiration and reproduction rates in fish. This may cause less vigorous and lower numbers of fish for a longer time than two or three site entries over a rotation.

Research is needed into sediment generation and transport mechanisms and differences in rates from varied land management activities and their cumulative effects upon water quality and aquatic organisms. This information is essential for developing and testing new BMPs and technology to improve existing BMPs. One major need is research on keeping erosion under control after roads are constructed across slopes. Improving revegetation of road cuts and fills with native vegetation is important. When sites disturbed are located at high elevations or in semi-arid areas, native plants often grow slowly. Asexual propagation of alpine species at lower elevations for revegetation purposes has not been extensively studied. Because high-elevation watersheds will become more critical for water supply purposes, research with species common at high elevations will become more important.

The cumulative effects of acid deposition and chemical buildups in watersheds need to be explored. Few long-term background data exist to evaluate temporal variability in rainfall constituents. Monitoring stations number nearly 200 but records are just a decade old.

Differences exist within the scientific community over the roles of acids versus ozone in decline in forest growth and in stream and lake chemistry. Some differences may arise from variability in rainfall constituents by season and geographic location. International cooperative work should continue among scientists at government laboratories and universities here and abroad.

Chemical buildups in watersheds are an issue of emerging importance. Nutrient and energy cycling are related to soil and site productivity. Residuals from fertilizers and pesticides must be fully explored. Differences in rates of movement within ecosystems should be studied as related to chemical composition and transportability. For example, is the chemical persistent or does it break down rapidly? If it breaks down, are decomposed products more or less mobile and more or less harmful than the original chemical? Does the chemical