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An Analysis of the Water Situation in the United States: 1989-2040

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USDA Forest Service

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A decade has passed since publication of *The Nation's Water Resources: 1975–2000* by the Water Resources Council. The 1979 RPA Assessment and the 1984 Assessment Update drew heavily upon that report. But because data for the former report are now 15 years old, new data and new projections were needed for this report. Water resource literature has expanded tremendously in the past 15 years, due largely to the proliferation of research and reports in response to the Clean Water Act. Susan Johnson reviewed more than 1000 abstracts and screened hundreds of publications for this report. Without her help, this report could not have been written.

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An Analysis of the Water Situation in the United States: 1989–2040

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CHAPTER 1: OVERVIEW

INTRODUCTION

Several Federal agencies have historically had responsibilities for conducting assessments of the Nation's water resources. The U.S. Geological Survey (USGS), U.S. Army Corps of Engineers, U.S. Department of Agriculture's Soil Conservation Service (SCS), and U.S. Environmental Protection Agency (EPA) and its predecessor agencies, among others, have conducted studies assessing the current situation and future prospects for water in particular regions of the country.

Responsibility for national water assessments was assigned to the U.S. Water Resources Council (WRC) by the Water Resources Planning Act of 1965. With the demise of the WRC in 1981, several member agencies have attempted to take over parts of the WRC role and improve their own analyses. USGS began to publish an annual National Water Summary in 1984. The first three annual reports, Water-Supply Papers 2250 (USGS 1984), 2275 (USGS 1985), and 2300 (USGS 1986), have been used extensively in the preparation of this Assessment. In some cases, extended portions of text have been lifted from those reports; in other cases, topics are presented in the same order. The 1986 Summary (USGS 1988) was published after preparation of this report was completed. Similarly, EPA publishes biennial reports to Congress on the National Water Quality Inventory. Information from these reports has also been extracted for this Assessment.

The Forests and Rangelands Renewable Resources Planning Act of 1974 (88 Stat. 476, as amended; 16 U.S.C. 1601–1614) (RPA) directs the Secretary of Agriculture to conduct an assessment of the Nation's forest and rangeland resource situation covering all renewable resources within the purview of the Forest Service. Water is one of the renewable resources. RPA legislation also directed the Forest Service to follow two principles in conducting assessments. First, assessments were to analyze the resource situation from a national perspective—including all ownerships, public and private. Second, the Forest Service was to use, to the extent practicable, information collected by other public agencies on the resources studied. This report faithfully follows that direction.

This report has nine chapters beginning with a broad overview of the current water resource situation in the United States. The extensive reference citations are a "road map" directing readers to more detailed discussions of individual topics in the reports of other agencies.

One requirement of the RPA legislation is an analysis, looking 50 years into the future, of prospective demands and supplies of each resource. Chapter 3 contains an analysis of historical trends in withdrawals and consumption and projections to 2040 based on data from USGS and SCS. In this report, withdrawals and consumption are treated as two different forms of demand for water. Both forms of demand are projected independently of supplies. Consumption is used in later chapters as the preferred definition of demand. Chapter 4 contains an analysis of historical trends in water supplies and projections to 2040 based upon generalized water budgets. The projections of demand and supply are the results of new analyses by the author. It is important to recognize that trends projected in these chapters are not in any sense "most likely." Rather, they portray what might occur if factors determining water resource management and use continue unchanged from those in effect since 1970. Obviously, projections of past trends will demonstrate conflicts between the level of consumptive use demanded and the level of supply projected to be available. A discussion of those conflicts is presented in Chapter 5 and the social, environmental, and economic implications of those conflicts is presented in Chapter 6. Chapters 5 and 6 also contain analyses of some alternative future scenarios for water resources having the potential to alter the demand and supply projections which were based upon recent trends.

Although projections of consumption demands and available supplies differ—creating either surpluses or shortages—these differences will not really occur. Rather, the economy will function and prices for water and other goods and services (such as water treatment) will change, thereby bringing supplies and demand into equilibrium. These adjustments, if not planned in advance, can lead to undesirable consequences. Water resource users and managers have opportunities to alter use and management practices inherent in the recent trends to achieve a more desirable future water resource situation. These opportunities are outlined in Chapter 7. Similarly, there are some obstacles—economic, social, environmental, institutional, and regulatory—to taking advantage of opportunities. These obstacles are discussed in Chapter 8. Chapter 9 discusses implications of these opportunities and obstacles on Forest Service resource management and research programs, providing guidance for agency strategic planning.

HIGHLIGHTS OF THE WATER RESOURCES SITUATION: 1989–2040

CURRENT WATER RESOURCE SITUATION

The United States has abundant supplies of fresh water. The renewable water supply of the coterminous United States amounts to about 1,400 billion gallons per day (bgd). Aggregate daily withdrawals amount to 343 bgd or 25% of renewable supply. Aggregate daily consumption amounts to 93 bgd or 7% of renewable supply.

The Nation's watersheds are generally in good condition. But special attention must be given to managing the soil and vegetation on more than 70% of our watersheds to maintain or improve the quality and quantity of water flowing from them. A survey of watersheds in the U.S. revealed that 28% are in prime condition; 50% require special consideration of soil and vegetation characteristics when resource management plans are prepared; and 22% require direct capital investments to restore watershed condition to a level consistent with resource management goals. Most watersheds in prime condition are in the West; most special emphasis watersheds are in the South and North; and most watersheds requiring direct capital investments are in the North and Rocky Mountains.

There are 90 million acres of wetlands remaining in the coterminous United States, less than one half the acreage that existed 200 years ago. Wetlands losses are continuing at an alarming rate estimated at 350,000 to 500,000 acres annually. The principal reason for the continued decline in wetlands is conversion to urban, suburban, and agricultural land uses.

Concerns about water shortages in the United States arise because water supplies are unevenly distributed in relation to the regional and seasonal distribution of water demands.

Water resource development has been the preferred way of increasing water availability but future large scale developments are unlikely due to economic and environmental costs. A total of 480 million acre-feet of storage exists in the 2,654 largest reservoirs and controlled natural lakes with capacities greater than 5000 acre-feet; fifty thousand smaller reservoirs exist and have capacities between 50 and 5000 acre-feet. In addition, there are 2 million smaller ponds.

Other methods of increasing water availability have been tried, such as weather modification, recycling wastewater, and reducing leaks, seepage, and evaporation. Recycling was touted in the mid-1970s as having great potential, but it is no more popular today than back then.

Acid deposition, erosion, and groundwater contamination are three important water related environmental problems. All three arise due to *externalities*—resource management actions that fail to take full account of potential disruption to ecosystems caused by pollutants.

A relative abundance of good quality surface water still exists; however, serious water-quality problems have developed in some stream reaches and some streams cannot support the full range of desired uses. Programs resulting from the 1972 Clean Water Act have made significant progress in cleaning up point-source pollution. For example, total biochemical oxygen demand declined for both municipal and industrial dischargers between 1972 and 1982 (46% and 71%, respectively). Monitoring studies have found widespread decreases in fecal coliform bacteria and lead concentrations. Phosphorus concentrations have also declined, but to a lesser extent.

Nonpoint-source pollution has become more prevalent and its importance better understood as point-source pollution has been cleaned up. Monitoring studies show widespread increases in nitrate, chloride, arsenic, and cadmium concentrations. Suspended sediment and nutrients from agricultural sources are the most damaging nonpoint-source pollutants nationally.

PROJECTED DEMANDS AND SUPPLIES

The rates of increase in demand experienced from the mid-1950s to the mid-1970s have slowed. Freshwater withdrawals in the South and Rocky Mountains increased (85 and 75% respectively) at twice the rate of increases in the North and Pacific Coast regions (42 and 37% respectively). Irrigation is both the largest withdrawal use and the largest consumptive use. Thermoelectric steam cooling withdrawals have been growing most rapidly in recent years and are now almost equivalent to irrigation, but consumption is much lower.

Shortages (the situation where demands exceed supplies) are projected by 2040 for the Lower and Upper Colorado River, Rio Grande, Great Basin, California, and Lower Mississippi River Valley. Offstream water users will find water unavailable or there will be insufficient instream flows remaining to provide good survival habitat for fish, wildlife, and other instream uses. Water surpluses exist, even in dry years, in most regions east of the Great Plains and in the Pacific Northwest.

Four common themes emerge from the analysis of projected surpluses and deficits:

1. The impetus to resolve deficits will come from a desire to mitigate adverse impacts on fish, wildlife, and recreation uses caused by low instream flows.
2. Irrigation is the predominant consumptive use in each region where deficits occur; consequently, eliminating deficits will require a reduction in projected rates of growth in irrigation water consumption.
3. Non-structural approaches, such as modifications in water rights institutions and freer functioning of water markets, will play a dominant role in solving water supply deficits.
4. 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 regional deficits.

Water quality in 2040 will be somewhat better than current quality because nonpoint-source pollution abatement efforts are just beginning to bear fruit. But water quality will be somewhat poorer than the baseline levels for forests and rangelands because some sites will undergo short-term disturbances.

Alternative futures have been briefly analyzed. If demand for water grows faster than in recent years so that total demand is 20 percent higher than projected by 2040, deficits will emerge sooner and be more severe. If the rate of increase in demand is reduced so that total demand is 20 percent lower than projected by 2040, deficits emerge later and are not as severe. If global climate changes produce average annual temperatures 2°C warmer and precipitation is 10% lower, renewable supplies are projected to be from 5 to 40% lower, depending on the region. Deficits occur everywhere except in the Lake States and Northeast and are often severe, given projected future demands.

ENVIRONMENTAL, SOCIAL, AND ECONOMIC EFFECTS

If recent patterns of water and related land resource use continue to 2040, there will be significant adverse environmental, economic, and social implications for American society. Avoiding the adverse consequences of these implications creates an impetus for changing soil and water resource management in the near future. A continuation of recent trends will:

- Reduce fish and wildlife habitat and populations and other instream uses, such as recreation;
- Lead to increased salinity causing disruptions in local economies relying upon surface water resources for potable supplies; and those relying heavily on irrigated agriculture and the processing, sale, and transportation of irrigated crops and products;
- Lead to significant additional reductions in waterfowl populations and reduction in fishing, hunting, and other recreational benefits;
- Lead to expansion of urban and suburban areas at the expense of prime agricultural land and wetlands;
- Lead to water shortages that will cause major social impacts on local residents and their communities and increase the cost of food for humans and livestock; and
- Lead to intensive groundwater mining.

MANAGEMENT OPPORTUNITIES

Many opportunities exist for changing watershed management practices on all types and sizes of ownerships to help avoid environmental, social, and economic implications of water shortages. Only through the coordinated efforts of all landowners can the use of water and related resources reach their full potential.

Major opportunities to protect minimum instream flow levels exist through administrative controls and state water rights procedures.

Major opportunities for improving watershed condition exist through increasing emphasis on maintaining water quality through vegetation management; managing runoff timing through vegetation management, snow-trapping structures, and weather modification; increasing emphasis on improving riparian areas to keep pollutants out of streams and to provide cover for fish and wildlife; and increasing opportunities to enhance soil productivity through consideration of chemical and biological aspects of soils in addition to soil physical characteristics.

Nonstructural measures, such as zoning flood plains to restrict certain types of development, provide State and local officials with the biggest opportunity for flood damage reduction.

Silvicultural nonpoint-source pollution abatement practices are well-developed; however, many opportunities exist to educate landowners about these practices and to apply them more consistently. Opportunities 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.

Legislative changes recently implemented in the Food Security Act of 1985 and expected increases in crop yields present major opportunities to reverse the trend in loss of wetlands.

OBSTACLES TO IMPROVING WATER RESOURCE MANAGEMENT

There is political resistance in some regions to free markets for water. Water institutions are giving high priorities to offstream uses to the detriment of instream uses such as fish and wildlife habitat and recreation.

Information that accurately assesses current watershed and stream channel conditions and capabilities on all ownerships has not been consolidated. Further, information available is often not displayed to managers in ways useful to evaluate management impacts or plan rehabilitation of watersheds in the poor condition.

Private landowners lack incentives to implement *Best Management Practices* to reduce nonpoint-source pollution.

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 to society.

Large-scale water yield augmentation entails significant environmental and social risks.

IMPLICATIONS FOR WATER RESOURCE MANAGEMENT

The challenge for forest and rangeland managers is to preserve the volume and *quality* of water for instream flows that promote fish and wildlife habitat and recreation and that will also satisfy emerging municipal needs in the next century.

The role of vegetation management, snow-trapping structures, and weather modification for increasing water supplies could be reconsidered. Although these practices have been extensively researched, social acceptability of implementing them over wide areas and their role in expanding regional supplies has not been clearly decided.

Institutional barriers have been erected in many areas that prevent a market for water from emerging, or where one has emerged, that constrain it from functioning efficiently. Freer functioning of water markets can help reduce shortages.

Recent gains in agricultural productivity are going to decrease the Nation's reliance on irrigation. In addition, society's preferences for water use are changing because demographic shifts are reducing the number of agricultural voters. Consequently, municipal supplies and adequate instream flows are becoming more important to society than increased irrigation usage.

Maintaining and improving water quality will become a top priority for land managers. Because municipalities prefer to pay the costs of transporting clean water long distances instead of the cost of cleansing nearby water to potable standards, municipalities outside the traditional bailiwick of the resource manager may become vitally interested in land and water management issues.

Private landowners need education and technical and financial assistance to help them make the most of their opportunities to improve water quality, to restore and protect riparian areas, and to reduce downstream flood damages.

Long-term data is an important tool for studying complex ecological problems such as acid deposition. Background information on how the ecosystem functioned before the problem emerged is also essential to determine true effects. A system of sites for long term ecological monitoring needs to be established and monitoring begun.

Additional research is needed on cumulative effects of changes in land ownership and land management objectives as applied temporally and across a watershed.

Additional research is needed on maintaining soil productivity. Work to predict vegetation growth and harvestable outputs as a function of site characteristics is in its infancy. The nutritional needs of agricultural crops and effects of nutrition on yields are much better understood. Similar kinds of information are needed for forest and rangeland species.

CHAPTER 2: THE CURRENT WATER RESOURCE SITUATION

PRECIPITATION PATTERNS[1]

The quantity of fresh water in rivers and streams is largely a function of the amount of precipitation. Nationwide, average precipitation is about 30 inches per year; however, precipitation patterns are quite variable. Average annual precipitation ranges from a few tenths of an inch in some southwestern desert areas to nearly 400 inches on some Hawaiian islands (fig. 1). East of the Great Plains, precipitation rates average 40 inches or more. In much of the West, however, precipitation rates are generally less than 20 inches annually.

After falling, precipitation moves in two general directions—directly back into the atmosphere or to streams. About two-thirds of the precipitation that falls either evaporates directly or is taken up by plants and transpired back to the atmosphere (when both are discussed together, the term used is *evapotranspiration*). Evapotranspiration rates are influenced significantly by temperature. The remaining third either runs over the soil surface to streams—perhaps causing erosion along the way—or percolates into the soil and moves through the soil profile to streams via groundwater flows. Underground geological formations containing water are called *aquifers*. Water withdrawn from streams, rivers, lakes, and reservoirs is called surface water withdrawal. Water withdrawn from aquifers via wells is called groundwater withdrawal.

RUNOFF-PRECIPITATION RELATIONSHIPS

The land area drained by a single stream is called a *watershed*. When talking about watersheds, all soil, vegetation, topographic and other factors that combine to make an integrated ecosystem are included.

It is important to understand the relationship between the amount of precipitation falling on a watershed and the amount of water in the stream flowing out of the watershed in order to measure the effect of land management activities. The relationship is usually expressed in per-acre terms comparing precipitation and runoff. The average annual runoff is computed as the average annual stream flow volume at the bottom of a watershed divided by the number of acres in the watershed.

Runoff rates are also highly variable across the United States (fig. 2). Part of the runoff variation is due to precipitation variability.[2] Other factors such as size, duration, and frequency of storms; climate, topography and geology of the watershed; and vegetation type and

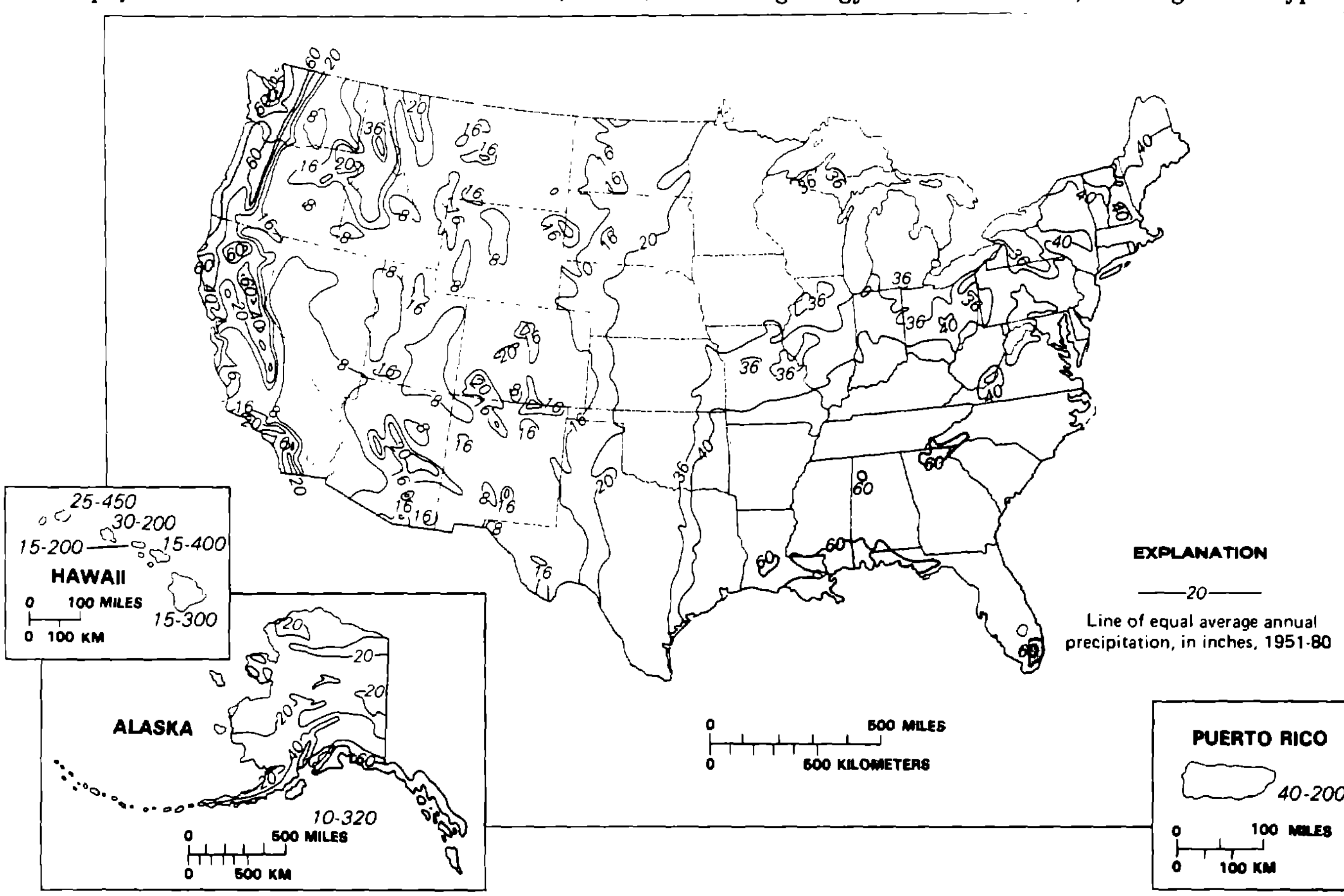


Figure 1.—Average annual precipitation in the United States and Puerto Rico, 1951–1980 (USGS 1983).

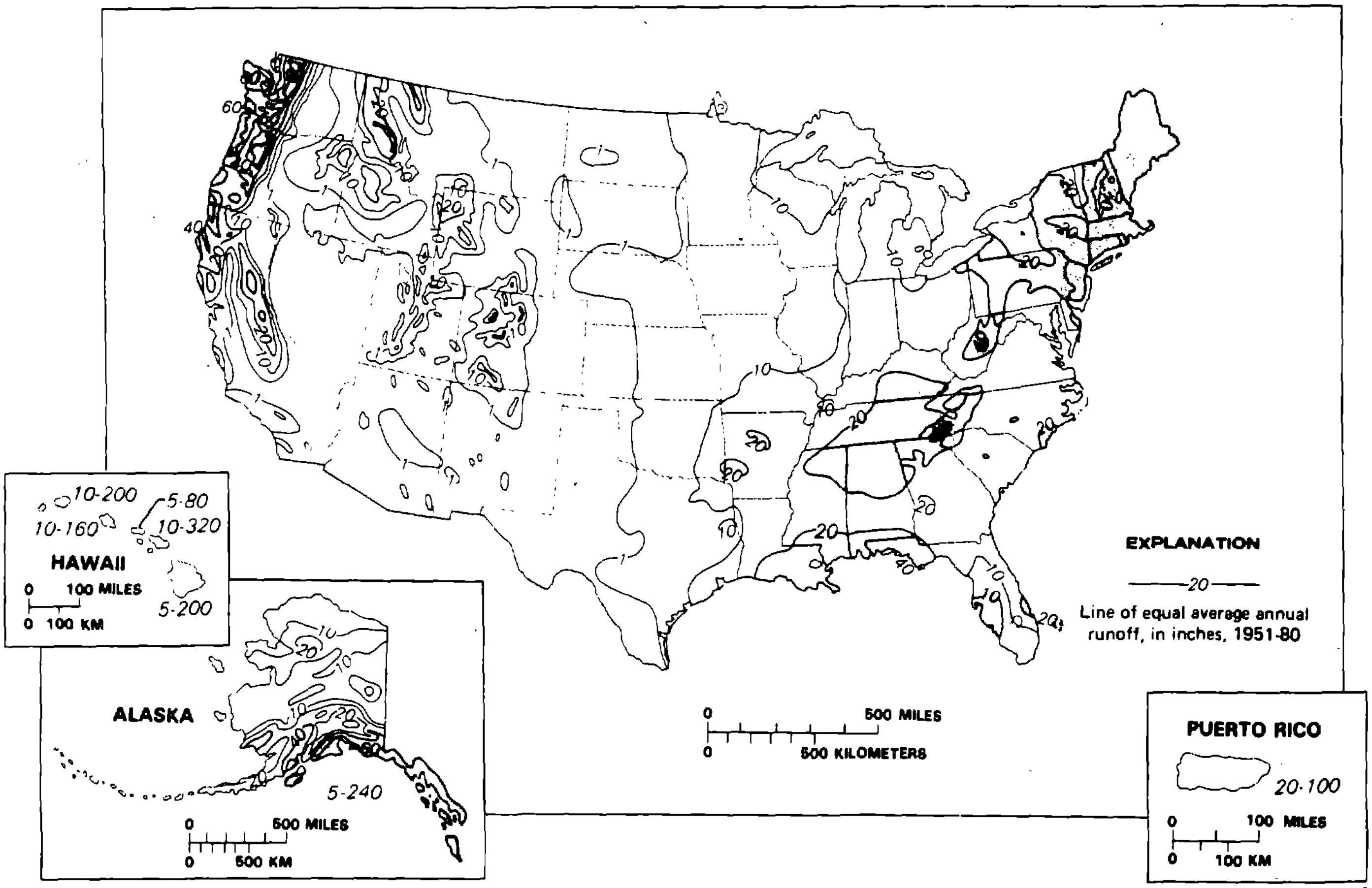


Figure 2.—Average annual runoff in the United States and Puerto Rico, 1951–1980 (USGS 1983).

distribution in the watershed also have a large bearing on runoff-precipitation relationships. The interrelationships among all these factors is what makes watershed management challenging.

Very high or very low runoff-to-precipitation relationships typically complicate managing forest and range ecosystems. High runoff-to-precipitation rates are typically associated with storms of high frequency and/or severe intensity, steep topography, and very fine or very coarse textured soils. Very low runoff-to-precipitation ratios are associated with infrequent storms or frequent ones with little rainfall per storm; storms that occur largely in summer when temperatures, evaporation, and transpiration rates are high; and with coarse textured soils or soils where high evaporation rates concentrate salts in plant root zones.

A comparison of figures 1 and 2 reveals a similarity in geographic patterns of precipitation and runoff. The highest annual runoff rates in the United States occur in Hawaii, typically exceeding 100 inches and occasionally reaching 320 inches. In southeastern Alaska and western Washington and Oregon, the annual runoff exceeds 60 inches in many watersheds. Runoff in the northern and central Rocky Mountains, the Adirondacks, and southern Appalachians exceeds 40 inches. Large areas west of the Great Plains, especially those on the east side of mountains, have runoffs of an inch or less.

Differences between precipitation and runoff are largely due to differences in evapotranspiration and groundwater recharge. Differences in evapotranspiration and recharge are due primarily to climate, topography, geology and cover.

The role of climate.—In semiarid and arid climates, most precipitation is lost to evaporation shortly after it falls. In some instances, rain can evaporate even before reaching the ground. Although potential evapotranspiration in semiarid areas may exceed 70 inches, actual evapotranspiration rates are much lower because precipitation is so scarce. Thus, actual evapotranspiration nearly equals precipitation and runoff is therefore very low. East of the Great Plains where the climate is more humid, precipitation is typically 15 to 20 inches greater than average evapotranspiration rates of between 20 to 40 inches and runoff volumes are greater.

Runoff amounts from equal annual precipitation rates vary depending on the nature of precipitation events. Given the same annual precipitation, more runoff comes from a few large storms than many small ones. Runoff is also affected by the timing of storms. Watersheds where storms are more common in summer will produce less runoff than watersheds where storms are more common in winter. The higher temperatures and more active vegetation respiration present in summer leads to more evapotranspiration than in winter.

The role of topography.—Watershed topography also affects the amount and character of runoff. A watershed with steep slopes at high elevation receiving the same precipitation as a watershed with gentler slopes at lower elevation will produce more runoff. Steeper slopes allow water to flow more rapidly through the watershed so less time exists for evapotranspiration. Higher elevations are also associated with lower temperatures, which also decrease the rate of evapotranspiration.

Watershed topography has a significant influence on runoff because it influences the amount of precipitation received. Precipitation is usually greater at higher elevations than lower ones. Further, location of mountains relative to prevailing storm paths is another topographic factor. As an air mass crosses a mountain range, most of the precipitation falls on the side from which the storm approached. In the United States, this windward side typically faces west. The leeward side is said to be in the *rain shadow*.

The role of geology.—Geology influences runoff largely through its effect on soil texture and permeability. Runoff patterns are a direct reflection of depth, storage capacity, and permeability of soil. Coarse-textured soils encourage rapid infiltration of precipitation and rapid percolation to aquifers. Groundwater flow in such situations is relatively rapid. Fine-textured soils impede infiltration and percolation, thereby encouraging overland flow to streams. Sedimentary rock, such as limestone, generally stores more water than igneous rock. Older rock formations tend to be more fractured than younger formations, thus they store more water than younger formations. Consequently, watersheds based on relatively new igneous formations will have more runoff than watersheds based on older, more sedimentary formations.

Groundwater storage quantity is largely a function of the porosity of rock formations. Groundwater is replenished, or "recharged," by percolation of precipitation and by seepage from stream channels. Where porous rock strata intersect stream channels, water can move back and forth between streams and groundwater. Whenever stream levels are higher than groundwater levels, streams recharge an aquifer in the porous strata. When stream levels drop lower than groundwater levels, groundwater seeps into streams and becomes part of streamflow. The ability of aquifers to store runoff is so great that groundwater seeping into streams may provide an average of 40% of the annual streamflow in some areas and nearly all the flow during periods of lowest flow when direct runoff from precipitation is nil.

The role of cover.—The type of cover and its pattern on a watershed strongly influence the quantity, velocity, and timing of runoff after precipitation falls. Cover can be natural vegetation (trees, grasses, forbs), manmade (asphalt or concrete), or absent (exposed bare soil). If a large percentage of precipitation becomes runoff, little precipitation is soaking into the soil to promote plant growth and recharge groundwater. If runoff velocity is high, the likelihood of soil erosion and its concomitant loss of site productivity increase because fast-flowing water has more energy to pick up and transport soil particles. Short durations between rainfall and runoff lead to reduced likelihood of infiltration and increased stress on aquatic ecosystems and the stream channel networks receiving runoff.

Precipitation falling on a vegetated area will experience a delay in movement between falling and runoff. The surface area of living vegetation and decaying litter on a site is immense and provides significant temporary detention of precipitation. By temporarily storing some precipitation, vegetation prolongs the period of time that water can infiltrate the soil. Once infiltrated, it becomes available for uptake by roots and percolation to groundwater. Vegetation (especially roots and litter) provide texture to soil surfaces and retard runoff.

Vegetation patterns can also influence precipitation detention. For example, contour plowing and stripcropping are excellent techniques for slowing runoff. "No-till" farming also helps conserve moisture. Manipulation of timber harvest patterns is another example. Cut areas can be designed to efficiently trap blowing snow and lengthen the period of snowmelt to allow for more infiltration and extend the period of runoff.

In contrast, precipitation falling on urban areas experiences rapid runoff from the impervious surfaces of parking lots and building roofs. Large peak flows due to extensive urbanization and rapid runoff can overwhelm stormwater conveyance systems and wastewater treatment facilities. These consequences can lead to discharge of partially treated wastewater to streams and subsequent declines in dissolved oxygen, which is harmful to fish. In estuarine systems, a massive dose of freshwater can temporarily upset the salinity balance. Nutrient cycling can also be disrupted.

Changes in land use patterns, particularly changes in cover types from forested or range to agriculture or urban uses, are an important factor in determining stream water volumes as well as the stability of aquatic ecosystems, their structure, and richness of their diversity.

Summary of roles.—Annual runoff from a watershed is the net result of all these natural influences interacting with the human influences of watershed use and management. For watersheds where natural influences predominate, the average runoff over a long period of years (to eliminate short-term climatic variations) is a reliable indicator of the long-term renewable supply of water. For watersheds where human influences predominate, mankind's effects are a much stronger determinant of the long-term renewable supply.

SEASONAL RUNOFF AND STREAMFLOW VARIATIONS

Within a given watershed, streamflows vary by season. A period of high flows is normally followed by a period of low flows. The timing of high and low flows differs by watershed location and is a function of seasonal distribution of precipitation and temperature.

Where temperatures are seldom below freezing for more than a few days at a time, the monthly distributions of runoff and streamflow volumes correspond closely to the monthly distribution of precipitation. For example, both precipitation and runoff are highest during winter in watersheds along the Pacific Coast.

Where temperatures are below freezing for extended periods, winter precipitation accumulates as snow and ice until temperatures climb above freezing and melting occurs. If snow and ice accumulate only in a limited area high in the watershed, the effect of melt water on streamflow will be minor. If only small amounts of snow and ice accumulate due to the occurrence of several freeze-thaw cycles during the winter, or if wintertime precipitation is low, little water will be stored as snow and ice, and runoff will have only a minor effect on streamflow. These are the normal situations in mountain watersheds across the United States at southerly latitudes. If wintertime precipitation is high and below-freezing temperatures occur for extended periods, then precipitation storage as snow and ice is large and the potential for a major increase in streamflow in the spring and summer is high.

The character of temperature warmup in spring after an extended period below freezing also affects streamflow variations. If the watershed is uniformly covered with snow and ice, streamflow will rise rapidly. Floods are likely in this situation. If warmup is gradual and mild, then snow and ice will melt slowly and streamflow will be higher for a longer period, albeit at a lower maximum daily flow. Flooding is less likely with this temperature scenario.

FLOW ANOMALIES

Annual variations in runoff from a watershed are caused by changes in weather patterns and precipitation. Runoff variations will be highest in arid and semiarid watersheds because a small change in precipitation has a large effect on runoff. In other watersheds, the varying intensity of storms has a large effect on streamflow. Hurricanes along the Gulf Coast can cause severe increases in streamflow.

Droughts

A drought is the prolonged and abnormal deficiency of moisture with concomitant decline in runoff to a level significantly lower than usual. The concept of moisture deficiency includes more than lack of precipitation. It also includes consideration of potential evapotranspiration, antecedent soil moisture conditions and factors influencing runoff. The effects of a drought are a function of the severity, duration, and geographic extent of the moisture deficiency; whether water supplies are drawn from streams, impoundments or aquifers; and the type and magnitude of water use.

In humid areas, a drought of a few weeks is quickly reflected in soil and vegetation moisture deficiencies. Dry-land (without irrigation) farming crop yields will decline if rain does not occur for a few consecutive weeks during the growing season. Municipal water supplies that depend on streamflow and have limited storage will not be adequate unless replenished by runoff every few weeks. Prolonged droughts rarely occur in humid areas. In more arid regions, the inhabitants protect themselves from short droughts by using stored ground or surface water. Only when these supplies run low does drought become critical in these areas. In semiarid watersheds, livestock often depend upon small reservoirs or stock ponds for water. If water users draw supplies from large rivers or major impoundments holding the equivalent of two or three years' annual flow, a critical drought is caused only by precipitation deficits that extend over several years or that are exceptionally widespread geographically. During droughts of this nature, usable water in both reservoirs and impoundments becomes progressively depleted until the usual rates of water withdrawals cannot be made.

Drought severity is often used to express the degree of adverse effects felt by vegetation, humans, and animals. Drought severity is normally expressed as a probability of a monthly low flow being attained. A streamflow drought is said to occur when streamflow for a 30-day period or longer is unusually deficient. An "80 percent" drought means that a monthly flow higher than that observed is expected every 8 of 10 years. In the water supply analysis of Chapter 3, the definition of a "dry year" is an 80% drought.

The effects of major multi-year droughts this century have been devastating. The "Dust Bowl" of the 1930s stemmed from a multi-year drought in the Great Plains. The effects of a decline in waterfowl habitat from that era are still being felt in current waterfowl populations. Other notable multi-year droughts occurred in the 1950s (Thomas et al. 1962, Nace and Pluhowski 1965) and 1970s (Matthai 1979). The years 1985–1988 have also been unusually dry in parts of the U.S.

Droughts are related to anomalous occurrences in the atmospheric circulation and solar phenomena. Droughts may occur in one part of the U.S. while another part of the country will be abnormally wet. There is as yet no agreement among meteorologists on how these abnormal atmospheric circulation patterns are generated. Some are convinced the climatic process is random. In this case, long-term accurate forecasting is impossible and the appropriate approach to the problem is through statistical probabilities. Others are convinced droughts are cyclical, so prediction involves extrapolation of historical trends to the future. In either instance, water shortages and droughts will continue to plague us. Strategies and techniques are available or are being developed that offer promise for reducing the adverse effects of droughts.

Floods

A flood is a streamflow so high that it overtops any part of a stream's natural or artificial (levee or dike) channel. Floods range from fairly common annual high flows that barely overtop natural stream banks to rare events that crest well above natural channels. Floods are usually compared according to the heights of their crest above some reference point or the probability that flows of a given size can be expected. For example, a "100-year flood" is a flow that has a one-in-one hundred chance of being exceeded in any given year.

Floods along the coast usually result from high tides and storm surges, such as expected with a hurricane. Floods along inland streams and rivers usually result from intense rains, rapid snowmelt, or a combination of the two. The largest floods usually are caused by intense rainfall occurring in several adjoining watersheds with the runoff peaks arriving simultaneously at the confluence of tributaries from the watersheds. Flood damages are often high in such cases because towns are often located at river confluences. The second most common cause of severe floods is the combination of rapid snowmelt and heavy rainfall. Such a situation occurred in the Colorado River basin in 1984 when abnormally heavy snowpack followed by unseasonably warm temperatures caused a near-record runoff that began about May 20, 1984. Heavy rains in part of the basin led to peak flows more than 1.5 times the estimated 100-year flood level on the Uncompahgre River at Delta, CO.

Floods can also be created or exacerbated by other watershed factors. These include mountain glaciers, unstable soil and rock formations, earthquakes, volcanic activity and the presence of impoundments in combination with the above. For example, the flood resulting from the June 5, 1976 collapse of Teton Dam in the Snake River drainage, Idaho, has been attributed to porous fractured rock formations used to anchor an abutment and that underlay the dam itself.[3] Mud flows resulting from the combination of glacier melt and volcanic explosion on Mount St. Helens in 1980 caused great damage—even obstructing the shipping channel in the Columbia River 70 miles from the volcano. Even after receding, the mud left along the Toutle and lower Cowlitz Rivers so constricted the channels that even the average annual high flow could have caused severe over-bank flooding (Foxworthy and Hill 1982).

About 6% of the land area in the lower 48 states is prone to flooding. Nearly 21,000 communities have flood problems. Floods cause about 10 times more deaths each year than any other natural hazard. During 1985, the economic loss due to flooding was about $500 million—the lowest amount since 1971. Despite these losses, floods do have beneficial effects. Because a large part of the annual runoff from some streams occurs during floods, such floods play a major role in replenishing reservoirs and are important elements in water supply management.

Intensive land use has drastically modified flood plains and streamflow characteristics from their natural condition 400 years ago. It is clearly established that virtually every change in land use alters, to some extent, the water quality and flow regime of a watershed. This is especially true of use changes in the floodplain. Development typically involves placing impervious surfaces (roofs, pavements, roads) over part of the area. Runoff from these surfaces is high and fast. Thus, development tends to increase flood peaks and shorten peak duration, thereby increasing flood damages. Because of the high cost of structural flood control and attendant undesirable side effects, emphasis in flood protection has shifted to non-structural measures. These include improving flood forecasts, installing community flood warning systems, zoning or limiting land uses in flood-prone areas, and publicizing flood hazards. The USGS, the U.S. Army Corps of Engineers, the Federal Emergency Management Agency (FEMA), the National Oceanic and Atmospheric Administration (NOAA), SCS, and various state agencies have cooperated to develop and implement flood control measures.

Despite non-structural measures, the long-term trend in flood damages is increasing. Much of the increase in economic losses can be attributed to continuing encroachment of development onto the floodplain. In spite of the risk, people continue to be attracted to floodplains by advantages such as flat land, desirability for transportation routes, access to water, and superior agricultural soils. Once floodplain uses are established, governments try to control flood damages by building dikes, levees, dams, and other flood control structures. Because these structures successfully reduce damages from small to moderate floods, additional incentives exist to develop the floodplain further. Thus, when a flood occurs that overwhelms flood control structures, resulting damages are often much greater than if development had been limited by periodic, small-scale flooding.

WATERSHED CONDITION

What happens to precipitation after it falls is affected by the intensity and duration of the rainfall as well as the climate. Short, light rains in arid climates evaporate nearly completely; long intense rains during a hurricane largely become runoff. The nature and condition of soils and vegetation where precipitation falls also play an important role in the amount of precipitation that evaporates, infiltrates the soil, or runs off the site. Dense vegetation intercepts precipitation and promotes evaporation and transpiration; scattered vegetation, perhaps due to recent disturbance by fire or management practices, intercepts less water so more is available for infiltration or runoff. Sandy soils and flat topography promote infiltration; clayey soils and steep topography promote runoff.

Human influences that modify soil and vegetative patterns in watersheds alter natural watershed responses to precipitation. For example, urban development paves and erects roofs over land making it impervious to rainfall; less infiltration and more runoff is the result. Removing forest cover or plowing prairie grasslands reduces evaporation and exposes soil to the erosive influences of runoff. Because the influence of mankind's use of the land and vegetation is pervasive in many watersheds, managing soil and vegetation on the watershed is a key factor in managing the quality and quantity of water draining out of the watershed.

National Forests were originally established "...to improve and protect the forest within the boundaries, or for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of the citizens of the United

States...''[4]. The central idea was to manage the forested ecosystem to maintain favorable (in terms of both quantity and quality) water flows and to maintain soil productivity to produce vegetation such as forage and trees. These goals for forest and rangeland management are embodied in the concept of *watershed condition*. Watershed condition describes the relative health of a watershed. It reflects the stewardship role of the Forest Service and is measured against management objectives in terms of factors affecting favorable conditions of flow and soil capabilities.

Maintaining favorable conditions of flow refers to behavioral characteristics of a watershed described in terms of its ability to sustain water quality, quantity, and timing necessary to support water-dependent ecosystems, instream uses, and downstream withdrawals of water. Included in this concept are managing land uses affecting water quality and quantity as well as managing the natural and manmade stream channels carrying flows to users. Also included is managing water in streams, associated fauna and groundwater flows.

Maintaining soil capability refers to the inherent capacity of a soil to support growth of specific plants, plant communities, and sequences of plant communities. Included in the concept of plant communities and the succession of communities are the associated fauna.

The concept of watershed condition provides an excellent basis for assessing the resource situation for water and related land resources. The condition of watersheds nationwide has been evaluated for this report by analyzing watersheds (40,000 to 180,000 acres in size) in each Forest Service Region. Each watershed was placed in one of three watershed condition classes described below. A regional summary was prepared describing the percentage of watersheds in each part of the United States that are in each condition class (table 1).

CLASS I: REGIMEN ATTAINMENT

Watersheds in this class provide a robust basis for sustained production of goods and services. Watershed management is such that no long-term changes are occurring even when major precipitation events occur. These watersheds represent an attainable, desirable condition. They are in dynamic equilibrium as evidenced by a stable drainage network. Response of a watershed to use is accommodated by the current channel network density, size, and process.

Table 1.—Watersheds by watershed condition class, 1987

Region	Condition Class I	II	III
	------- *percent* -------		
North	15	60	25
South	20	67	13
Rocky Mountains	27	49	24
Pacific Coast	36	45	19
U.S. Total	28	50	22

In Class I watersheds, production of goods and services can be sustained with low risk of deterioration in watershed condition. These watersheds are most prevalent in the Pacific Coast and Rocky Mountain regions. Legislation and regulations governing use of land designated as wilderness have a major influence in keeping watersheds in Class I condition because they have proscribed many surface-disturbing uses such as off-road vehicle use and timber harvesting. Considerable roadless land not designated wilderness is in watersheds having such rugged terrain that land-disturbing activities can only occupy limited areas if they can occur at all.

CLASS II: SPECIAL EMPHASIS

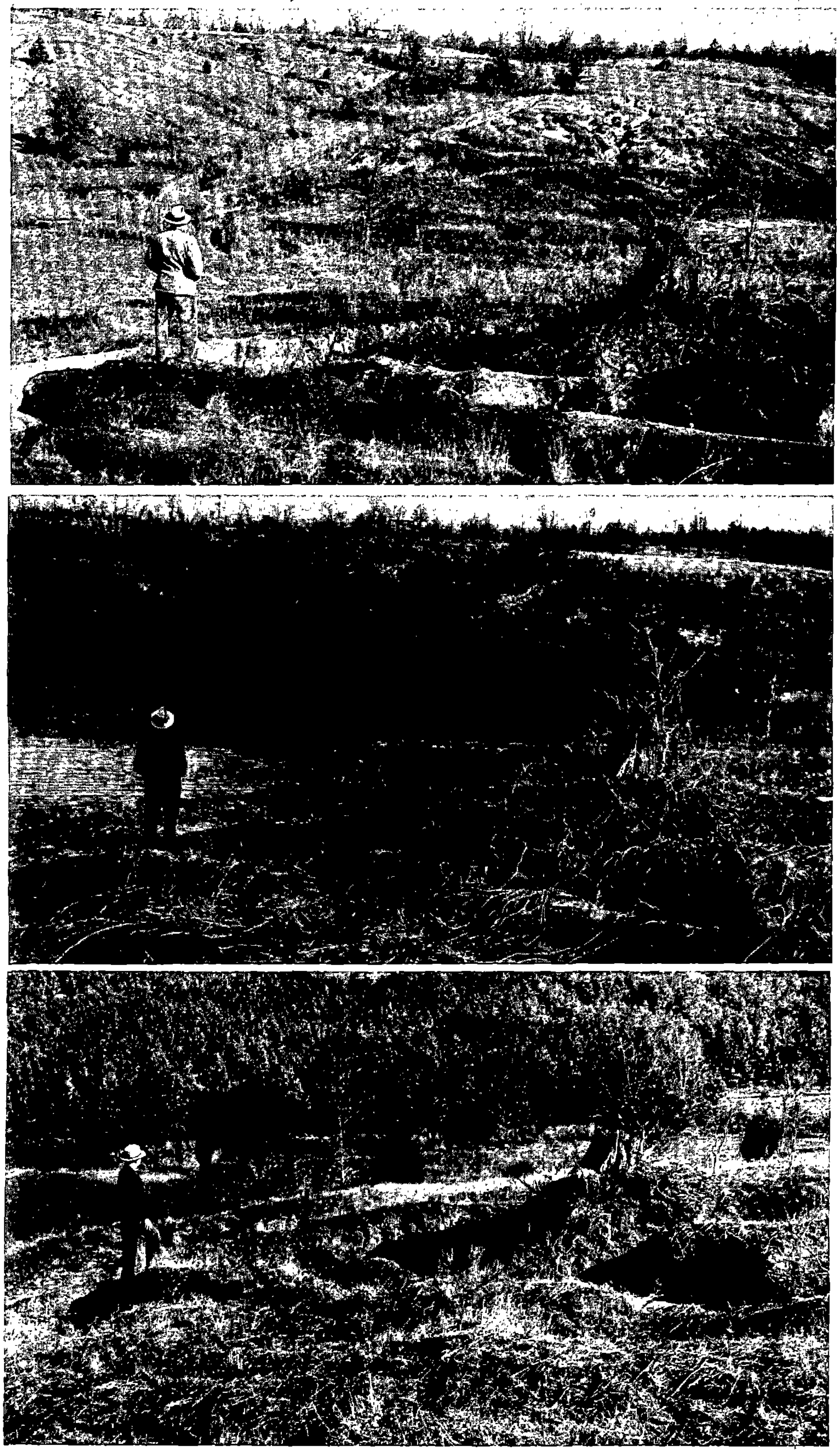
Watersheds in this class are not attaining Class I requirements but do not require capital investments to restore Class I watershed conditions.

One-half of watersheds surveyed are in Class II. Watersheds in this class require special consideration of soil and vegetation characteristics when resource management plans are prepared because soils in these watersheds have a high potential for erosion and significant risks to water quality exist. In short, improper or insensitive management may quickly lead to major soil or water problems and deterioration to Class III conditions.

Many Class II watersheds are currently performing to management objectives. There are four reasons why most watersheds are in Class II. Some are sensitive to specific land-disturbing activities such as mining, off-road vehicle driving, or timber harvesting. Other watersheds are sensitive to the cumulative effect of activities. Cumulative effects can result from activities having a light per-acre impact, but a total effect that has overwhelmed the watershed's ability to tolerate widespread use. Also in Class II are watersheds where use potential is inherently limited due to fragile soils and stream channels, and watersheds that have not reached a dynamic equilibrium in recovering from past abuses.

The South and North have the greatest number of watersheds in Class II primarily because of high water tables, severe erosion hazards, and a lower percentage of wilderness and other unroaded lands than in the Pacific Coast and Rocky Mountain regions. High water tables reduce trafficability. Lands with limited potential for maintaining favorable water flows are most common in the Rocky Mountain region; and comprise the bulk of Class II watersheds there. Watersheds in Class II in the Pacific Coast region are subject to landslide hazards, primarily in high rainfall areas. Because of steep terrain in the Rocky Mountains and Pacific Coast regions, watershed condition concerns often relate to location of transportation corridors and protection of riparian areas. Steep terrain also increases the risk to downstream areas of flooding because of rapid runoff. Therefore, any activities that disrupt infiltration and increase overland flow are of particular concern in Class II watersheds in these regions.

Factors affecting watershed condition and risks to sustaining condition vary greatly among and within a



The Yazoo-Little Tallahatchie Flood Prevention Project demonstrated how tree planting could help restore soil productivity in badly eroded watersheds. (a) Eroded field typical of many thousands of acres in northcentral Mississippi, 1948. (b) Loblolly pines were planted in 1949; four years later, the area is beginning to recover, 1953. (c) By 1957, rehabilitation of the site was well underway.

region. Because such a large proportion of watersheds are within Class II, opportunities to improve conditions through integrated resource management are greater than through direct capital investments. While both approaches cost time and money, the process of integrating resource management is often more affordable per acre. However, integrated resource management requires highly professional skills and creativity.

CLASS III: INVESTMENT EMPHASIS

Watersheds in this class require technologically and economically feasible capital investments to restore watershed conditions to a level consistent with resource management goals. Determination of feasibility must consider environmental, social, and economic desirability. Land treatments and structural measures are necessary to provide an improved watershed equilibrium, which will improve the watershed to Class II condition. In contrast, non-structural measures—integrated multiple-resource activities—are used to improve a Class II watershed to Class I status.

Nationwide, about 22% of all watersheds need capital investments to restore water quality, quantity, timing, or soil productivity to acceptable levels. This does not mean that 20% of the land area or channels are in Class III condition. A relatively small area can disrupt an entire watershed system by its contribution of sediment, mine waste, increased flow volume, or other impacts that influence soil productivity and favorable conditions of water flow.

The South has the fewest watersheds needing capital investments to restore watershed conditions to levels consistent with management goals. In other regions, between one-fifth and one-fourth of watersheds need capital investments. At the beginning of the 20th century, many watersheds across the South were badly deteriorated because of abusive farming practices in the 1800s. After agriculture was abandoned, many watersheds seeded naturally to southern pines. Reforestation restored the watershed condition to Class II in most cases.

A classic example of the kinds of capital investments necessary to restore Class II conditions is the Yazoo-Little Tallahatchie (Y-LT) Project in north-central Mississippi. Watersheds of the Yazoo and Little Tallahatchie Rivers contain highly erodible soils, many of loessal origins. By the 1930s, after being farmed for a century, soil capability to produce crops was exhausted. Due to a lack of vegetation to serve as ground cover, precipitation caused massive and widespread gully erosion. In 1946, the Forest Service and SCS began a joint rehabilitation program. The project area covered 4.2 million acres in 19 counties. Four major goals of the Y-LT Project were to reduce floodwater and sediment damages, to promote proper land use, to stabilize stream channels, and to improve the local economy in north-central Mississippi (Guttenberg and Pleasonton, 1961). In the early 1960s, it was the largest individual land and water management program in the United States.

Farm conservation plans based on land capabilities were developed with the assistance of SCS District personnel. Following approval of the conservation plans, financial assistance was provided to plug gullies and plant trees. On "critical" areas (exposed soil, slopes over 8%, gully erosion present, and downstream damage occurring), the entire cost was paid by the government. On other areas, free tree seedlings were provided and costs of planting and control of competing vegetation were shared between the government and landowner. Today, watersheds of the Yazoo and Little Tallahatchie Rivers support productive stands of southern pine with sufficient volumes to attract new wood processing industries to the north-central Mississippi town of Grenada. Some areas are currently being harvested, providing jobs and income to the local economy. Of course, harvesting must be done carefully to avoid creating new erosion and replanting is essential.

The Y-LT Project is an example of how direct capital investments can be used to rehabilitate Class III watersheds and move them to Class II conditions. Its success has been the impetus for more recent watershed rehabilitation and improvement programs, such as the Soil Bank Program of the 1950s and 1960s, and the Conservation Reserve Program of the 1980s.

SUMMARY

Watershed condition strongly influences the quantity and quality of water available for use. Current status of the Nation's watersheds is less than ideal—one-fifth need capital investments and one-half need especially careful management to attain long-term land and water resource management goals. Consequently, the quantity and quality of water currently available for use is also less than ideal.

The current situation for water use from a quantity perspective is examined next. Following that, the Nation's water quality situation is reviewed along with the wetlands situation. These discussions of rainfall and runoff volumes, watershed condition, quantity and quality of water currently used, and wetlands condition provide the necessary background to assess future demands and supplies of water as outlined in Chapters 3 and 4.

QUANTITY OF WATER AVAILABLE FOR USE

The renewable water supply of the coterminous United States amounts to about 1.4 trillion gallons per day. Even though total offstream withdrawals of surface water nearly doubled from 1960 to 1985, withdrawals still remained only 21% of the renewable supply in 1985. Despite major droughts, such as the one in the eastern United States in 1985 and 1988, and despite chronic water shortages in some localities, the nation is not "running out" of water. Periods of drought will be followed by periods of above-normal precipitation and runoff as in the past. Most concerns about water shortages arise because of uneven water distribution in relation to the regional and seasonal distribution of water demands. Concerns also arise because of increasing demand for existing supplies and related difficulties in distribution. In some situations, changes in engineering, management, or institutional procedures can improve the situation.

Although the available supply appears unlikely to change appreciably in the near future, estimates of that supply may not be very accurate because there is no objective way of selecting a representative period of record that includes the full range of possible variations. Moreover, even if the long-term average supply could be closely estimated, the actual supply over a specific future period probably will deviate from that average. One problem facing water resource planners is the inability to define accurately the amount of water available. This uncertainty should be considered in developing and allocating water resources.

INSTREAM VERSUS OFFSTREAM USES

Water has value both instream and offstream. Instream uses of water include navigation, fish and wildlife habitat, hydropower generation, recreation activities, and dilution of wastes. Instream uses usually require some minimum flow rate, thus they compete directly with offstream uses which reduce instream flows. For example, instream flows must not fall below some minimum rate if navigation is to continue. Some instream uses can tolerate reductions below the minimum essential level for a short period of time with little or no long-term adverse effect. For example, navigation can be suspended for several weeks during exceptionally low flows and start up when sufficient water is available without incurring a significant long-term reduction in navigation benefits. Wildlife and fish habitat, on the other hand, can suffer devastating long-term losses from several weeks of abnormally low flows. Of the instream uses mentioned above, fish and wildlife habitat is the most sensitive because long-term damage results from low flows.

Offstream uses are also called diversions or withdrawals because water is withdrawn or diverted from the stream channel or pumped from the ground and transported to the point of use. Offstream uses include cooling power generators (thermoelectric steam cooling in USGS parlance), irrigation, industrial and commercial use, and potable use. For all uses except irrigation, most water is returned to the stream following use, usually with some aspect of its quality (temperature, dissolved solids, other chemical constituents, sediment load) changed. That part of the water withdrawn from the stream and not returned is "consumed", principally by vegetation which subsequently transpires it back to the atmosphere or by evaporation during use. In Chapter 3, the trends in demand for water will be discussed in terms of withdrawals and consumption by six main uses.

In parts of the country, large flows are withdrawn from watersheds and transferred by pipes or aqueducts to other watersheds where demands for withdrawals exceed available flows. For example, water from streams in central and northern California and from the Colorado River are currently transferred to southern California. Such interbasin transfers of water are equivalent to a 100% consumptive use from the perspective of the watersheds where the water originates.

Pumping groundwater is also considered an offstream withdrawal of water. Where a porous stratum containing groundwater intersects a stream bed, pumping water from the aquifer can not only intercept water that would otherwise seep into the stream channel, but if sufficiently intensive, can induce water to flow from the stream into the aquifer. Reductions in instream flows occur some time after the onset of pumping, and unless the wells are very near the stream, usually do not coincide with the times of peak withdrawals from the streams.

GROUNDWATER DEVELOPMENT[5]

The volume of groundwater in storage in the upper half-mile of the Earth's crust within the coterminous United States has been estimated to be about 50,000 cubic miles (55,000 trillion gallons). Some water is highly saline and unsuitable for most uses. The recharge, or the rate of flow through the groundwater system, is estimated to be near 1 trillion gallons per day. A large percentage of this flow moves through very shallow aquifers which discharge to streams without reaching major aquifers. Only a portion of this shallow recirculation could be recovered by wells.

The pumping rate of fresh groundwater in the United States in 1985 was approximately 83 billion gallons per day (bgd), or about 8% of the estimated daily flow through the Nation's groundwater systems. From a national perspective, the groundwater resource is not overdeveloped. However, problems do exist in many localities.

The total groundwater withdrawn in 1985 represented about 24% of the total freshwater withdrawals in the United States. The largest single use is for irrigation—slightly more than 56 bgd. Although irrigation is the largest withdrawal, roughly half the population in the United States relies upon groundwater for potable supplies. About two-thirds of the groundwater withdrawals in 1980 were concentrated in eight states: California (21 bgd); Texas (8 bgd); Nebraska (7.2 bgd); Idaho (6.3 bgd); Kansas (5.6 bgd); Arizona (4.2 bgd); Arkansas (4 bgd); and Florida (3.8 bgd). Nine states use more groundwater than surface water—Arizona, Delaware, Florida, Hawaii, Kansas, Mississippi, Nebraska, Oklahoma, and Texas.

The pumping rate for groundwater increased steadily from 1960 to 1980 (fig. 3). Some factors responsible for the increase include: 1) a significant expansion of irrigation in the humid East as well as the West, particularly through the use of center-pivot irrigation systems; 2) water supply requirements of growing urban areas, particularly in the South and Southwest; 3) water demands associated with energy production; 4) a desire to establish drought-resistant supplies; 5) objections to the construction of surface reservoirs; and 6) objections to exporting water from one watershed to another. The quantity of groundwater withdrawals in 1985 represents the first reduction in withdrawals reported in the past 3 decades. The 10% reduction is more than a data anomaly—it reflects some changes in factors contributing to the increase since 1960.

Aquifer Declines

Aquifer declines have occurred in many areas since development began. But not all declines are of major concern. In most areas, declines occurred at depths substantially deeper than the water table. But because of artesian processes involved, declines do not represent the loss of large quantities of water from storage.

In some areas, however, declines are serious. For the High Plains region of Kansas, New Mexico, Oklahoma, and Texas, and for the alluvial watersheds of southern Arizona, aquifer declines resulted in a significant lowering of the water table. In these areas, very large volumes of water have been withdrawn, and continue to be withdrawn from storage. In some parts of central California, substantial withdrawals of groundwater in local areas have largely dewatered porous strata, leading to compaction of the strata and surface land subsidence. A description follows of the situation's severity in the four areas most heavily affected.

The High Plains

The High Plains encompass 174,000 square miles in northwestern Texas, the Oklahoma panhandle, western Kansas, Nebraska, and the eastern fringes of Wyoming, Colorado, and New Mexico. A rapid expansion in groundwater withdrawals for irrigation began in the southern High Plains in the early 1940s. Irrigation spread to the middle High Plains in the 1950s and to the northern High Plains in the 1960s. As irrigation spread, so did groundwater withdrawals. In 1949, about 2 million acres in the High Plains were irrigated by 1,303 billion gallons.

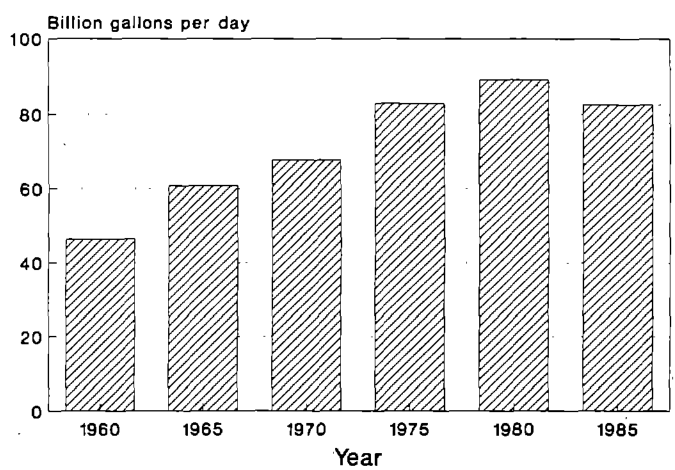


Figure 3.—Trends in groundwater withdrawals in the United States, 1960-1985.

By 1980, 5,865 billion gallons were pumped to irrigate 13 million acres.

Between 1940 and 1980, 68.4 trillion gallons of groundwater were withdrawn for irrigation in the southern High Plains. It is estimated that 43% of this volume was water from storage, 45% was recycled irrigation water percolating back to groundwater, and the remaining 12% was groundwater diverted from two sources as water tables dropped. The sources were groundwater that would otherwise have drained into streams and additional groundwater entering aquifers from streams. Floods in the early 1970s contributed significantly to recharge.

Between 1950 and 1980, 31.3 trillion gallons of groundwater were withdrawn for irrigation in the central High Plains. Withdrawals from storage were 57%, recycled irrigation water 39% and groundwater diversions/recharge 4%. The 1970 floods provided little recharge here.

Between 1960 and 1980, 34.2 trillion gallons of groundwater were withdrawn for irrigation in the northern High Plains. About 14% was withdrawn from storage, 36% by recycled irrigation water, and 50% from diversions/recharge.

Several factors contribute to the differences between the northern High Plains and the other High Plains areas. In the northern High Plains, more surface-water irrigation occurs. Groundwater recharge rates before irrigation development began were also higher in this area. Land use changes have also had an effect. As more land was brought under cultivation, increased infiltration of rainfall led to more recharge. Because rainfall is more prevalent in the northern High Plains, more recharge occurs. Finally, irrigation in the northern High Plains requires a much lower rate of pumping per square mile than in the southern High Plains.

In the southern and central High Plains, withdrawals from storage have been so great that the aquifer has been dewatered by more than 50% in over 3,500 square miles. This decline affected irrigation in two ways. First, increased energy costs are required because water is pumped from a greater depth. Second, as the saturated thickness of the strata declined, yields of individual wells also declined, so additional wells must be drilled to provide the same water volume. These economic impacts led to the beginning of a gradual decline in the use of groundwater in the High Plains—withdrawals in the southern High Plains declined 11% since 1964. Growers are taking other approaches such as installing more efficient irrigation hardware and shifting to crops and varieties that require less water.

Central Valley of California

The Central Valley of California is the most heavily pumped contiguous area in the United States. The watershed encompasses 20,000 square miles. Prior to development, total groundwater circulation through the aquifer system was 650 billion gallons per year. From 1961 to 1978, about 7.2 trillion gallons per year were used for irrigation in the Central Valley—about half from groundwater. During this period, groundwater recharge was about 90% of withdrawals; however, 82% of the recharge water came from irrigation water percolating back to the aquifers. Consequently, 261 billion gallons per year were withdrawn from groundwater storage. About half this amount lowered the water table and about half came from dewatering sediments that compacted and led to surface subsidence.

Since 1978, generally wet conditions in the Central Valley stimulated recharge to the point where groundwater withdrawals from storage ceased and some additions to storage occurred. Given the wet weather and current equilibrium in groundwater withdrawals and recharge, Central Valley water managers believe that subsidence can be controlled. The key appears to be limiting withdrawals to keep the water level above its historical low point in subsidence-prone areas.

Southeastern and Atlantic Coastal Plain

Two regional aquifers provide water over a wide area along the Atlantic Coast. One underlies Florida, southern and eastern Georgia, and adjacent areas of South Carolina and Alabama. The second underlies the Atlantic Coast between South Carolina and Long Island. Both have been extensively developed for agricultural, industrial, and municipal supplies. The former aquifer exists primarily in limestone and dolomite rock formations; the latter in unconsolidated sands and gravels of the coastal plain. In both, recharge is excellent due to humid climate and plentiful precipitation.

Extensive development in both aquifers led to declines in water levels. In both aquifers, the effective lower boundary is the transition from circulating freshwater to underlying saline water which moves much slower, if at all. Transition layer location is deepest where recharge is greatest and rises toward the coastlines in the general direction of streamflow. In some parts of coastal Florida, especially the area south of Lake Okeechobee, brackish or saline water extends to the top of the aquifer. Here, and also along the Atlantic Coast, development of the groundwater resource is encouraging saltwater intrusion.

In addition to saltwater intrusion, heavy pumping in these coastal plain aquifers results in a reduction in instream flows. Both the limestone formations beneath the Southeastern Coastal Plain and the unconsolidated sands and gravels beneath the Atlantic Coastal Plain have many intersections with streambeds. Part of the reason that recharge is excellent for these aquifers is due to the ease with which streamflow can be diverted into the rock, sands, and gravels. Because heavy pumping induces a recharge response from all directions, intensive development of these coastal aquifers draws saline water from the oceans and drains freshwater from streams. In some aquifers, such as the Castle Hayne in eastern North Carolina and Virginia, heavy withdrawals for municipal and industrial uses created several large zones of depression that are merging regionally.[6] The long-term consequences of both situations are unfavorable.

Arizona Lowlands

The semiarid lowlands of Arizona cover 50,000 square miles and are the most heavily pumped region in the state. Irrigation is the largest use of water with two-thirds drawn from groundwater. In recent years, competition has been growing between irrigators and municipalities. Tucson is entirely dependent upon groundwater and more than half of Phoenix's supply comes from groundwater.

Vast quantities of groundwater are stored in sediments beneath the basin. Because potential evapotranspiration greatly exceeds precipitation, only limited amounts of water are available for natural recharge to the groundwater. Thus, extensive withdrawals of groundwater from storage resulted. In 1981, about 1.7 trillion gallons of groundwater were pumped, of which 1.4 trillion gallons were used for irrigation. The current annual depletion of groundwater in the area is estimated at 650 billion gallons, or roughly 40% of withdrawals.

A number of hydrologic changes resulted from intensive withdrawals of this magnitude. Groundwater levels declined as much as 400 feet in some places since the 1940s and rates of water-level decline been as great as 8 feet per year. In many areas, water-level declines altered natural flow patterns that existed prior to development, creating a series of small, self-contained individual flow systems near each pumping center. In some areas of extensive water-level decline, the land surface subsided as much as 12 feet and earth fissures caused damage to public and private property. Concerns over land subsidence together with the self-limiting factors inherent in groundwater storage depletion—declining well yields and rising energy costs for pumping—are acting to reduce withdrawal rates.

Groundwater Summary

Patterns of water development in the nation have varied between two general conditions. In water deficient areas, such as southern Arizona and the southern High Plains, long-term withdrawal of groundwater from storage (groundwater mining) has supplied agricultural and municipal needs for many decades. These withdrawals cannot be sustained indefinitely. Decreases in withdrawals are taking place as falling water levels cause well yields to decrease and pumping costs to rise. In humid areas such as the Southeastern and Atlantic Coastal Plains, groundwater development has redistributed the natural flow pattern so that water which originally discharged to streams, to the sea, or to evapotranspiration, is now diverted to well fields. In these areas, the groundwater system conveys water from source areas to points of use and provides short-term storage during drought. The net depletion of groundwater in storage has been small since the aquifers were first developed. In the Central Valley of California, groundwater development has followed a course somewhat between these two conditions. Substantial withdrawals occurred, but the system now appears to be in equilibrium between withdrawals and recharge. Coordinating the use of both surface and groundwater withdrawals, in which short-term depletions of groundwater are used to make up deficiencies in surface supplies during droughts, and recharging aquifers when surface supplies become more plentiful, should be possible on a sustained basis.

INSTREAM USE

Instream uses include fish and wildlife propagation, recreational activities, maintenance of estuary salinity balances, hydropower generation, navigation, and waste dilution and transportation. In the past, waste dilution and transport was considered the primary use of instream flows. Findings by Wollman and Bonem (1971) ignored water flows needed for navigation and fish habitat, assuming that if sufficient water was available for waste dilution, those needs would also be met. They calculated flows needed for waste dilution at different wastewater treatment rates. They concluded that if municipalities removed 70% of the waste delivered to them and private treatment facilities (generally industrial plants) removed 50% of the waste delivered, then instream flows needed to preserve instream water quality would vary from 1,423 bgd in 1985 to 5,569 bgd in 2020. If 90% of the waste was removed by both public and private facilities, the instream flow needs would be reduced to 231 and 740 bgd in 1985 and 2020 respectively. The maximum volume of instream flows reported by Wollman and Bonem was 956 bgd. Thus, it was clear that with the assumption of 70% and 50% treatment levels, instream water quality would seriously deteriorate.

These findings served as a major impetus for passage of Public Law 92–500, the Federal Water Pollution Control Act Amendments of 1972, also known as the Clean Water Act. This law revised national policy toward instream water quality and wastewater treatment by limiting use of instream flows for additional waste dilution and setting goals for attaining "fishable-swimmable" water quality in most streams through use of "best practicable" and "best attainable" wastewater treatment technologies.

Instream flows for hydropower electricity generation are typically provided by dams. Instream flows typically do not have the required "head" to generate power without some sort of storage and/or diversion structure. These uses will be reviewed below in the surface water development section.

Freshwater stream flows are essential to keep the proper salinity balance in estuaries. Estuaries are often very fertile interfaces between saline ocean waters and freshwater from streams. The resulting brackish waters support extensive commercial and sport fisheries. For example, along the Gulf Coast, brackish water serves as vital breeding habitat for brown and white shrimp, blue crabs, redfish, and speckled trout. Black bass will come down freshwater streams to feed on grass shrimp produced in the brackish water. Thus, maintaining the proper salinity balance with instream freshwater flows becomes critical to sustaining fisheries. Too much freshwater during floods or too little freshwater during droughts are both equally harmful to fisheries depending on brackish water.

Instream flows are also essential for maintaining wetlands and swamps. These ecosystems are also the source of wildlife and fish habitat.

Navigation and recreation activities, such as water skiing and swimming, generally do not suffer benefit losses over a long-term if low instream flows occur. Wildlife and fish populations, on the other hand, do suffer long-term effects from low flows—effects from which they may take years to recover. Recreational and commercial activities associated with wildlife and fish will also suffer long-term losses in benefits if low flows destroy habitat or breeding populations. This Assessment defines necessary instream flow levels based upon wildlife and fish needs.

Generalized Water Budgets

Generalized water budgets have been used by resource planners and managers to evaluate water resource allocations (USGS 1984, Foxworthy and Moody 1986, and Flickinger 1987). Updated water budgets for water resource regions were developed for this Assessment and reflect the latest information (water use data for 1985 from USGS). The first portion of the water budget is presented here, with the final part in Chapter 4, where water supply projections are developed. The objective of the first portion of the budget is to account for groundwater depletion rates and instream flows necessary for optimum wildlife and fish habitat. The balance of instream flows are then available for additional consumption by offstream uses.

Average annual stream outflows at the downstream end of major water resource regions were estimated by Graczyk et al. (1986) (table 2). Average annual stream outflows come from gauging stations and reflect current consumptive use and net reservoir evaporation levels in the basins. For this table, outflows, consumptive use and evaporation are regarded as fixed. When the annual depletion of groundwater storage (from Foxworthy and Moody 1986) is deducted under the assumption it will cease, the balance is the average annual net streamflow available for instream and additional offstream withdrawal uses. Net reservoir evaporation was estimated by Foxworthy and Moody (1986). The instream flows necessary for optimal fish and wildlife habitat were defined by Flickinger (1987). The amount of water available for additional offstream uses is the net amount remaining after instream flow requirements are deducted from average annual net streamflow. Put another way, the remainder is the limit on volume of surface water available for growth in consumption in each water resource region. The analysis shows that instream flows in the Rio Grande, Upper Colorado, and Lower Colorado water resource regions are insufficient to meet current needs for wildlife and fish habitat, much less allow any additional offstream use.

Table 2.—Average annual net streamflow (billion gallons per day), by water resource region, 1985

Water resource region	Area (1000 sq. miles)	Average annual stream outflows[1]	Annual depletion of ground-water storage	Average annual net streamflow	Instream flow requirement[2]	Net flow available for additional offstream uses
New England	69	76.4	0.0	76.4	69.0	7.4
Mid-Atlantic	103	93.8	0.0	93.8	68.8	25.0
South Atlantic-Gulf	271	207.2	0.0	207.2	188.7	18.5
Great Lakes	134	73.0	0.0	73.0	64.0	9.0
Ohio[3]	160	137.4	0.0	137.4	122.0	15.4
Tennessee	43	42.9	0.0	42.9	38.5	4.4
Upper Mississippi[4]	181	79.5	0.0	79.5	69.7	9.8
Lower Mississippi[5]	106	382.9	5.8	377.1	359.0	18.1
Souris-Red-Rainy	55	7.2	0.0	7.2	3.7	3.5
Missouri	511	55.8	2.2	53.6	34.0	19.5
Arkansas-White-Red	244	61.5	3.6	57.9	46.2	11.7
Texas-Gulf	178	34.2	3.1	31.1	22.9	8.2
Rio Grande	137	2.1	0.0	2.1	2.3	-0.2[6]
Upper Colorado	103	7.6	0.0	7.6	8.0	-0.4[6]
Lower Colorado	155	1.4	2.1	-0.7	6.9	-7.6[6]
Great Basin	139	4.5	0.0	4.5	3.4	1.1
Pacific Northwest	271	277.6	0.0	277.6	214.0	63.6
California	165	71.8	1.4	70.4	32.6	37.8
Alaska[7]	586	921.0	0.0	921.0	---	---
Hawaii[7]	6	13.6	0.0	13.6	---	---
Caribbean[7]	4	4.8	0.0	4.8	---	---

[1]*Gauging station outflows, which include current consumptive use, imports/exports, and net reservoir evaporation.*
[2]*Instream flow requirements were taken from Flickinger (1987). They represent the optimal flows for fish and wildlife habitat—the most critical of instream uses—in average flow years.*
[3]*Excluding outflows from the Tennessee region.*
[4]*Excluding outflows from the Missouri region.*
[5]*Land area for the Lower Mississippi region alone. Flows include inflows from the entire Mississippi River basin, including the Ohio, Tennessee, Upper Mississippi, Missouri, and Arkansas-White-Red regions.*
[6]*Negative numbers indicate that insufficient water currently exists to maintain optimal instream flow conditions and also avoid groundwater depletions.*
[7]*No information on instream flow requirements was available for Alaska, Hawaii, and the Caribbean in Flickinger (1987).*

There are two implications of this current resource situation. The first is that groundwater withdrawals are essential in these regions to maintain current levels of consumptive use. The second is that if growth in offstream uses exceeds the net amount shown or that occurs in the Rio Grande, or Upper or Lower Colorado regions, then either groundwater mining is occurring in excess of current depletion estimates or fish and wildlife habitat is sub-optimal and other instream uses may be curtailed at certain times of the year. In addition to providing habitat, instream flows are essential for maintaining wetlands and swamp ecosystems and for maintaining salinity balances in brackish water ecosystems.

SURFACE WATER DEVELOPMENT[7]

The nation's total endowment of surface water is more than adequate to meet current demands. The real issue is that water is not always available when and where needed. Besides groundwater depletion, the other major reason for water scarcity in an area is increasing competition for what is essentially a fixed supply. For example, from 1960 to 1985, total withdrawals from surface water increased 55% while population increased 32%. This means that surface withdrawals per capita per day have risen from 937 gallons to 1,086 gallons—an increase of 16%.

Water use is analyzed from two perspectives—withdrawals and consumption. Withdrawals are water withdrawn or diverted from a source for use. Consumption is water no longer available for use because it has been evaporated, transpired, incorporated into products or crops; consumed by humans or livestock; or otherwise removed from the water environment. Water withdrawn from a stream is either consumed or returned to the stream, usually after treatment. Water returned is then available for withdrawal and consumption downstream.

Surface water development issues in a particular reach of stream are often most concerned with withdrawals. But from a regional perspective, consumption is the more important measure of use. It is not unusual for withdrawals in a basin to be a multiple of runoff volume because much of the water withdrawn is returned to streams following waste treatment. But total annual consumption cannot exceed total annual runoff at the foot of the basin unless water is withdrawn from groundwater or surface storage. Consequently, water budgets focus on consumption. Surface water structures such as dams, pipes, and canals focus on withdrawals.

In 1985, total freshwater withdrawals in the United States were 343 bgd—83 billion from groundwater, 260 billion from surface water, and 0.6 billion from wastewater. Consumption in 1985 totaled 94 bgd—27% of withdrawals. Irrigation is the use that has the highest ratio of consumption to withdrawals—51% (73.8 bgd consumed of 142.5 bgd withdrawn). Thermoelectric steam cooling has the lowest consumption ratio, 3% (4.8 bgd consumed of 130.9 bgd withdrawn). These are the two uses with the largest withdrawals. Domestic self-supplied and livestock watering have consumption ratios approaching the ratio of irrigation (47% and 45% respectively), but their combined withdrawals in 1985 only totaled 8.3 bgd. Municipal and industrial self-supplied uses fall in the middle, with consumption ratios of 16% and 22% respectively, and withdrawals of 36.7 and 24.5 bgd respectively. Further information on withdrawal and consumption trends is presented in Chapter 3.

The annual consumption rate of 93 bgd is directly comparable with the "net flow available for offstream uses" column in table 2. Because irrigation consumes 10 times the water of any other use and more than 3 times the total consumed by all other uses, obtaining more water for irrigation was the prime water development problem in the U.S. earlier this century. In recent years, however, increasing population and development of diversified commercial and industrial economies in water resource regions where irrigation was historically the dominant water use have increased the competition for water. Emergence of competing uses for water, both in the short-term during droughts and in the long-term to stimulate development, has heightened concern over the adequacy of water supplies and likelihood of water scarcities that hinder growth of both agricultural and nonagricultural economies.

Four approaches have been used to resolve problems of surface water availability: (1) developing structures to store water when it is plentiful and convey it to the area where and when needed; (2) reducing or preventing certain water losses or uses deemed not beneficial; (3) attempts to increase the amount of precipitation; and (4) changing the nature and efficiency of water uses and treatment processes so water of lower quality can be used. Only the second approach deals with altering demand, the other three all seek to modify timing or amount of the available supply.

Structural Surface Water Developments

Of the four approaches available for dealing with surface water scarcity, society invested the most in building storage and conveyance structures. Unregulated flow of many of the Nation's rivers is highly variable throughout the year. For example, the rate of flow during floods is many times greater than during droughts. Some streams are called "intermittent" because they cease flowing during parts of the year. Most withdrawals, on the other hand, show much less variability—many being nearly constant on a weekly basis. When the rate of withdrawals approaches the average daily flow rate of a river, there are many days during the year when the desired amount of water is unavailable. Thus, reliance upon surface water as a source of supply usually requires damming to create a reservoir to store water from wet periods for use during dry periods. If the reservoir is located upstream from where water is used, water stored behind the dam may be released during dry periods to flow downstream to the point of use. In some cases, stored water is withdrawn directly from the reservoir and carried by pipe or canals to the point of use. In either situation, there are usually minimum instream flows that must be maintained below the dam or the point of diversion.

There are 2,654 reservoirs and controlled natural lakes with capacities of 5,000 acre-feet or more in the United States and Puerto Rico. These have a combined normal storage capacity of 480 million acre-feet. The 574 largest reservoirs account for almost 90% of total storage. In addition, there are at least 50,000 smaller reservoirs with capacities in the range of 50 to 5,000 acre-feet and about 2 million smaller farm ponds used for storage, table 3 (U.S. Army Corps of Engineers, 1981). Distribution of reservoir capacity in the water resource regions of the Nation, expressed as the sum of the normal capacities of all reservoirs larger than 5,000 acre-feet, is shown in table 4 (U.S. Army Corps of Engineers 1981). Normal capacity—the capacity exceeded only during floods—represents a desired storage level for the reservoir and averages about two-thirds of maximum capacity.

Reservoirs are often described as having a "safe yield" which is the amount of water that can be withdrawn or released on an ongoing basis with an acceptable risk of a supply interruption. If the desired safe yield is small in comparison to the average flow rate of the river (say 10% of average flow), then the dry period for which the reservoir stores water may be a few weeks or months of the year's driest part. For a safe yield approaching the average annual river flow (between 50% and 90% of average flow), the dry period for which the reservoir stores water may span several years. The required size of a reservoir to satisfy a given demand is determined by the volume of water necessary to carry users through

Table 3.—Summary of reservoir storage capacity, including controlled natural lakes, in the United States and Puerto Rico, 1981

Reservoir size[1] (acre-feet)	Number of reservoirs	Total reservoir storage: Capacity (1,000 acre-feet)	Percent of total
Greater than 10,000,000	5	107,655	22.4
100,000 to 10,000,000	569	322,852	67.3
50,000 to 100,000	295	20,557	4.3
25,000 to 50,000	374	13,092	2.7
5,000 to 25,000	1,411	5,632	3.3
Total[2]	2,654	479,788	100.0

[1]*Reservoir size is expressed as normal capacity of storage, which is the total storage space in a reservoir below the normal water retention level. Normal capacity includes dead storage and inactive storage but excludes any flood-control or surcharge storage.*

[2]*In addition, there are perhaps at least 50,000 reservoirs with capacities ranging from 50 to 5,000 acre-feet, and about 2 million smaller farm ponds used for storage.*

Source: U.S. Army Corps of Engineers (1981), cited in Anon. (1984)

Table 4.—Distribution of reservoir storage by water resource region, 1981

Water resource region	Area in region 1000 mi²	Average renewable supply, bgd	Normal reservoir capacity		
			Million acre-ft	Acre-ft per square mile	Percentage of renew. supply
New England	69	77.3	13.0	188	15.0
Mid-Atlantic	103	96.5	10.3	100	9.5
South Atlantic-Gulf	271	213.0	38.7	143	16.0
Great Lakes	134	76.8	6.9	51	7.9
Ohio[1]	160	140.0	19.6	123	12.0
Tennessee	43	43.3	11.2	260	23.0
Upper Mississippi[2]	181	79.7	12.2	67	14.0
Lower Mississippi[3]	160	76.0	5.7	36	6.7
Souris-Red-Rainy	55	7.7	8.0	145	93.0
Missouri	511	67.3	84.3	165	112.0
Arkansas-White-Red	244	63.7	31.8	130	45.0
Texas-Gulf	178	35.9	24.7	139	61.0
Rio Grande	137	5.0	10.4	76	189.0
Upper Colorado	103	12.3	37.7	366	261.0
Lower Colorado[4]	155	-1.1[5]	32.7	211	299.0
Great Basin	139	8.3	3.3	24	35.0
Pacific Northwest	271	291.0	60.9	225	19.0
California	165	86.9	38.8	235	42.0
Alaska	586	921.0	1.5	3	0.1
Hawaii	6	14.3	0.0	2	0.0
Caribbean	4	5.1	0.3	90	5.2

[1]*Exclusive of outflows from the Tennessee water resource region*
[2]*Exclusive of outflows from the Missouri water resource region*
[3]*Exclusive of outflows from the Ohio, Tennessee, Upper Mississippi, Missouri, and Arkansas-White-Red water resource regions.*
[4]*Represents conditions in the Upper and Lower Colorado water resource regions.*
[5]*The annual renewable supply of the combined Upper and Lower Colorado water resource regions is 11.2 bgd. The supply for the Upper Colorado was reported as 12.3; the estimate for the Lower Colorado was computed.*

U.S. Army Corps of Engineers (1981), cited in Anon. (1984)

the dry period. This volume is the product of flow deficiency (demand minus flow) and duration of the dry period.

As is the case with pumping groundwater, the law of diminishing returns applies. Each successive increment in safe yield requires more storage than the preceding increment. For example, doubling safe yield would require more than doubling storage capacity, which, in turn, requires more than doubling construction costs. Hardison (1972) found that, for all water resource regions in the continental U.S., the point at which safe yield reaches its maximum is when storage is in the range of 160 to 460% of average renewable supply of the region. The variation depends, in part, upon the use or variety of uses (such as water supply, flood control, power generation) served by the stored water.

Another index of reservoir capacity is normal reservoir capacity in the region per unit area of the region. If Alaska and Hawaii are excluded, the range in intensity of development among regions is considerable—ranging from 24 acre-feet per square mile in the Great Basin to 366 acre-feet per square mile in the Upper Colorado. Factors influencing the intensity of development include availability of precipitation and groundwater to help satisfy water demands, magnitude of the surface flows available for development, existence of suitable reservoir sites, and political and institutional factors governing reservoir development. The upper limits on development of suitable sites among regions appear to range from about 250 to about 500 acre-feet per square mile (Langbein 1982).

Historical trends in reservoir development show an average growth rate in capacity of major reservoirs in the United States of about 80% per decade from 1920 to the early 1960s. Since then, reservoir capacity increased at a much slower rate. The current status of reservoir development is about 450 million acre-feet. Based on a number of intensive surveys, there remain about 750 million acre-feet of potential storage in the continental U.S. where building dams is feasible from an engineering perspective. Because most cost-effective sites have been developed, adding a significant portion of the potential storage to the current level of development will entail very high investments—so high as to be nearly prohibitive. If so, the Nation's current reservoir capacity may be near the limit of development.

There are, however, other means for coping with providing water to meet future demands. Most of these are non-structural measures that require changing management guidelines or regulations. Such changes, of course, often have costs of their own—social and environmental as well as economic. For example, there are a large number of multiple-purpose reservoirs where withdrawals are not now the primary purpose of management. A shift in water allocation could make additional capacity available to meet future water supply shortages in time of drought. Better management has the potential for increasing safe yields, up to a limit, without increasing storage (Toebes 1981).

An example of better reservoir management is found in the Washington, DC metropolitan area (Sheer 1983). The area's water supply comes from three rivers and four reservoirs: the Potomac, with one reservoir 200 miles upstream; the Patuxent in Maryland, with Tridelphia and Rocky Gorge Reservoirs; and the Occoquan, with Occoquan Reservoir. The sum of safe yields of these three sources is 513 million gallons per day, but demand for water is expected to reach 750 million gallons per day by the year 2000. Through analyses of the complete system—intentionally ignoring certain institutional constraints of three separate water supply agencies—it was found that existing structures could reliably supply water until the year 2030. After recognizing the large gains that could be achieved through flexible and integrated operations, those involved forged the necessary legal and financial agreements to make this possible. The savings are in excess of $200 million. These savings were achieved through systems analysis techniques such as linear programming, synthetic hydrology, statistical analysis, hydrologic modeling, long-range probabilistic forecasting, and computer simulation.

The trend towards using nonstructural measures to solve problems instead of building more dams places greater dependence upon management skill, understanding the nature of river behavior, and better river forecasting. At some point, potentials for conservation and better management may become less cost effective than building additional storage.

Controlling Losses and Low-Priority Uses

A number of options are available for eliminating or curtailing water losses and uses judged not beneficial, given current supplies. One is to reduce water leaks from pipes and ditches delivering water to municipal and irrigation users. Stopping leaks does not make more water available in a region because leakage returns to aquifers. But it is a way of increasing the usable supply at low cost because leakage water has been diverted, treated and transported—often at high cost—yet is never available for use. Moyer et al. (1983) and Pilzer (1981) analyzed leak detection programs.

Implementing voluntary or mandatory rationing schemes is the quickest way to curtail low priority water uses. Mandatory actions such as restricting lawn watering to one day in three or prohibiting automobile washing during a drought period were employed during recent droughts in the East. Some citizens adapted to such restrictions by using rinse water from laundry to water vegetable gardens or wash vehicles—a form of household recycling. Other forms of voluntary household conservation include installing a showerhead that emits fewer gallons per minute and bending the float arm in toilet tanks to reduce the volume of water per flush.

Voluntary or mandatory rationing schemes are but one type of institutional modification that can reduce demand and stretch available supplies. Experience with such institutional changes demonstrates that there are few absolute water requirements. Most offstream water users have considerable flexibility in selecting rates of water intake and recycling. Water use may change, for example, in response to changes in water prices or waste treatment charges (Foster and Beattie, 1979; Strudler and Strand, 1983; and Young et al., 1983). Installation of water meters has led to reductions in water use in some areas; a contributing factor is often the switch from flat rate to variable rate structures. Industrial users may change water use practices in response to energy prices and waste treatment regulations (Babin et al., 1980). Irrigators are moving to more efficient irrigation hardware and management methods. The Federal Interagency Task Force on Irrigation Efficiencies (1979) estimated that $5 billion in public and private expenditures on water conservation by 2010 could reduce withdrawals by 13 to 18 bgd and thereby make 1.7 to 4.5 billion gallons available for new consumptive uses. In some western states, the appropriation doctrine of water rights limits user flexibility to sell water not currently needed, often placing users in a "use it or lose it" situation. Modifications in the water-rights institution can help shift water from users who have more senior rights to those with junior rights. Ideally, such changes could be temporary so the owner of senior rights does not lose them permanently or through markets enabling junior users to bid for rights.

A detailed discussion of the many forces influencing water use and of various demand management practices and policies is beyond the scope of this Assessment. Kelso et al. (1973) examined some of these problems in a case study of Arizona. Hirshleifer et al. (1969) and Baumol and Oates (1979) provide a more general discussion of these topics.

Increasing Precipitation

Weather modification is another approach to enhancing water supplies. Serious scientific attention to techniques for artificially increasing precipitation began around 1946. There have been more than a dozen major research projects dealing with this subject in the United States. Findings of these studies are the subject of controversy in scientific literature. See, for example, Hess (1974), Tukey et al. (1978) and Braham (1979).

Ski areas in California and Colorado are practicing weather modification on a commercial basis. However, serious impacts on stream channels can occur where snow accumulates in excess of what stream channels can handle during snowmelt. Reservoir capacity must be available to store increased snowmelt if this runoff is to contribute to increased regional water supplies.

Using Low Quality Water

Using water of lower quality, such as recycling treated wastewater, has not become as popular as some forecast when Congress debated the Federal Water Pollution Control Act Amendments of 1972. Wastewater use today is 5% lower than in 1960. Between then and now, use peaked 10% higher than present and dropped 20% below present. A decided trend in wastewater use is not evident, except it has not increased nearly as much as expected. Wastewater reuse is not new. Bethlehem Steel in Baltimore, MD has used over 100 million gallons per day of Baltimore's treated wastewater since 1942.

Saline water use has increased seven-fold from 1950 to 1980 (Solley et al., 1983), mostly for industrial cooling purposes. Saline water use represents an enhancement of supply, but presents problems for industry. The rate of increase in saline use, however, demonstrates that solving those problems has proven less costly than acquiring additional supplies of freshwater.

QUALITY OF WATER AVAILABLE FOR USE[8]

Water-quality degradation is widely publicized but has not become a major limitation on water availability or use nationwide. A relative abundance of good quality surface water still exists, even though serious water-quality problems have developed in some stream reaches and some streams cannot support the full range of desired uses.

There are six major categories of pollutants:

1. Disease-causing organisms—Fecal coliform bacteria are used as indicators of the presence of other infectious agents including bacteria, fungi, and viruses.
2. Nutrients—These stimulate aquatic plant growth, and can result in altered aquatic communities, fish kills, excess weed growth, unpleasant odors and tastes, and impaired recreational uses.
3. Silts and suspended solids—These modify aquatic communities through habitat alteration, impair fish respiration and reproduction, and reduce plant productivity by reducing sunlight penetration and photosynthesis. Silts and solids, known as turbidity, may reduce aesthetic appeal and recreational uses.
4. Biochemical oxygen demand (BOD)—These materials reduce availability of dissolved oxygen crucial to respiration of fish and aquatic invertebrates.
5. Salinity and total dissolved solids—These materials impair the use of water for drinking and crop irrigation and adversely affect aquatic ecosystems.
6. Toxics—These substances can cause death, mutation, or reproductive failure in fish and wildlife and may pose carcinogenic or other health threats to humans.

Water pollution is usually attributed to one of two sources—point or nonpoint—depending upon how water enters the aquatic environment. Point sources discharge a flow to the aquatic environment through a pipe, ditch, or other mode of conveyance. Nonpoint sources discharge a flow to the aquatic environment as runoff, not collected or concentrated by a conveyance structure.

During the 1960s, growing environmental awareness of water quality issues led to passage of several laws pertaining to water quality. The Clean Water Act of 1972 (amended in 1977 and 1981) and the Safe Drinking Water Act of 1974 (Public Law 93–523) were two of the most prominent. These laws motivated both the public and private sectors to spend billions on different types of pollution abatement programs, designed mainly to reduce point-source pollution and improve instream quality. For example, more than $100 billion was spent for pollution control between 1974 and 1981 (U.S. Environmental Protection Agency 1984). From 1972 to 1982, total biochemical oxygen demand (BOD) load from municipal waste treatment plants decreased an estimated 46% and industrial load decreased at least 71% (ASIWPCA 1984). These gains in waste treatment occurred simultaneously with increases in population and real Gross National Product (GNP) of 10% and 27% respectively.

Significant improvements have been reported by the National Stream Quality Accounting Network (NASQUAN) stations operated by USGS and the National Stream Quality Surveillance System (NWQSS) operated by EPA. Between October 1974 and October 1984, widespread decreases in fecal coliform bacteria, lead concentrations, and phosphorus concentrations have been monitored downstream of major point-source dischargers (Smith et al., 1986 and 1987). These trends provide some evidence of benefits of improved wastewater treatment for point-source discharges and benefits from the switch to unleaded gasoline. The same studies, however, have also shown widespread increases in nitrate, chloride, arsenic, and cadmium concentrations. Recorded increases in nitrogen fertilizer applications and use of salt on highways along with regionally variable trends in coal production and combustion are reflected in increasing nonpoint-source pollution loads.

Every two years, EPA summarizes water-quality reports submitted by the States and other jurisdictions in accordance with Section 305(b) of the Clean Water Act, as amended. The 1986 Report (EPA, 1987) marked the first time that all states and jurisdictions submitted data.[9] These data show that three-fourths of the Nation's rivers, lakes, and streams are fully supporting their designated uses (table 5).

States were asked to rank pollution sources impairing the ability of surface and groundwater to fulfill desired uses. Nonpoint sources are responsible for impairing water quality much more frequently than point-source pollution. Of assessed waters with impaired uses, nonpoint sources of pollution were responsible in 76% of lake acres, 65% of stream miles, and 45% of estuarine square miles. Point sources were responsible in 34% of estuarine square miles, 27% of stream miles, and 9% of lake acres.

In 1986 reports under Section 305(b) of the Clean Water Act, States were asked to provide individual discussions of issues found to be of either current or emerging special concern (EPA 1987). Surface water concerns most often discussed by States included mine drainage, nonpoint-source pollution, toxics and public health, acid deposition, groundwater protection, and wetlands loss.[10]

Table 5.—Degree of designated use supported by the Nation's waters, 1986

	Rivers (miles)	Lakes (acres)	Estuaries[1] (sq. miles)
Total in U.S.	1,800,000	39,400,000	32,000
Total Assessed	370,544	12,531,846	17,606
(% of total in U.S.)	(21%)	(32%)	(55%)
Fully supporting uses	274,537	9,202,752	13,154
(% of total assessed)	(74%)	(73%)	(75%)
Uses are impaired			
Partially supporting uses	70,196	2,181,331	3,224
(% of total assessed)	(19%)	(17%)	(18%)
Not supporting uses	22,974	859,080	1,177
(% of total assessed)	(6%)	(7%)	(7%)
Unknown support of uses	2,127	288,684	51
(% of total assessed)	(1%)	(2%)	(0.3%)

[1]*Total U.S. estuarine square miles exclude Alaska*

Source: EPA (1987)

In the mid-1970s, experts believed that point-source pollution was the more significant source. Accordingly, efforts to improve water quality were focused upon point sources discharging more than 5 million gallons per day. The effect was to target grant and enforcement programs on roughly a fifth of the dischargers, who in total, created nearly four-fifths of the total volume discharged. Obtaining compliance by this group required substantial public and private investments and water quality has improved. Obtaining similar compliance by the remaining large number of small point-source dischargers will be more difficult and not nearly as cost-effective. Further, as the large point-source discharges were brought into compliance, it became more and more evident that nonpoint sources (which are even more difficult to track and costly to control than small point sources) were also a major cause of water quality problems.

POINT-SOURCE POLLUTION

There are three major types of point-source dischargers—municipal sewage treatment plants, industrial facilities, and combined sewer overflows. Municipal sewage treatment plants commonly discharge BOD, bacteria, nutrients, ammonia, and toxics. Industrial facilities commonly discharge BOD. There are a wide variety of other substances discharged by industries, depending upon their manufacturing processes. Chief concerns center around toxics. Combined sewer overflows occur where urban stormwater runoff flows into catch basins that empty into the same sewer pipes as residential and industrial wasteflows. If the runoff volume exceeds the short-term conveyance capacity of sewers, excess water causes sewers to overflow and dump a mixture of stormwater runoff and untreated residential and industrial waste into nearby surface waters. The most common pollutants in combined sewer overflows are BOD, bacteria, turbidity, total dissolved solids, ammonia, and toxics.

Biochemical Oxygen Demand

In the decade after passage of the Clean Water Act, municipal loads of BOD decréased 46% and industrial BOD loads decreased 71% nationally. Industrial sources currently contribute about one-third of the total point-source BOD load nationwide. Most industrial BOD load reduction occurred in the mid-1970s shortly after the law was passed. Municipal reductions occurred later, in the early 1980s. Federal expenditures for upgrading municipal facilities under the Construction Grants Program reached a maximum in 1980 and totaled $35 billion from 1972 to 1982. Smith et al. (1987) outlined results of statistical analyses of BOD reductions and changes in dissolved oxygen deficits. They reported little statistical support for concluding that construction expenditures reducing BOD loads had a significant effect on reducing dissolved oxygen deficits. This finding is contrary to surveys of state and local pollution control personnel (ASIWPCA 1985) which reported increased instream dissolved oxygen concentrations.

Bacteria

Decreases in fecal coliform and fecal streptococcal bacteria were widespread from 1972 to 1982. Decreases in fecal streptococcal bacteria were especially common in parts of the Gulf Coast, central Mississippi, and the Columbia basins. Decreases in both forms of bacteria were common in the Arkansas-White-Red basin and along the Atlantic Coast. A major emphasis of the Construction Grants Program was installation of secondary treatment as the minimum treatment level. This led to construction of centralized waste collection and treatment facilities for the first time in many communities. Whenever new collection sewers were installed, they were kept separate from stormwater collection sewers. In many cases, new residential and industrial sewers were constructed to segregate residential and industrial wastes from stormwater.

Another major source of fecal bacteria is runoff from animal feedlots, a nonpoint source of bacteria. Several lines of evidence suggest that the widespread decreases in fecal bacteria are due to improved municipal waste treatment and not to any concerted effort to reduce feedlot runoff. Where fecal bacteria increases have been measured in recent years, they are positively associated with cattle population density and feedlot activity in the watershed (Smith et al. 1987).

Mine Drainage

When thinking of industrial facilities, manufacturing plants more often come to mind than resource extraction facilities. But water pollution from resource extraction operations was recognized as a major problem as far back as the 1800s. Although most resource extraction operations create nonpoint-source pollution, mines create both point- and nonpoint-source pollution.

In spite of tremendous strides that the mining industry has made to clean up abandoned mines and control discharges from active ones, mine drainage was still reported as one of the major point-source concerns by nine States in their 305(b) reports (EPA 1987) (fig. 4). In addition, mining activities were widely reported by states as a cause of use impairment across the Nation.

Mine-related sources cause a variety of impacts to rivers and lakes. Acid mine drainage occurs when sulfur-bearing minerals are exposed to water and air in the mining process and join to form sulfuric acid. Contaminated water draining or seeping from mines can create acidic conditions in receiving streams. This may dissolve metals from geologic formations and carry these into waterways and, when entering a pH-neutral stream, may form iron compounds that "settle out" and smother bottom-dwelling aquatic organisms, thus creating havoc with aquatic ecosystems (EPA 1987). These factors can devastate streams for miles downstream of mining activity. Cleanup and control, always a complex issue, is complicated further because many of the worst problems come from mines operated and abandoned long before water quality impacts were a consideration.

Metal mines, such as silver, lead, and copper, most widely found in the western U.S., can directly contribute metal-laden runoff through tailings piles and mine seepage. Sedimentation, erosion, and habitat destruction resulting from earthmoving activities are also significant problems associated with mining.

Point-source discharges from active mines are regulated by EPA and state National Pollutant Discharge Elimination System permits. Many states also use Best Management Practices (BMPs) to regulate nonpoint emissions from mines. Pollution from abandoned mines is addressed in the Federal Surface Mining Control and Reclamation Act of 1977 (Public Law 95–87). Programs to control runoff from abandoned mines include treating wastes; reclaiming land through refilling, regrading, and replanting; and sealing mine openings.

NONPOINT-SOURCE POLLUTION

There are seven major types of nonpoint-source pollution dealing with some form of runoff. Categories and the types of pollutants commonly found include:

1. Agricultural runoff—Nutrients, turbidity, total dissolved solids, toxics, and bacteria;
2. Urban runoff—Same pollutant categories as agricultural runoff, but in different concentrations;
3. Silvicultural runoff—Nutrients, turbidity, toxics;
4. Construction runoff—Same pollutant categories as silvicultural runoff, but in different concentrations;
5. Mining runoff—Turbidity, acids, toxics, total dissolved solids;
6. Landfills/spills—Toxics, miscellaneous substances;
7. Septic systems—Bacteria, nutrients.

Bacteria, nutrients (principally nitrates, ammonia, phosphorus), and turbidity (suspended sediments) are the key nonpoint-source pollutants.

Thomas (1985) suggested that nonpoint-source pollution may prevent achievement of national water-quality goals even after complete implementation of planned point-source controls. Sixteen states identified nonpoint-source pollution as an issue of special concern in their 305(b) reports (fig. 5). Suspended sediment and nutrients

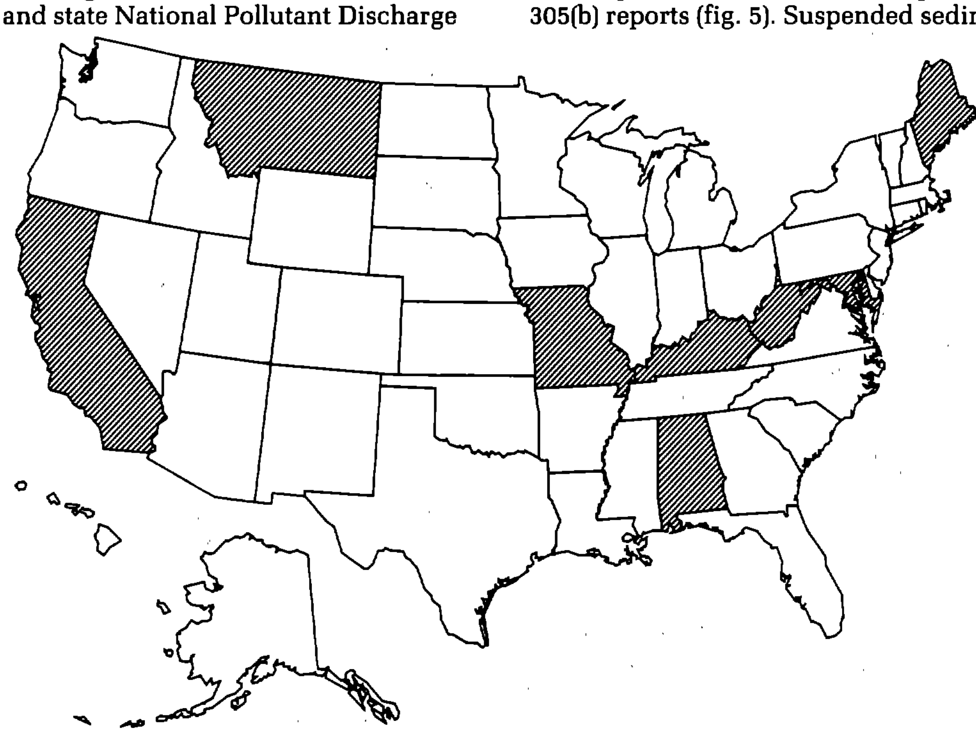


Figure 4.—States reporting mine drainage a special concern (EPA 1987).

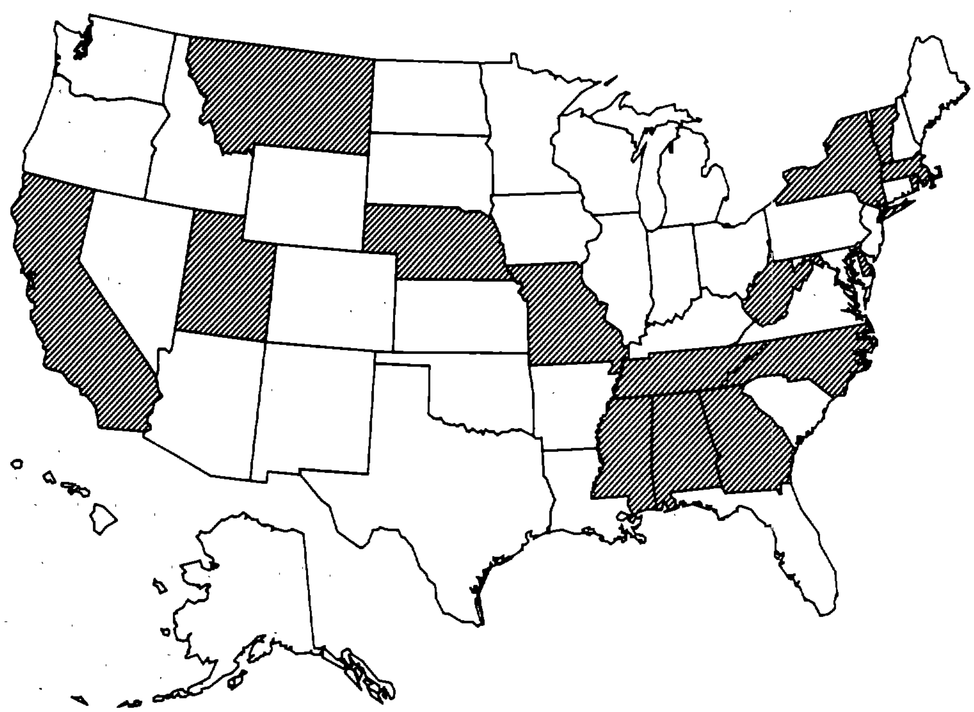


Figure 5.—States reporting nonpoint-source pollution as a special concern (EPA 1987).

from agricultural sources are cited as the most damaging nonpoint-source pollutants nationally. The cost of the hydrologic impacts of soil erosion and related nutrients on aquatic ecosystems has been estimated at $3.5 billion annually (Clark et al. 1985). In spite of wide recognition of nonpoint-source pollution problems, little information is available on long-term trends of nonpoint-source pollution.

Farm activity increased significantly between 1972 and 1982. Fertilizer application rates increased 68% between 1970 and 1981 as farm production increased rapidly (Smith et al. 1987). The extent to which these and other changes in land management practices, primarily agricultural, are reflected in trends in suspended solids, nitrogen, and phosphorus concentrations in streams has largely been a matter of guesswork because no systematic long-term studies are available (Smith et al. 1987).

Suspended Sediment

Nationwide trends from 1974 to 1980 in suspended sediment concentrations were mixed, reflecting both increases and decreases. Increases in suspended sediment concentrations occurred in watersheds where the predominant forms of land use have historically been associated with high rates of soil erosion. An example is logging in the Columbia basin. Smith et al. (1987) tested the association between suspended sediment trends in streams and erosion rates for specific land use categories by using the USDA National Resources Inventory from 1982. They found that trends in suspended sediments were not significantly associated with estimates of total watershed soils erosion. Increases in suspended sediments, however, were significantly related to soil erosion contributed by cropland in the watershed. In contrast to these results, suspended sediment concentrations were *not* associated with erosion rates on forest land, pasture, or range.

Factors other than soil erosion have played an important part in suspended sediment concentrations in streams in some watersheds. For example, some streams in the Columbia basin carried increased sediment loads in 1980 and 1981 after the eruption of Mount St. Helens. Declining concentrations have been reported at several locations in the Missouri River basin and have been clearly traced to the effects of reservoir construction throughout that basin in the 1950s and 1960s (Williams and Wolman 1986).

Phosphorus and Nitrates

Trends in total phosphorus concentrations followed a pattern similar to that of suspended sediments with the exception that decreases in total phosphorus were prevalent in the Great Lakes and Upper Mississippi basins. Decreases in the Great Lakes region resulted partly from point-source reductions in the late 1970s. Increases in the Great Lakes region resulted largely from nonpoint sources. As with sediments, phosphorus increases are significantly associated with various measures of agricultural land use including fertilized acreage and cattle population density. Additional evidence is provided by the close relationship between changes in phosphorus concentrations and changes in suspended sediment concentrations which have already been shown closely linked to agricultural land use changes.

In contrast to suspended sediments and total phosphorus, increasing trends in total nitrate concentrations were common and widespread. Increasing trends were most prevalent in the North and South. Increases in total nitrates were strongly associated with several measures of agricultural activity including fertilized acreage as a percentage of watershed areas, livestock population density, and feedlot activity.

In addition to agricultural runoff, atmospheric deposition became a major source of nitrate in surface waters, especially in forested watersheds of the North. Few nitrate deposition records exist for the years before 1980, but those that do (National Academy of Sciences, 1983; Galloway et al., 1982), together with emission estimates for nitrous oxides (Gschwandtner et al., 1985) show a general pattern of increasing rates during the 1974-to-1981 period. Consistent with this trend, total nitrate increases at monitoring stations were strongly associated with high levels of atmospheric nitrate deposition, particularly in the Ohio, Mid-Atlantic, Great Lakes, and Upper Mississippi water resource regions.

Point-source nitrogen loads declined in many watersheds during the late 1970s as a result of improvements in municipal wastewater treatment facilities. But improvements in point-source nitrate loads had no statistically significant effect upon nitrate concentrations instream (Smith et al. 1987). Consequently, total nitrate trends appear more related to nonpoint sources than to point sources. In particular, atmospheric deposition of nitrates may have played a large role in the frequent occurrence of total nitrate increases in midwestern and eastern watersheds.

Given the large increases in fertilizer application rates that occurred in the 1970s and early 1980s, it is not surprising that trends in both total phosphorus and total nitrates show strong associations with measures of agricultural activity. Despite the importance of agricultural sources, however, distinct differences exist in trend patterns for phosphorus and nitrates. Increasing trends in phosphorus and suspended sediment concentrations occurred with only moderate frequency and were largely confined to major mid-continent watersheds. In comparison, increasing trends in nitrate concentrations occurred with high frequency and were widely distributed from the Great Plains eastward. The differences in pollution patterns appear to result from three factors. First, atmospheric deposition seems to have played a large role in the high frequency of increasing trends in nitrate concentrations, especially among forested watersheds in the Lake States, Central States, and East. Second, low frequency increasing trends in, and strong association between, phosphorus and suspended sediment concentrations suggest that anticipated increases in phosphorus concentrations resulting from increases in agricultural activity in the 1970s were moderated or delayed by temporary storage of phosphorus in the soil and sediments in stream channels. Ellis (1973) and Hook et al. (1973) described mechanisms whereby phosphorus applied to forest and agricultural soils in wastewater was either adsorbed by soil colloids and sediments or precipitated from soil solution. Both mechanisms functioned most effectively in the top 6 to 12 inches of the soil. These findings support the moderation or delay findings of Smith et al. (1987). Third, point-source control efforts during the late 1970s and early 1980s focused much more heavily upon phosphorus than nitrates because phosphorus was considered more limiting to eutrophication in freshwater ecosystems. Results of this policy difference are observable both in the greater ratio of phosphorus-decreasing trends to increasing trends and in the stronger association of phosphorus-decreasing trends with point-source load concentrations.

Perhaps the greatest consequence of differences in the nitrogen and phosphorus concentration trend patterns is seen in recent changes in volumes of nutrients delivered to coastal freshwater and marine estuaries. Nitrate loads to Atlantic Coast estuaries, the Great Lakes, and the Gulf of Mexico increased between 25% and 45% between 1974 and 1981 while phosphorus concentrations declined as much as 20%. The exception to this phosphorus finding is the South Atlantic Coast and Gulf Coast where increases in sediment deliveries have also brought increases in phosphorus. There is increasing concern over the problem of eutrophication in estuaries and debate has arisen over the need for nutrient controls in tributary basins (Thomas 1985). Increased deliveries of nitrate to estuaries are a major concern because of the tendency of nitrogen to be the limiting factor for eutrophication in many estuarine environments. For example, emerging problems due to excessive nutrients in the Chesapeake Bay resulted in the Governors of Maryland, Pennsylvania, and Virginia and the Mayor of the District of Columbia creating the Chesapeake Bay Agreement of 1983. Since signing the agreement, interagency networks were developed to deliver educational, technical and financial assistance to dischargers and landowners. Grants to install BMPs for control of nonpoint-source pollution reduced runoff and erosion from 61,120 agricultural acres by 364,000 tons of sediment and provided controls for 830,000 tons of animal waste. EPA (1987) contains additional case studies where reductions in nutrient and sediment deliveries to estuaries, lakes, and streams were recently accomplished.

Total Dissolved Solids (Salinity)

Increasing trends in concentrations of chloride, sulfate, and sodium in streams have occurred since the mid-1970s. The magnitude of the increase—averaging 30%—and the wide distribution of these trends represents a significant increase in salinity in the Nation's waters.

Several factors appear responsible for the general pattern of salinity increases. First, chloride trends were moderately correlated with population changes from 1974 to 1981. Because human wastes are a major source of chloride in many populated basins, increasing trends are not unexpected. Second, salt use on highways increased nationally by a factor of 12 between 1950 and 1980. This trend stands out as a likely cause for sodium and chloride trends in watersheds where a significant portion of annual precipitation falls in the winter months. Increasing sodium and chloride concentrations were significantly associated with high rates and large increases in highway salt use, especially in the Ohio, Tennessee, lower Missouri, and Arkansas-White-Red water resource regions. Although irrigated agriculture has a large influence on salinity in certain western rivers, chloride trends were not significantly correlated with changes in irrigated acreages nationally (Smith et al. 1987).

Increases in sulfates were especially frequent in the Missouri, Arkansas-White-Red, and Tennessee water resource regions and were highly correlated with changes in open-pit coal production. Sulfate trends were not significantly correlated with underground coal mining in the same water resource regions.

In contrast to most of the nation, the Upper and Lower Colorado water resource regions showed significant decreases in salinity between 1974 and 1981. Decreases in chloride concentrations in these watersheds are noteworthy in view of the history of salt problems there. Decreases were traced to salinity control efforts and temporary effects of reservoir filling in the early 1970s.

Toxics

Although many chemicals have toxic effects if present in sufficient amounts (e.g. table salt) a number of chemicals appear to have adverse and long-term effects at extremely low concentrations. These are commonly referred to as *toxics*. They may be either naturally occurring, such as heavy metals, or synthetic, such as some pesticides. They may be persistent or dissipate quickly. The key is that effects result from very low dosages and often are cumulative so that consequences do not emerge until some time after exposure.

In 1986, 16 states reported that toxic substances or some aspect of toxic substance control is an issue of special concern (fig. 6).

The problem of controlling toxics is particularly troublesome because of the Nation's dependence upon products that may contain hazardous substances or lead to the creation of hazardous substances. Over 60,000 commercial chemical substances are currently in use in the U.S. More than 50,000 pesticide products have been registered since 1947. About 3.5 billion pounds of formulated pesticide products are used each year. Benefits created by using these products in everyday life is substantial, so a wholesale retreat from their use is unlikely. Therefore, the key is to prevent misuse of these products and avoid actions resulting in environmental degradation and health risks. There is also a need to clean up those sites and waters that are contaminated.

Recent advances in monitoring and analytical precision have allowed a much more detailed description of trace elements in surface waters than was available a decade ago. Although no long-term records exist, short-term records frequently show increasing trends in the dissolved forms of two potentially toxic heavy metals—arsenic and cadmium. The dissolved forms are of particular concern because they can enter potable water supplies more readily than suspended materials. Increasing trends in arsenic and cadmium concentrations occurred with greatest frequency in watersheds in the Lake States and northern Great Plains. Evidence suggests that increased atmospheric deposition of fossil-fuel combustion byproducts was the predominant cause of increases in both elements (Smith et al. 1987). Runoff from

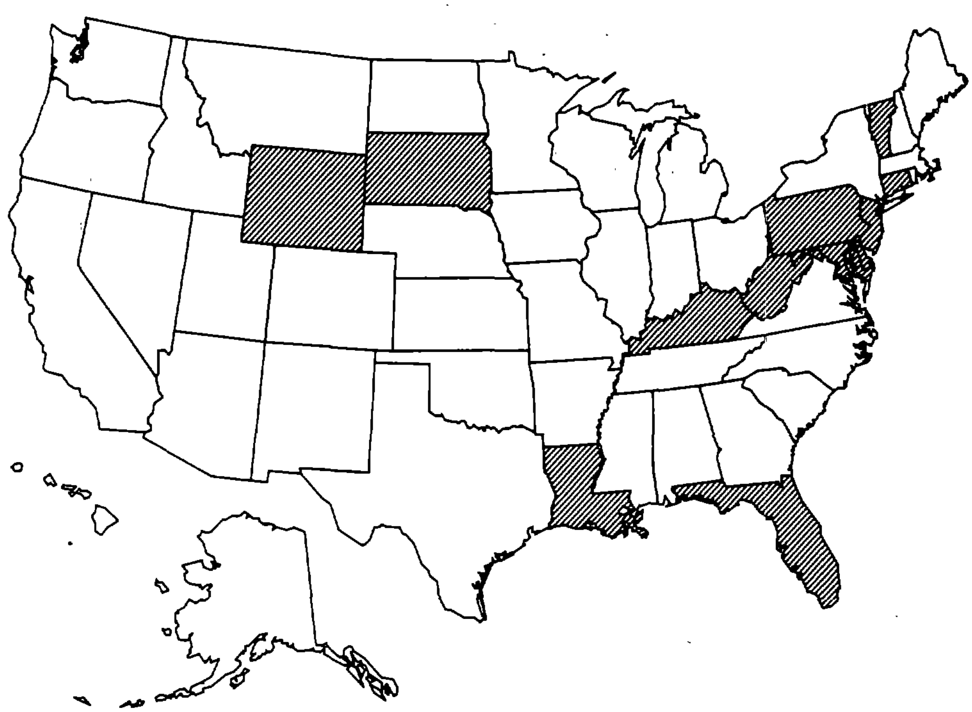


Figure 6.—States reporting control of toxic substances as a special concern (EPA 1987).

fly-ash storage areas near power plants and nonferrous smelters is the other typical way that combustion byproducts enter surface waters. Other sources of arsenic and cadmium entering waste streams include primary metals manufacturing and plating, pesticides, herbicides, and phosphate-bearing commodities such as detergents and fertilizers.

In contrast to arsenic and cadmium, concentrations of dissolved lead have decreased across the Nation. Principal areas of decrease are heavily populated areas of the East and West coasts and along the Missouri and Mississippi Rivers. The decline is due to a shift from leaded to unleaded gasoline. Consumption of leaded gasoline declined 67% between 1975 and 1981. In addition, lead concentrations in leaded gasoline also declined in the same period. Declines in airborne lead have been reported for many U.S. cities. Exceptions to the observed decline of lead in streams and air are the Ohio and Great Lakes water resource regions. Although leaded gasoline consumption declined in these regions, lead concentrations in streams did not. Unknown factors related to the solubility and transport of lead have influenced lead concentrations in streams in these regions.

Urban stormwater runoff is a major source of heavy metals entering surface waters. Concentrations of some heavy metals can be significantly higher in street sweepings than in naturally-occurring soils, rocks, and sediments (table 6). Shale was selected as the rock for comparison because it is a sedimentary rock and represents naturally occurring concentrations in the absence of human influences. All metals in the table are used in common industrial processes or in domestic materials.

Pesticides, including insecticides and herbicides, are applied extensively to crop, pasture, and forest land throughout the Nation. In urban areas they are used on lawns, gardens, and to exterminate pests in buildings and homes. Pesticides in runoff from cropland have been investigated, but little work was done on pesticide residues and other organic substances in urban runoff, although significant concentrations of many of these substances have been measured in urban runoff.

Because of the wide variety of pesticides in use, diversity of application from place to place, and complexity of processes which control amounts of these substances washing from agricultural land, studies attempting to quantify pesticide concentrations in streams from particular land uses or land applications have proven fruitless (Anon. 1984). However, some broad patterns have been recognized in relationships between application methods, chemical properties of certain common pesticides, and losses from the soil (Wauchope 1978).

Table 6.—Average concentrations (parts per million) of heavy metals in street sweepings compared to shale.

Heavy metal	Street sweepings[1]	Shale[2]
Cadmium	3.4	0.3
Chromium	211	100
Copper	104	57
Iron	22,000	47,000
Lead	1,810	20
Manganese	418	850
Nickel	35	95
Zinc	370	80

[1]*Bradford (1977)*
[2]*Krauskopf (1967)*

The greatest release of pesticides has been on farms (Eichers et al. 1978), of which about 98% was applied to crops and 2% to livestock. Corn, cotton, wheat, sorghum, rice, other grains, soybeans, tobacco, peanuts, alfalfa, other hay and forage, and pasture and rangeland accounted for 85% of pesticides used on crops. Nationally, the total volume of insecticides used annually is shrinking; largely because new products are more potent and thus applied at lower rates. For example, since 1976, fenvalerate and permethrin use on cotton at very low application rates largely replaced toxaphene and methyl parathion which were applied at much higher dosage rates to obtain equivalent protection. Less than 100 million pounds of insecticides are currently applied annually to crop, pasture, range, and forest land. Nationally, the total volume of herbicides applied to crop, pasture, range, and forest land increased from 100 million pounds in 1966 to 500 million pounds in 1982. These poundages do not include quantities applied in urban and suburban areas, primarily by homeowners.

Organochlorine insecticides, such as DDT, chlordane, and dieldrin, are strongly adsorbed by soil particles and enter surface waters as a result of soil erosion. Use of these products has been largely banned but, because they are so resistent to decay, they continue to be found in stream sediments. From 1975 to 1980, the Pesticide Monitoring Network (Gilliom 1985) found traces of organochlorine pesticides in more than 50% of streambed sediments sampled, but in less than 5% of water samples. Historically, toxaphene, methoxychlor, DDT, and aldrin were most heavily used; consequently, they should show up in samples most frequently. However, available tests for toxaphene and methoxychlor are the least sensitive of the tests for all organochlorine pesticides so they are seldom found. DDT and aldrin break down rapidly, so are rarely detected. Byproducts of their degradation, however, are found frequently. In contrast to these more heavily used compounds, lindane has been used relatively little, but was the most frequently detected organochlorine in water because of lindane's relatively high solubility, high persistence, and easy detection. Lindane is one of the products recommended for use in control of the southern pine beetle and, given its properties just cited, care is needed to keep lindane out of surface waters. Chlordane was one of the most common termiticides used to treat building foundations. From a quantity standpoint, it was about as popular as lindane. Because chlordane is only one-third as soluble as lindane, it is almost never found in water samples. Yet, it is prevalent in stream sediments. Thus, the patterns of detection that would be expected from use data alone do not occur because of varying chemical properties and analytical capabilities.

Organophosphate insecticides are highly soluble in water and usually last only days or weeks before degrading. Although they do not accumulate in organisms, they are more acutely toxic than organochlorine insecticides. Examples of these pesticides, also known as carbamates, are malathion and diazinon. Because they are so soluble in water, they are able to dissolve readily and move off the land surface as runoff or infiltrate the soil surface and move to groundwater if precipitation occurs while they are still active. Also, because of their high solubility and short life, they were very rarely detected in stream sediments, although they were detected in 5% of stream samples taken between 1975 and 1980. Of the organophosphates, only diazinon use is increasing. Methyl parathion was used in the largest quantities, mainly on cotton. No trends are evident in pollution by organophosphate insecticides on a national scale.

Chlorophenoxy and triazine herbicides account for the third major pesticide category. Atrazine and 2,4-D are responsible for most of the five-fold increase in herbicide use in the past 25 years. By 1980, however, use was shifting from atrazine and 2,4-D to newer products that are used in much smaller dosages. Data from the Pesticide Monitoring Network show virtually no detections of herbicides in streambed sediments and, except for atrazine, few detections in water samples. Atrazine was found in roughly 5% of water samples and chlorophenoxys in 0.2% of samples or less (Gilliom 1985). Atrazine is widely used on corn; most samples where atrazine was found were downstream of major corn-production areas. 2,4-D alone, and in combination with related products, is widely used in granular and liquid formulations for turf management in residential and recreational settings (such as golf courses and parks).

In the 1950s and 1960s, chlorophenoxy herbicides were very popular for forestry applications. In the 1970s and early 1980s, new products were introduced that are more selective, have modes of activity that are less toxic to animals, and are available in formulations that are less likely to drift or drain out of the target area. Triazine derivatives and 2,4-D are still popular but new families of herbicides, such as the sulfonated ureas, have become quite popular. When applied according to registrations and label directions, the latter have a very low probability of contaminating streams and aquifers.

Other toxic organic chemicals not used in land management have also entered the aquatic environment. The most significant of these are polychlorinated biphenyls (PCBs). PCBs typify compounds used in production of goods and services that are then disposed of when usefulness is exhausted. Among other things, PCBs are used to cool electrical transformers. EPA (1987) reviews some cases where PCB contamination of stream sediments has led to moratoria in 15 states on consumption of fish caught in streams below points of known PCB discharges.

Because many toxics are long-lived, disposal of wastes and sediments contaminated by toxics is a major problem. Hazardous waste in groundwater was mentioned as a problem by 39 States and in surface water by 16 States (Anon. 1984). Groundwater contamination by toxics is regarded as a more serious threat than surface water contamination because groundwater pollution is much more difficult to treat. Consequently, preventing toxics from entering groundwater is the major emphasis of toxic waste disposal.

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980, referred to as the "Superfund" legislation, established procedures for EPA to identify abandoned hazardous waste sites in need of remedial cleanup action. By 1982, EPA had selected more than 400 sites for action and initiated cleanup measures. The list is updated regularly with sites added and deleted as appropriate. The Resource Conservation and Recovery Act of 1976 gave EPA the authority to regulate disposal of newly generated hazardous materials. As part of this process, the agency has identified 14,000 hazardous-waste disposal sites across the nation. These sites are carefully tracked as potential point sources of pollution.

RESOURCE MANAGEMENT EXTERNALITIES AFFECT WATER RESOURCES

When pollutants generated at one place move off-site and affect stream ecosystems or downstream water users, the off-site effects are called *externalities*. Although externalities may create benefits free of charge, the more likely scenario is that externalities create uncompensated costs. The key to creating externalities is that off-site effects to others do not enter the initial resource management decision. For example, where soils are saline, irrigators periodically apply extra water to dissolve the salt and flush it out of the crop rooting zone. Salt-laden irrigation return flows move downstream where other irrigators reusing the water must either use more water to avoid salt accumulations in their fields or suffer crop damage from the salt. Using more water costs money and so does crop damage; neither cost is borne by the upstream water user who put the salt into the water.

The standard solution to an externality problem is to find a way to make the party creating the damage bear the full costs of that damage. One characteristic of externalities is that it is not usually possible to assign responsibility to a particular action or landowner. Rather, the best that can be done is assign responsibility to a certain class of actions or group of landowners. This characteristic complicates solving the externality; it means that some level of government must regulate activities causing off-site damages.

This section outlines three major water resource problems and illustrates how externalities contribute to them. The first is acid deposition. Emissions of certain byproducts of combustion processes to the atmosphere create externalities when those airborne emissions undergo chemical reactions and are subsequently deposited on downwind sites. When sites receiving deposits are at high elevations and ecosystems are fragile, externalities pose significant environmental problems for water resources. The second case is erosion. When sediments and related materials, such as nutrients, pesticides, and organic acids, flow off a site and into streams, there are adverse impacts on stream ecology and downstream water users. The third case is groundwater contamination from land management. Contamination most commonly arises from improper water management although it can arise from many different and normal land management activities. Municipal, industrial, and livestock waste disposal each have the potential to alter chemical composition of groundwater. All three of these problems stem from externalities that are forms of nonpoint-source pollution. Yet each presents special problems for regulators because of the nature of the pollution and its effects on other water users.

ACID DEPOSITION[11]

Acid deposition is a comprehensive term incorporating precipitation of acids in rain and snow; contact of acidic clouds, dew, and fog with the land and vegetation; and dry deposition of solid and gaseous acid precursors. The major acids involved are sulfuric and nitric. Neither of these acids is emitted directly into the atmosphere in significant quantities. Rather, they are formed in the atmosphere by the oxidation of sulfur dioxide, nitrogen oxides, and a variety of volatile organic compounds by a number of atmospheric oxidants.

Sulfur dioxide is emitted primarily by combustion of coal and heating oil containing high amounts of sulfur and by metal smelters. Coal-fired electric generators are the largest source of sulfur dioxide in the East and the second largest source in the West. The Ohio water resource region contains a high percentage of older powerplants that have historically used high-sulfur coal. In the West, metal smelting is the largest source and accounts for one-half of all sulfur dioxide emissions (Roth et al. 1985). Denton (1987) reported that, according to Canadian authorities, the Inco smelting facility in Canada was responsible for 3% of the total North American emission of sulfur dioxide on an annual basis. According to EPA in 1977, stationary fuel combustion was responsible for the largest share of sulfur dioxides (20%) and nitrogen oxides (13%).

Few argue about the need to reduce sulfur dioxide emissions. But few can agree on who should pay or how much. The decision on how to reduce emissions will affect jobs, electricity rates, and the environment throughout the East. For example, a low-cost way to reduce sulfur dioxide emissions is to switch to low-sulfur coal. But there are 30,000 jobs mining high-sulfur coal and two to three times that number in related industries such as railway transportation of coal. A switch to low-sulfur coal could halve the existing market for high-sulfur coal with devastating economic results for many small towns in Appalachia. Alternatively, new technology could be installed on power plants burning high-sulfur coal to remove sulfur from emissions, thereby protecting mining and related jobs. If costs of the new technology were passed to consumers, electricity rates would increase 5% to 25%. New emissions technology is most expensive for small power plants and those whose fuel is predominantly high-sulfur coal. Consumers may seek federal assistance for utilities hardest hit, thereby spreading the cost to taxpayers across the nation. In total, reducing sulfur dioxide emissions by 10 million tons annually (40%)—considered by many to be a politically and economically realistic goal—would cost the nation from $3 – $6 billion annually for the foreseeable future (Davis 1988). Who should pay to clean up future emissions and how much has not yet been decided. The reality of the situation is that the environment is forced to pay the total cost.

Nitrogen oxides are emitted primarily by motor vehicles and, to a lesser extent, electric utilities. In the West, motor vehicles contribute half of all the anthropogenic nitrogen oxide emissions.

Volatile organic compounds are released during petroleum refining, chemical manufacturing, paint and solvent use, and transportation. Industrial processes emitted the largest share of volatile organic compounds (10%) and also contributed the biggest share of suspended particulate (5%). Transportation was responsible for 85% of the carbon monoxide emissions.

The chemical transformations of sulfur dioxide and nitrogen oxides into acids can occur in clear air or in clouds, near or far from the point of emission. Eventual deposition is influenced both by prevailing meteorological conditions and surface characteristics. Chemical transformations of sulfur dioxide and nitrogen oxides into acids requires intervention of oxidants in the atmosphere. Oxidants, in turn, are the result of an interaction of volatile organic compounds with nitrogen oxides in the presence of sunlight. A most important recent finding in atmospheric chemistry is that oxidant availability may limit the production of sulfuric acid, at least during some portions of the year.

Thirteen states cited acid deposition as an issue of special concern in their 1986 Section 305(b) reports (fig. 7). In general, states cite lowered pH of rainfall as evidence of potential problems even though effects of acid deposition remain uncertain and unquantified. Nonetheless, factors other than rainfall pH must be considered when evaluating impacts of acid deposition. Perhaps the most significant other factor is the geology of the area. Some soils and rock formations have a few natural carbonates to neutralize acidity ("buffering capacity"), while other soils and rock formations are generally well buffered.

The government conducted a review of knowledge about acid precipitation in the 1970s. That review resulted in passage of the Acid Precipitation Act of 1980 (Title VII of the Energy Security Act of 1980, Public Law 96–294) and establishment of the National Acid Precipitation Assessment Program (NAPAP). NAPAP is an interagency effort with the objective of conducting a ten-year research program crucial to understanding processes involved in acid deposition and assessing their quantitative impacts on ecosystems.

In cooperation with the states, NAPAP has constructed a detailed inventory of anthropogenic emissions for 1980 (and is currently developing an inventory for 1985). This inventory concluded that natural emissions of sulfur are small relative to man-made ones. Dampier (1982) noted

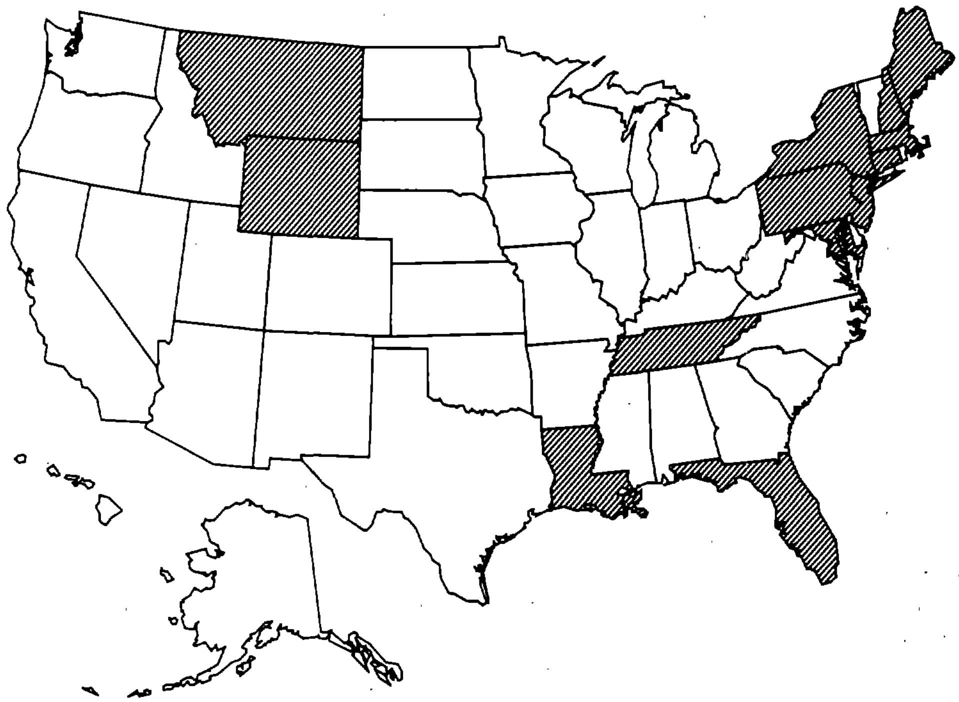


Figure 7.—States reporting acid deposition as a special concern (EPA 1987).

that sulfur dioxide emissions are much higher in the northern hemisphere than southern hemisphere (145.5 million tons per year versus 5.5 million tons, respectively), and are steadily increasing at the rate of 5% annually. Considerable uncertainty exists regarding the relative importance of natural versus man-made nitrogen sources. Some estimates of natural emissions range from 8% to 30% of man-made levels. Natural volatile organic compounds emissions are believed large relative to man-made emissions.

The general geographic pattern of precipitation acidity has changed very little since extensive monitoring began in 1978. Rain and snow acidity for 1985 was highest in the northeastern U.S. The highest acidities, below pH 4.2, were found in the upper Ohio River Valley of eastern Ohio and western Pennsylvania and extended across the Canadian border into southcentral Ontario. Precipitation monitored at remote sites generally has a pH between 5.0 and 5.5 (Roth et al. 1985). Precipitation pH below 5.0 is generally taken as indicative of anthropogenic influences. Roth et al. (1985) note that the amount of deposition measured in precipitation is typically doubled to account for all the different types of deposition when estimating total deposition load. But it is not known whether this rule of thumb is adequate for more arid western locales where most precipitation falls as winter snow.

Linkages to Other Air Quality Problems

It is important to note that while acid deposition is normally viewed as an independent issue, chemical changes occurring in the atmosphere are inextricably related to one another. Problems of ozone depletion, visual impairment, "greenhouse warming," and acid deposition are all interconnected to some degree and all are associated with changes in atmospheric composition. For example, gases which are predicted to modify the distribution of stratospheric ozone (i.e. carbon monoxide, methane, nitrous oxide, and chlorofluorocarbons) are the same gases which are infrared active (greenhouse gases) and are predicted to warm the planet. In addition, increasing concentrations of methane are also predicted to increase ozone in the troposphere and may be responsible for some forest damage that is occurring. Increased atmospheric levels of sulfur may possibly influence climate through enhanced levels of sulfate aerosols. Oxides of nitrogen strongly influence the production of ozone in the troposphere. Many of these chemicals and byproducts of chemical reactions are responsible for gases and aerosols that create visual impairment.

Implications for Aquatic Ecosystems

Lake and stream acidification, which can damage aquatic organisms, may result from natural or man-made causes. Surface water chemistry can change either over the long term or during short episodes such as spring snow melt. Budiansky (1981) noted that the greatest pH shock to lakes occurs when snow melts and runs off. Soil type, hardness of the winter freeze, and amount of dry deposition, together with type and amount of snow and ice, all determine the amount of acidic material that has accumulated over winter and the portion likely to be absorbed by the soil, given its buffering capability. The larger the portion of annual precipitation that falls as snow and the lower the soil buffering capability, the greater the potential for damage due to a pulse of acidity entering a waterbody during snowmelt. Roth et al. (1985) note that springtime acid pulses from snowmelt can severely harm sensitive aquatic ecosystems even if the ecosystems do not permanently acidify.

Middleton and Rhodes (1984) concluded that acid deposition has the potential to contribute to drinking water toxicity. Raw drinking water that is acidic can free toxic metals such as aluminum from the chemical bonds normally immobilizing them to soil colloids. If not adequately neutralized as part of water treatment, acid remaining in water can dissolve toxic metals such as lead from water distribution pipes. Because of the number of areas in the northeastern U.S. using surface water sources for drinking water supplies, the impact could be considerable. Water treatment processes exist for dealing with acidity in raw water and for removing toxic metals during water treatment; however, they are more costly than conventional treatments.

Analysis of historical records by the National Academy of Sciences shows no net acidification of lakes in the past 50 to 60 years in either Wisconsin or New Hampshire, although a few high elevation lakes in the Adirondack region of New York may have suffered some increased acidification. The study noted that quantifying the amount of acidification was not possible at this time. Our understanding of how acid deposition interacts with individual biological, geological, and chemical processes in watersheds and surface waters is considerable. However, major uncertainties exist regarding how individual processes work together over broader areas to result in observed surface water chemistry, according to the Council on Environmental Quality (1987).

New York and Canada allege a much greater impact on high elevation lakes than determined by the National Academy of Sciences. New York considers damage to some 500 lakes in the 6 million-acre Adirondack Forest Preserve to be catastrophic (USDA 1987). About 2 million acres in the Catskill area are also reported to be affected to a lesser extent. By Canada's count, 13 salmon-bearing lakes and 14,000 other lakes in eastern Canada are incapable of supporting fish life (Denton 1987). Studies cited by Roth et al. (1985) report that between the 1930s and 1970s, the percentage of lakes in the Adirondacks with pH less than 5.0 increased from 8% to 48% and the percentage with no fish increased from 10% to 52%. In New England, a study of 95 lakes for which there are historical pH data showed an average alkalinity decrease of 100 milliequivalents per liter between the 1930s and 1960s.[12] Likens (1976) found a clear correlation between geographic areas where precipitation is particularly acidic and areas where lake acidification has occurred. Evidence that other mechanisms could have caused acidification is less convincing.

Roth et al. (1985) summarized the prevailing hypotheses about how lakes and streams subject to acid deposition lose fish populations. Chemical reactions that are dependent upon low pH and that mobilize aluminum, found in most watershed soils, are identified as the primary culprit. Laboratory studies show that fish are injured directly by low pH and indirectly when concentrations of toxic metals result. Both combine to cause reproductive failure in fish and also in organisms in the fish's food chain. Low pH and metal concentrations are thought to be more damaging to aquatic organisms in the spring when many are in early developmental stages. This coincides with onset of snowmelt. Roth et al. (1985) report that the effects of partial acidification due to presence of some natural alkalinity are less well understood.

Implications for Forests

Observations of diminished growth in southern softwoods at low elevations and of visually apparent deterioration of spruce-fir forests at high elevations have heightened concern over the causal factors and the possible role played by air pollution generally, and acid deposition in particular. Budiansky (1981) said that the real question is how the entire forest responds when perturbed by pollution. He noted that the major problem facing vegetation in the Northeast may be ozone, not acid precipitation or sulfur dioxide. Williams et al. (1977) found widespread damage to ponderosa pine, apparently from ozone, in dry regions downwind of Los Angeles and Central Valley. The injury suggested that trees growing in a relatively dry habitat on sensitive soil may be subject to direct damage from air pollution, possibly including acidic deposition interacting with ozone and other pollutants (Roth et al. 1985). Weisskopf (1988), reporting results of a recently released study by World Resources Institute, identified ground-based ozone as the primary cause of death or damage to 87% of the Jeffrey and ponderosa pine on the San Bernardino National Forest near Los Angeles, to white pines in the East, and to major crops in the Midwest and Southeast, including corn, soybeans, wheat, peanuts, barley, and hay. Annual crop losses caused chiefly by ozone are estimated at $5 billion (Weisskopf 1988).

Scientists are not yet able to show that changes in acid deposition will result in changes in forest growth or other measures of forest vigor. The problem is a complex one involving related chemical, physical, and biological systems and requiring a comprehensive, interdisciplinary approach. Current research involves efforts to explain observed forest changes by systematically testing a long list of hypotheses including natural cycles, climate change, pests and disease, forest stand history effects (e.g. exhaustion of residual fertilizer nutrients from previous agricultural use of the land), land management practice effects, and air pollution and acid deposition. A diversity of views exist currently about the impact of acid deposition on forested ecosystems and tree growth, as illustrated by the three sources cited below.

Woods (1987) noted that long-term effects of acid deposition on soils include making elements normally bound by soil particles (such as aluminum ions) more available for plant uptake. Aluminum ions can be concentrated in plant roots to toxic levels. Aluminum ions also reduce the availability of calcium. These changes lead to nutrient imbalances in plants which can cause reductions in productivity well before toxicity causes death. Small changes in the physiology of trees can cause losses in forest growth. Trees are vulnerable because of long growth cycles. Conifers are especially vulnerable because needles persist for two to four years and are exposed longer to atmospheric deposition.

Brown (1987) noted that the amount of acidity generated by natural sources in the eastern U.S. is much greater than for acid rain. Animal waste and decaying vegetation are responsible for many soil acids. Heavy rains wash these acids into rivers and streams before they can be neutralized by deeper soil layers. Unusual damage to forests is more likely to stem from the combination of natural stresses, such as droughts, frosts, insects, and pathogens coupled with the impact of various air pollutants. Ozone may be a contributor to the problem.

Johnson and Siccama (1983) noted that available evidence does not show a clear cause and effect relationship between acid deposition and forest decline and dieback in the U.S. Given the lack of other causal agents and characteristics of observed dieback, it appears that mortality is probably related to some environmental stress or combination of stresses. Mortality was only significantly correlated with elevation. Several stress factors are related to elevation; it is not currently possible to determine which factors are relevant. Wind speed, exposure to cloud moisture, hydrogen ion concentration, and heavy-metal content of soil all increase with elevation. Drought stress, in combination with predisposing factors related to site conditions, has triggered forest declines in the past. Growth reductions in red spruce during the mid-1960s represent initiation of dieback and decline in these trees. The early and mid-1960s were a period of drought in the Northeast. Available information does not suggest that either sulfur dioxide or ozone plays a major role in spruce decline. Other studies cited by Johnson and Siccama support drought as a prominent factor in observed forest diebacks in North America and Europe.

EROSION

The off-site impacts of sediment were identified in USDA (1987) (the Appraisal) as one of the most significant impacts created by agricultural land management practices on non-federal lands. Erosion reduction is the major focus of the *National Conservation Plan* currently being developed by the SCS in response to the Appraisal. It is also one of the primary water-related impacts of forest and rangeland management on federal lands.

Clark et al. (1985) focused specifically on the off-farm impacts of erosion measured largely by the effects of sediment on water use. The study examined problems caused by sediment and other contaminants carried off by storm water after leaving eroding fields. They found that sediment causes a variety of instream and offstream damages influenced by a complex set of hydrological, physical, chemical, and biological interactions. Christensen and Ribaudo (1987) estimate that sediment in water causes $7.1 billion in damages annually, of which cropland's share is $2.6 billion.

Instream damages are caused by sediment, nutrients and other erosion-related contaminants in streams and lakes and affect aquatic organisms, water-based recreation, water storage facilities, and navigation. Offstream damages occur before sediments reach a waterway, during floods, or after water is diverted from a waterway for use.

Erosion Impacts

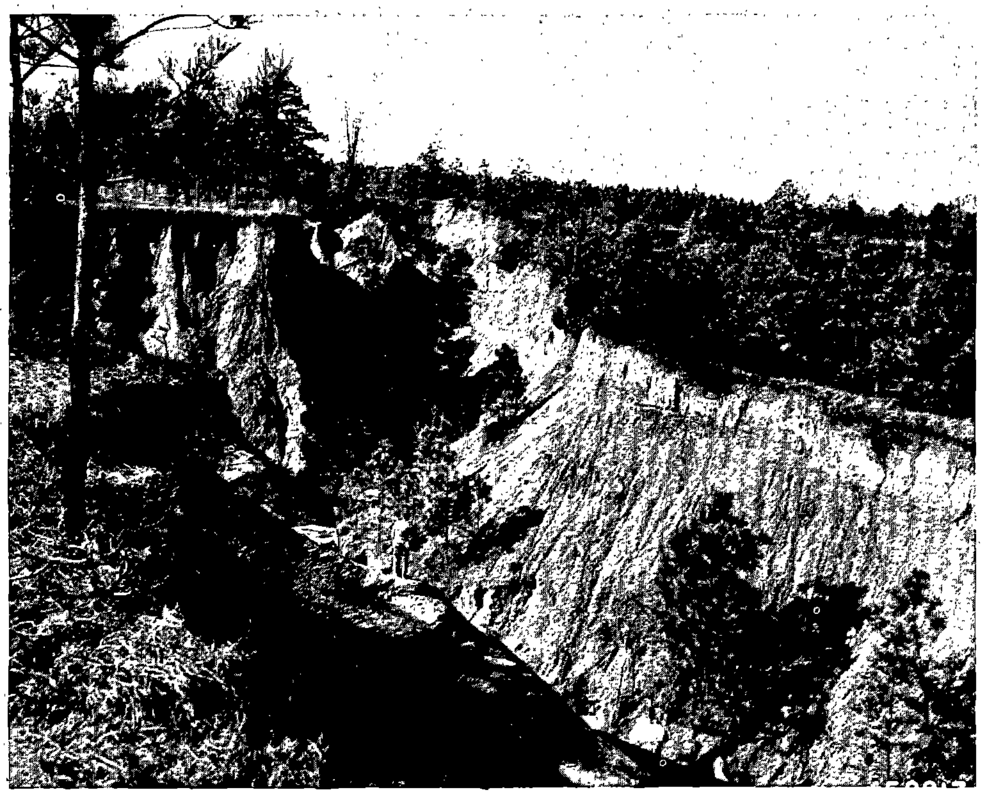
Biological impacts of erosion.—Aquatic ecosystems are affected in a variety of ways generally related either to reproduction or respiration. Sediment destroys spawning areas, food sources, and habitat and causes damage to fish, crustaceans, and other aquatic wildlife. Algal growth stimulated by nutrients blocks sunlight while algae are alive; when dead, algal decomposition strips dissolved oxygen from the water rendering respiration impossible. Pesticides and other contaminants from agricultural lands can be directly toxic to fish and to organisms lower in the food chain. Clark et al. (1985) identified agricultural runoff as chronically affecting fish communities in 30% of the nation's waters. Fish kill reports identified such runoff as a major cause of acute episodes.

Although some of these biological impacts are reflected in damage estimates to recreational and commercial fishing, the overall magnitude of impacts cannot be measured because methodology is not available. This is not to say that damages are small or nonexistent.

Recreational impacts of erosion.—All types of water-based recreational activities are adversely affected by erosion-related pollutants. The value of freshwater fishing is reduced because of the demise of valued species and reductions in fish populations. Fishing is also less successful in turbid water because fish have difficulty seeing lures. Many of the same problems affect marine recreational fishing. Many marine species reproduce in estuaries and rivers. As the deterioration of Chesapeake Bay fisheries amply demonstrates, eroded sediments and excess nutrients can lead to severe reductions in fin and shellfish populations.

Boating and swimming are affected because weed growth and siltation physically interfere with recreational activities. Hunting is also affected because many waterfowl depend upon aquatic vegetation and other affected aquatic wildlife for food. Total economic cost of these recreational damages was estimated by Christensen and Ribaudo (1987) at $1.9 billion per year and $544 million for marine fishing.

Erosion damages to water storage.—Damage to reservoirs from sediment is measured by the increasing cost of building and maintaining water-storage capacity. An estimated 1.4 to 1.5 million acre-feet of reservoir and lake capacity is permanently filled each year with sediment. Recent construction of new storage capacity averages 1 million acre-feet annually at a cost of $300 to $700 per acre-foot. Not only is the nation failing to keep up with the rate of sedimentation, but costs of providing additional storage are increasing because low-cost dam sites have already been utilized.



Erosion not only creates major problems on sites where it occurs, annual off-site damages caused by transported sediments exceed $7 billion.

Sediment and nutrients affect the rate of evaporation and transpiration from water bodies. Evaporation is a particularly serious problem in arid regions because more than an acre-foot of storage has to be constructed to provide an acre-foot of yield. Here, suspended sediments and algae may provide a benefit because they reflect much of the solar energy that would otherwise warm the water and enhance evaporation. However, sediments and nutrients are a two-edged sword because they also increase the transpiration rate by stimulating growth of water-consuming vegetation in shallow lake areas.

Lake cleanup is a final cost related to water storage. Lakes are the only water bodies that have suffered a net decline in water quality since 1975. All levels of government are spending substantial amounts for weed control and other cleanup activities. The total annual cost of all these impacts on water-storage facilities is estimated to be $1.1 billion (Christensen and Ribaudo 1987).

Impacts of erosion on navigation.—Sedimentation affects navigation in diverse ways. The major economic cost is maintenance dredging of harbors and waterways. The major environmental cost is disposal of dredged spoil. Prior to the 1950s, spoil was typically disposed of by filling wetlands for further urban development. This practice has largely ceased. Coastal dredged spoil was often barged to sea and disposed offshore. In either case, the dredging process causes temporary turbidity plumes downstream. If these coincide with critical reproduction times, the effects can be just as severe as longer term turbidity. Other costs include accidents and shipping delays. The total annual cost to navigation is estimated to be $680 million annually (Christensen and Ribaudo 1987).

Other instream impacts of erosion.—Soil erosion damages commercial fisheries in much the same way that it affects recreational fisheries. The total cost of other instream impacts of erosion on commercial fishing was estimated to be $409 million (Christensen and Ribaudo 1987).

Soil erosion can also reduce preservation/option/bequest values—the benefits people place upon clean water even though they may never make direct use of the water body. Some studies have shown these values to be even higher than the costs borne by recreational and other uses. Damage to preservation/option/bequest values is not currently estimable with the same accuracy as the other damages. Comparing Clark et al. (1985) and Christensen and Ribaudo (1987), perhaps up to $600 million in damages to these values occurs annually.

Other offstream impacts of erosion.—Water often contains sediment or agricultural byproducts such as dissolved salts in concentrations that are too small to justify treatment. Yet these constituents in water cause increased operation and maintenance costs and more frequent replacement of irrigation equipment. Salt and alkali buildups in pipes can lead to added maintenance and replacement costs. Irrigators using turbid water experience increased costs and reduced yields if fine silt causes a crust to form on the soil surface, impeding water infiltration and seed germination. Christensen and Ribaudo (1987) estimated that the net cost of all these other offstream impacts at $135 million annually.

Flood damages of erosion.—Sediment contributes to flood damages in three ways. First, by settling out in streambeds and clogging waterways, it increases frequency and depth of flooding. Second, because suspended sediment is carried by flood water, the volume of the water/soil mixture is increased, thus raising flood crests. Third, many flood damages are caused by sediment, not by the water itself. There may be long-term damages to agricultural land if floods leave infertile silt behind. The total of all these damages was estimated by Christensen and Ribaudo (1987) to be $888 million per year.

Water-conveyance impacts of erosion.—Some sediment settles out in drainage ditches before water reaches streams. Clark et al. (1985) cited estimates from Illinois that highway department crews annually remove from drainage ditches an amount of sediment equal to 1.4% of the total erosion occurring in the state. The annual cost of controlling weeds and removing sediment from the 110,000 miles of irrigation canals in the U.S. accounts for 15% to 35% of annual canal maintenance costs. Total cost of these damages is estimated to amount to $214 million per year (Christensen and Ribaudo 1987).

Water-treatment costs of erosion.—The cost of treating water before municipal or industrial use increases when raw water is turbid. Sedimentation basins must be built and periodically cleaned out, chemical coagulants must be added, filters must be cleaned more frequently, and special treatment apparatus installed to handle nutrients and other contaminants. For example, nutrients and algae may clog heat exchanger tubes in steam boilers or cooling towers and necessitate increased maintenance costs. Christensen and Ribaudo (1987) estimated that these procedures cost $1.2 billion annually.

Summary

The total estimate of erosion-related damages is $6.1 billion annually of which $2.2 billion is attributable to cropland. If sediment damages are isolated from nutrient, pesticide, and other erosion-related damages, the totals are $3.5 billion of which $1.2 billion is attributable to cropland.

Erosion-related damages not attributable to cropland fall into two categories. The first is erosion from other land management practices. Examples are construction, forestry, grazing, and mining operations. Forestry activities with high erosion potential include road building, timber harvesting operations, and wildfire.

Overgrazing is the primary source of erosion from rangelands. The Appraisal found that at present, 20% of rangeland has erosion exceeding T.[13] The Appraisal concluded that erosion on rangeland is a potential problem on 61% of non-federal range. The assumption made when evaluating this potential was that all range in less than good condition is susceptible to damage. The watershed condition class discussion earlier in this chapter pointed out that 72% of watersheds are either in the Special Emphasis class and need careful management to avoid problems, or in the Investment Emphasis class and need technological and economically feasible investments to restore watershed conditions to a level consistent with watershed management goals. The most significant factor placing these forests and rangelands at risk is the potential for erosion and movement of sediment off-site.

The second category of erosion-related damages not attributable to cropland comes from sediment deposits currently in streams. In some areas where erosion was a major problem such as the abandoned cropland in some parts of the South, streams no longer carry the fresh sediment loads they did at the turn of the century. As sediments were prevented from entering streams either by conversion of the land to forests or more enlightened land management, water energy formerly used to carry sediments has begun scouring old sediment deposits from stream channels and is carrying these previously-deposited sediments downstream. This water action has confounded many studies seeking to demonstrate that land management activities had direct effect on reducing instream sediment concentrations because little reduction in sediment in the water was observed. In some streams, long-buried bridges and other historical artifacts reemerging from silt are offering historians fresh opportunities for studying pioneer and plantation life of the 1700s and 1800s. It may take another 50 to 100 years for these entrained sediments in stream channels to be scoured out and streams returned to the channel configurations they enjoyed before development began.[14]

Clark et al. (1985) concluded that developing an effective, efficient program to control off-farm impacts of eroded materials will be difficult. They called for new regulatory programs that were more accurately targeted at erodible soils and land management practices insensitive to erosion. A key element identified was taking the most seriously eroding lands out of row-crop production or out of production altogether. The Food Security Act of 1985 contained a section dealing with soil conservation measures having several provisions that respond quite closely to the conclusions reached by Clark et al. (1985). Four notable provisions to reduce cropping of erodible land and the environmental implications of land management were (1) creation of the Conservation Reserve Program (CRP), (2) the Conservation Compliance provision, (3) the "Sodbuster" provision, and (4) the "Swampbuster" provision. These provisions only apply to lands with the potential to erode more than eight times faster than new soil can be regenerated. There are 118 million acres of such soils in the U.S., 35 million of which are being managed to prevent erosion in excess of the rate of regeneration (Reichelderfer 1987). It is estimated that 40 to 45 million acres will be enrolled in the CRP by 1990.

The conservation compliance provision is designed to keep erosion low on 35 million acres of erodible lands currently being farmed. Failure to do so causes the farmer to forfeit the right to participate in other farm programs offered by USDA.

The sodbuster provision denies eligibility for USDA programs to farmers who newly cultivate highly erodible land without using an approved conservation system. The swampbuster provision denies eligibility to farmers to convert wetlands to production of agricultural commodities.

The latter two provisions are designed to discourage conversion of grasslands and river bottomlands which are predominately forest to crop production.

GROUNDWATER CONTAMINATION

Most groundwater supplies in the U.S. are of good quality. In some localities, however, contamination has caused well closures, public health concerns, and economic losses. These problems could spread. The challenge is to prevent localized problems from becoming local crises or regional problems.

The Conservation Foundation (1987) concluded that groundwater protection efforts have been limited at best. Regulatory programs put in place often have failed to exercise much of the statutory authority available. Because many laws were written at different times and for different purposes, they often add up to a program of groundwater protection that is neither coherent nor consistent even if those laws are implemented to the limits of enacted authority.

Groundwater can be contaminated in a variety of ways. EPA (1987) summarized major sources of groundwater contamination reported by states. More than 40 states reported septic tanks, underground storage tanks, and agricultural activities as major sources of contaminants. More than 30 states reported landfills, lagoons, and abandoned waste sites as major sources of groundwater contamination.

Underground storage tanks.—Underground storage tanks were listed as the primary source of groundwater contamination by 11 states. These are Alabama, Alaska, Florida, Michigan, Montana, New Jersey, New York, North Carolina, Pennsylvania, South Dakota, and Virginia. The Conservation Foundation (1987) provides additional detail on the magnitude of problems associated with underground tanks by citing a recent Congressional Research Service report. That report estimated there are between 5 and 10 million underground tanks of all kinds (EPA's estimate is 3 to 5 million), of which 1.5 million tanks contain petroleum or hazardous substances (1.4 million by EPA's estimate). Most existing tanks are made of carbon steel, unprotected from corrosion, and range in size from 10,000 to 50,000 gallons. Some fiberglass tanks are also used, but they tend to be smaller, averaging 10,000 gallons. The Congressional Research Service estimated that 25% to 30% of tanks containing petroleum products may be leaking (a limited EPA survey in 1986 found 35% leaking). Vehicle filling stations accounted for the majority of leak locations. Other studies found that the majority of leaks occur from operating tanks and not abandoned ones. Leaks of solvents are proportionately more prevalent than leaks from petroleum tanks. Corrosion of tanks and associated pipes and fittings accounts for 90% of the leaks according to the Conservation Foundation (1987).

Septic tanks.—Failure of septic systems was reported as the primary cause of groundwater contamination by nine states, including Arkansas, Delaware, Illinois, Kentucky, Maine, Maryland, Nevada, Ohio, and Tennessee. Contamination from this source is not a new problem; however, shifts in housing patterns and land use, particularly increasing housing densities in suburbs, have made septic system discharges a more prevalent problem. About one-fourth of American homes (20 million homes) use on-site sewage disposal; most of these are east of the Great Plains.

Septic systems are far more popular than cesspools or pit privies. A 1980 study cited by Conservation Foundation (1987) reported that up to one-third of the systems were operating improperly. Groundwater pollution by nitrates, phosphates, heavy metals, other inorganics, and toxic organics often used as system cleaners, result when systems are not operating properly. The efficiency of a septic tank decreases over time, even with proper maintenance (periodic removal of sludge), because of a buildup of film on the outside of drains or clogging of the drainage bed material. One study reported by the Conservation Foundation (1987) found that 75% of septic system failures can be attributed to overloading the drain field with sludge. The cleaning and sludge removal process often uses chemicals such as trichloroethane, benzene, or methyl chloride, to dissolve sludge in tanks and drain fields—chemicals that should not come in contact with groundwater. Widespread use of these chemicals on Long Island in 1979 (an estimated 400,000 gallons total, many applied by homeowners themselves) resulted in closure of many public and private wells (Conservation Foundation 1987). Careful location, construction, and maintenance provides some measure of protection against groundwater contamination.

Agricultural activities.—Agricultural activities were cited as the primary source of groundwater contamination by 6 states including Arizona, Arkansas, California, Connecticut, Hawaii, and Iowa. The primary contaminants are nutrients from fertilizers, livestock waste disposal, and pesticides.

Fertilizer use in the U.S. has grown drastically, rising 300% between 1960 and 1980. Nitrogen fertilizer applications have quadrupled over the same period. In addition to the large increases in fertilizer applications to cropland, large amounts are also applied in urban areas to turf and gardens. The Conservation Foundation (1987) recounts results of several studies in Wisconsin, Nebraska, and Iowa linking increases in nitrate concentrations in well water to heavy usage of nitrogenous fertilizers.

Animal wastes are another source of nutrients and bacteria. Feedlots are often viewed as major sources of contamination but manure disposal on individual farms can also cause problems. Southeastern Pennsylvania is one of the most concentrated areas of dairy farms in the nation. The volume of manure created and the small size of the typical dairy farm combine to create manure disposal problems. Application rates exceeding 2 tons per acre per year are not uncommon; at a 5% nitrogen content, this equates to more than 200 pounds of nitrogen per acre annually. Runoff from fields contaminates surface waters and leachate percolates to groundwater. Because of the limestone geology of Southeastern Pennsylvania, there are many channels and solution cavities providing speedy access of percolate to aquifers which exacerbates manure disposal problems. The Conservation Foundation (1987) recites manure disposal problems associated with beef production in Colorado and poultry production in Delaware. Methods of solving nutrient contamination problems from agricultural operations include matching fertilizer requirements and timing of applications more closely with actual crop needs and collecting, storing, and treating livestock and poultry wastes before applying them to fields.

Pesticide applications were the second concern related to agricultural operations. The Conservation Foundation (1987) reported that herbicide use has grown by 200% between 1966 and 1981 as chemicals replaced mechanical cultivation for controlling weeds. In 1982, 91% of all U.S. cropland farmed was planted with row crops and 44% of those acres had herbicides applied. However, 85% of the herbicides and 70% of the insecticides were applied to only four crops—corn, cotton, soybeans, and wheat. The two most heavily used substances are the herbicides alachlor and atrazine; accounting for 25% of the total national usage. The two states using the largest quantities are Iowa and Illinois, which account for 21% of total usage. Soluble formulations of pesticides and those products designed to kill soil pests have the greatest potential for contaminating groundwater. Problems with groundwater contamination can be minimized by using formulations that do not migrate through the ground, by taking greater care in where, when, and how pesticides are applied, and by combining pesticide usage with other non-chemical techniques in a program of integrated pest management.

Landfills.—Five states identified landfills as the primary source of groundwater contamination. It is estimated that between 15,000 and 20,000 municipal dumps and sanitary landfills exist in the U.S. An exhaustive list is not available; the actual number could be as high as 40,000. Four out of five facilities are small, handling less than 100 tons of waste daily. Two hundred seventy five million tons of municipal solid wastes are disposed of in landfills annually. Older landfills and open dumps were often uncovered, unlined, and located with no consideration of their potential for contaminating groundwater. In addition, many landfills were located on marshlands, abandoned gravel pits, and old strip mines. Such sites are susceptible to groundwater contamination if infiltration flowing through the disposal site is a source of groundwater recharge and if underlying soils are sufficiently permeable to allow leachate to enter the groundwater system. Percolation of leachate from landfills is inevitable unless the site is completely sealed on all sides. Few are. Groundwater contamination from landfills can be minimized by improved design, construction, operation and maintenance. Design considerations should always include hydrogeology of the landfill location, area to be served, and types of wastes. The use of liners and covers, as well as collection and treatment of leachate, further reduce the potential for groundwater contamination (Conservation Foundation 1987).

Hazardous wastes.—Hazardous wastes, while a major cause of concern by 29 states, were a primary concern of only three states. About 5,000 sites in the U.S. are treating, storing, and disposing of hazardous wastes. The largest number of sites are in the Great Lakes region followed by the Southeast and Southwest. As of June 1986, 888 abandoned hazardous waste sites were listed or proposed for listing on the National Priorities List and thus targeted for federally-funded cleanup under the Superfund. Seventy-five percent of the sites on the National Priorities List have documented groundwater contamination problems. The most commonly found substances include trichloroethane, lead, toluene, benzene, PCBs, chloroform, phenol, arsenic, cadmium, and chromium.

The potential for contaminating groundwater can be reduced in several ways. Careful siting and operation of treatment, storage, and disposal facilities can minimize the potential for unforeseen problems. Liners and leak detection systems can be installed to reduce the possibility that contaminants can escape unnoticed. Enclosing more hazardous substances in concrete, glass, or ceramic vessels reduces potential for leakage. Alternative disposal techniques such as incineration or waste solidification may have less environmental hazard than burial. Finally, reducing the generation of hazardous wastes through modifying plant processes, recycling, detoxifying, drying, or substituting nonhazardous materials should also be examined. These steps provide the most attractive long-term methods for reducing the problem (Conservation Foundation 1987).

A Groundwater Protection Strategy

The 1987 National Groundwater Policy Forum (Conservation Foundation 1987) concluded that the nation must adopt a much more aggressive policy of groundwater management if the resource is to be adequately protected for current and future users. Because the problem is complex, a highly coordinated attack is required with participants from all levels of government and industry. Partnerships must be forged to achieve the common goal of protecting the groundwater resource. Four principles should guide the development of a protection strategy: (1) active management is required to meet human and ecological needs; (2) contamination should be prevented wherever possible because of the technical difficulties and costs of cleanup; (3) degradation of the most valuable aquifers and critical water supplies must be prevented; and (4) the strategy must recognize the wide variation across the country in the nature, vulnerability, and use of groundwater, and in state and local governments' ability to manage it.

The Policy Forum recommended a new environmental partnership to avoid creation of a new and burdensome bureaucracy. Partners should include federal, state, and local governments, private industry, and public interest groups. The Forum recommended that the partnership be structured so that a clear national mandate is set forth while ensuring that states, assigned the lead role, have ample room to operate. Two key aspects from the states' perspective are (1) consolidating groundwater laws and programs under the jurisdiction of a single state agency to facilitate a coordinated approach to problem prevention and solution; and (2) having substantial flexibility to design programs that respond to specific local needs. The federal government's role was envisioned as balancing national consistency with the reality of geographic differences. Ten components of a prototype state groundwater protection program were identified:

1. Comprehensive mapping of aquifer systems and their associate recharge and discharge areas;
2. Anticipatory classification of aquifers;
3. Ambient groundwater standards;
4. Authorities for imposing controls on all significant sources of potential contamination;
5. Programs for monitoring, data collection, and data analysis;
6. Effective enforcement provisions;
7. Surface-use restrictions to protect groundwater quality;
8. Programs to control groundwater withdrawals to protect groundwater quality;
9. Coordination of groundwater and surface-water management; and
10. Coordination of groundwater programs with other relevant natural resource protection programs.

Other institutional arrangements to implement the prototype program are discussed by the Conservation Foundation (1987).

SUMMARY

The three major water-related environmental problems identified in this Assessment are acid deposition, erosion, and groundwater contamination. All stem from externalities—resource management actions that fail to take full account of the potential disruption to ecosystems caused by pollutants. Pollutants are nothing more than resources out of place. When removed from their proper place, these resources cause ecosystems to change in ways not desirable to society.

There are several steps in solving problems created by resources out of place. The first is deciding how we want ecosystems to function. This step involves deciding how much ecological change society deems acceptable. "No change" is rarely a viable option because resource use invariably changes ecosystems in one way or another. The second step is identifying mechanisms by which unacceptable ecosystem changes are occurring. With erosion, this step has been answered more fully than for acid deposition or groundwater contamination. The third step is devising a way to alter mechanisms causing unacceptable ecosystem changes.

Tools to help solve problems include market-oriented processes and institutional processes, such as regulations or legislation. Today's society appears to prefer using market forces instead of institutional processes. But if market pressures are demonstrated to be ineffective, society has no qualms about insisting on using institutional processes. Dickering over ways, means, and costs via the political system is the way our society achieves consensus on attacking problems.

This section of Chapter 2 focused specifically on the second step in a general process outlined above. The major causes of acid deposition, erosion, and groundwater contamination have been reviewed with the objective of describing the sources and scope of the problems. The abbreviated discussions of acid deposition, erosion, and groundwater contamination presented are only abstracts of the highlights from literature cited in this chapter. Interested readers should consult the literature cited as they contain a wealth of more detailed information on the subjects.

CONDITION AND DISTRIBUTION OF THE NATION'S WETLANDS

PRESENT DISTRIBUTION OF WETLANDS BY SIZE AND REGION

There are 90 million acres of wetlands in the lower 48 states or about 5% of the total land area. Of all wetlands, 95% are inland freshwater wetlands and 5% are of the coastal saltwater type.

Wetland ecosystems are especially prevalent in Alaska. That state alone has approximately 200 million acres of wetlands (60% of its land area); over twice the total of the lower 48 states. Outside of Alaska, the largest concentrations of wetlands are found in the North and South. Those located in the South are primarily caused by sedimentation where soil is eroded from seacoasts or riverbanks and deposited behind barrier islands or onto alluvial plains. Wetlands caused by glaciation are found in the North and scattered throughout the West.

Glaciers form wetlands in three ways: large blocks of ice melt to form depressions; rivers are dammed by glacial debris; and lake beds are formed by scouring action. Other causes of wetlands are beaver dams, human activity, wind erosion, geologic movement such as sinkholes, and freezing/thawing. Alaska's wetlands are caused by the last category—soils near one surface thaw on a seasonal basis but their moisture is prevented by permafrost from entering the water table. Wetlands are especially prevalent in the upper Midwest, the lower Mississippi River valley, and along the Atlantic Ocean and Gulf of Mexico (fig. 8 and table 7).

Throughout history, wetlands have been considered wastelands that could only be put to productive use if they were drained or filled. Within the last 200 years, over 50% of the wetlands in the lower 48 States have been converted to other uses such as agriculture, mining, forestry, oil and gas production and urbanization. Wetland losses are continuing today at an alarming rate, estimated at 350,000 to 500,000 acres annually.

The most extensive inland wetlands losses have occurred in Louisiana, Mississippi, Arkansas, North

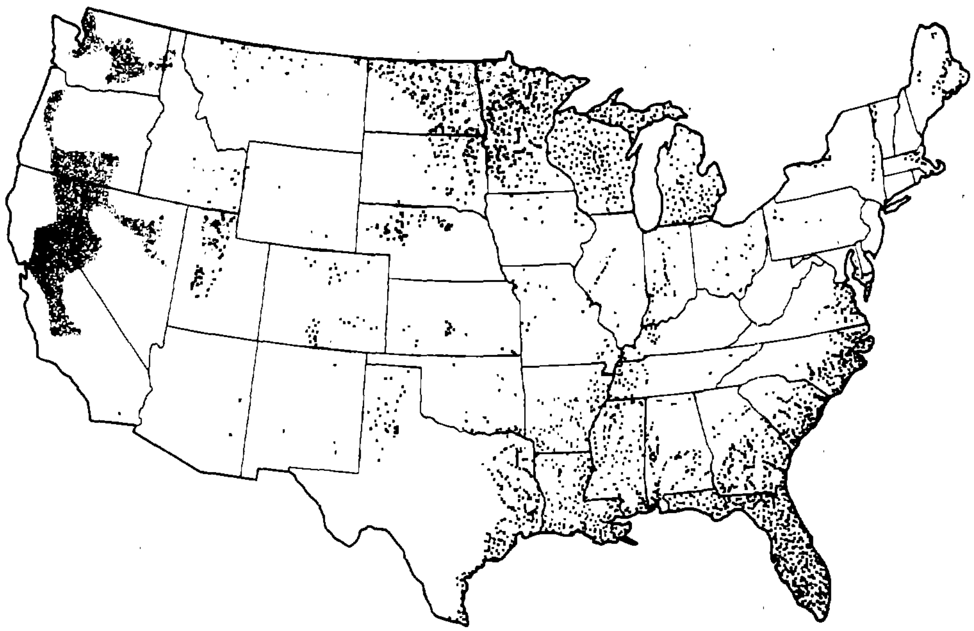


Figure 8.—Distribution of wetlands (OTA 1984).

Table 7.—Geographic distribution of wetlands, by type

Wetland type	Water resource region
Inland freshwater marsh	South Atlantic-Gulf Souris-Red-Rainy Texas-Gulf
Inland saline marsh	Lower Colorado Great Basin Pacific Northwest California
Bogs	South Atlantic-Gulf Great Lakes Ohio Upper Mississippi Lower Mississippi
Tundra	Alaska
Shrub and wooded swamps	South Atlantic-Gulf Great Lakes Ohio Upper Mississippi Lower Mississippi Texas-Gulf
Bottomland hardwoods	South Atlantic-Gulf Lower Mississippi Texas-Gulf
Coastal salt marshes	New England Mid-Atlantic South Atlantic-Gulf Texas-Gulf Pacific Northwest California
Mangrove swamps	South Atlantic-Gulf Texas-Gulf
Tidal freshwater wetlands	Mid-Atlantic South Atlantic-Gulf Texas-Gulf

Source: After OTA (1984)

Carolina, the Dakotas, Nebraska, Florida, and Texas. Estuarine wetlands losses have been greatest in California, Florida, Louisiana, New Jersey and Texas.

Results of these wetlands losses have been devastating. In many coastal areas where estuarine wetlands losses are high, urbanization and increased ground-water withdrawals have resulted in saltwater contaminating public water supplies. In Chesapeake Bay—the largest estuary in the U.S.—sea grass, wild celery beds, and tidal wetlands have been declining since the 1960s. In the upper Bay, they have almost disappeared. Canvasback ducks that thrived on the wild celery beds at the turn of the century are rarely found in the upper Bay and their population in the lower Bay is down significantly.

In North Carolina, forestry and agriculture have played an important role in the loss of considerable evergreen forested and scrub-shrub wetlands known as *pocosins*. Most of these areas were transferred to large-scale agriculture even though difficult to drain. In addition to extensive land clearing and ditching, large quantities of fertilizers and lime must be added to these wetlands to keep them fertile and productive. Runoff carries nutrients which degrade the water quality of adjacent estuaries. Development of pocosins for intensive softwood silviculture changes their character but the lands remain wetlands. In EPA (1987), 11 States reported that wetlands were a special concern (fig. 9).

INFLUENCE OF WETLANDS ON REDUCING PEAK FLOW RATES

Some wetlands have been used to help reduce flood damages to developed areas. Because wetland hydrology is extremely complex and variable by wetland type, not all such areas can provide temporary detention of runoff or a time lag between entering and exiting a wetland.

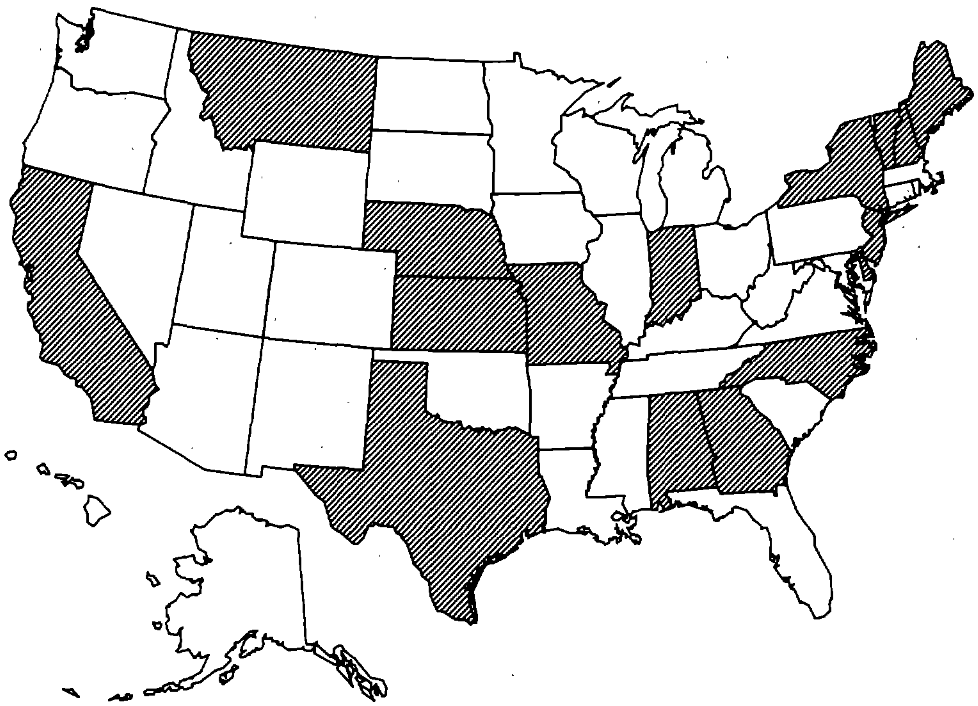


Figure 9.—States reporting wetlands loss as a special concern (EPA 1987).

When wetlands can provide temporary detention and a lag in runoff timing, they help reduce flood damages by lowering the peak flow rate of flood waters. A high peak flow for a short period of time tends to cause more damage to developments than a lower peak flow rate over a longer period of time. A second way that wetlands can help reduce flood damages is by slowing flood water velocities. When the velocity drops, flood waters experience a reduction in their ability to carry debris and sediment. Debris such as tree limbs, shopping carts, and sediment are responsible for a significant portion of flood damages both by crashing into objects and breaking them, as well as by being deposited in developed areas necessitating expenditures for cleanup. A third way that wetlands can help reduce flood damages is by helping to siphon off floodwaters and carry them around or away from developed areas. The classic example of how wetlands help in this way is found in southern Louisiana. When the lower Mississippi River reaches a certain flood stage, the U.S. Army Corps of Engineers diverts a portion of the Mississippi River around Baton Rouge and New Orleans through the Atchafalaya Swamp to the Gulf of Mexico. Also, the Bonnie Carrie Spillway above New Orleans can be opened to divert more of the river's flow across several miles of marshland to Lake Pontchartrain and through the Lake's outlet to the Gulf. A fourth way that wetlands can help reduce flood damages applies specifically to coastal wetlands. They help absorb the energy of the tidal surge accompanying hurricanes.

When development encroaches on coastal wetlands, periodic major storms can cause extensive damages. An example from southern Louisiana illustrates the point. The Pearl River is the border between eastern Louisiana and southern Mississippi. The lower 15 miles are a classic freshwater bottomland hardwood and cypress swamp, nearly 5 miles wide at points. Interstate 10 cuts across the lower part of the swamp forming a 5 mile-long dike punctured by 5 bridges and several culverts. In recent years, major floods on the Pearl have backed up behind the I-10 roadway causing damage to residential areas rimming the swamp, flowing over the roadway closing I-10, and threatening to wash out the roadbed.

INFLUENCE OF WETLANDS ON MAINTAINING WATER QUALITY

Richardson (1988) concluded that some wetlands are valuable from an ecological perspective because of their ability to transform, store, and recycle nutrients and sediments. By temporarily or permanently retaining pollutants such as toxic chemicals and disease-causing micro-organisms, wetlands can improve the quality of water that flows over and through them. Some pollutants that are trapped in wetlands may be converted by biochemical processes to less harmful forms. Some pollutants may remain buried; others may be taken up by wetland plants and either recycled within the wetland or transported from it. By temporarily delaying the release of nutrients until the fall when marsh vegetation dies back, wetlands can prevent excessive algal growth in open-water areas in the spring and summer. This characteristic led some communities in coastal areas to move their wastewater effluent pipes from rivers and offshore areas to wetlands where marsh vegetation can remove the nutrients. Not all types of wetlands have these characteristics.

REGULATIONS INFLUENCING WETLANDS CONVERSIONS

Section 404 of the Clean Water Act gives the U.S. Army Corps of Engineers authority to issue permits for the discharge of dredged or fill material into the navigable waters at specified disposal sites. This program is discussed in more detail in Chapter 8.

Inland freshwater wetlands comprise 95% of the remaining wetlands resource in the U.S. and more than 90% of the estimated 300,000 acres of freshwater wetlands lost each year to development. Many of the losses involve drainage without a discharge which is not regulated by the 404 Program. The swamp buster provision of the 1985 Farm Bill should help mitigate this problem by discontinuing subsidies to farmers who drain and plant wetlands.

Approximately 11,000 permit applications under Section 404 are processed by the Corps of Engineers each year. The EPA , the Fish and Wildlife Service (FWS), and the National Marine Fisheries Service all have a role in the permit review process as do states and other interested parties. One role of EPA is to determine if the proposed use will have "an unacceptable adverse effect on municipal water supplies, shellfish beds and fishery areas (including spawning and breeding areas, wildlife, or recreational areas)." If so, they can prohibit or restrict proposed site use.

As a result of this process, the Corps of Engineers annually denies about 3% of permit applications. About one-third of the permits are significantly modified from their original application and about 14% of permit applications submitted each year are withdrawn by the applicants. The Office of Technology Assessment (OTA 1984) estimated that these denials, modifications, and application withdrawals save 50,000 acres of wetlands every year.

NOTES

1. The material in this section is drawn largely from Foxworthy and Moody (1986).

2. Precipitation variability is even more extreme than depicted in figure 1 because of gauging station locations. Gauging stations are typically located at or near settlements to facilitate daily reading of the instruments. In mountainous areas, settlements are nearly always situated in valley bottoms where precipitation is often much lower than on the slopes or tops of the nearby mountains.

3. See the discussion by Reisner (1986).

4. Organic Administration Act of June 4, 1897 (Ch. 2, 30 Stat. 11, as amended; 16 U.S.C. 475).

5. The information in this section is drawn largely from "Water Availability Issues" in USGS (1984; p. 36–45).

6. Dr. James B. Gregory, Associate Professor of Forest Hydrology at North Carolina State University, brought this example to my attention.

7. The discussion is drawn largely from Foxworthy and Moody (1986).

8. Information in this section is drawn largely from three sources: Anon. (1984) provided an overview; Smith et al. (1987) reports trends based upon information data from two stream sampling networks operated by USGS; and EPA (1987), a biennial report to Congress.

9. The discussion that follows was drawn largely from EPA (1987).

10. Funding needs for waste treatment was also listed as a concern by 10 states. The funding concerns reflect expectations of additional funding cutbacks; because they have not yet occurred, the funding cutbacks were not analyzed in this report.

11. The discussion in this section is drawn largely from Council on Environmental Quality (1987), unless information is otherwise cited.

12. Alkalinity is a measure of the acid neutralizing capability of a waterbody. When a strong acid, such as sulfuric, enters the water, the natural alkalinity in the water buffers the acid added by chemically neutralizing it. In so doing, some of the alkalinity is consumed. So, a decline in alkalinity shows that acid entered the waterbody and was neutralized.

13. T is a measure of the erosion potential of the soil and its associated vegetative cover. Its use to evaluate land condition is explained more fully in USDA (1987).

14. Personal conversation with Wayne Swank, Forest Service Research Hydrologist, during the review of the water aspects of the *South's Fourth Forest* (USDA Forest Service 1988).

CHAPTER 3: THE DEMAND SITUATION FOR WATER

HISTORICAL OVERVIEW OF DEMAND FOR WATER

The emergence and growth of the United States as an industrialized nation has been closely tied to water use. Settlement along the Atlantic Coast was initially tied to use of water for transportation—settlements quickly sprung up at good harbors. Commercial fishing and trade were early water-based stimulants to local economies. Inland waterways became transportation corridors for trade in both raw materials and finished goods. In the West, Spanish settlers and missionaries established modest irrigation works in the 17th century. By the early 1800s, settlements were well established at many locations where favorable conditions of flow and topography permitted waterpower to be harnessed for milling products such as grain, logs, and wool. Development of the steam engine in the early 1800s suddenly freed industries from having to locate on stream banks to secure waterpower and the Industrial Revolution was underway. Mormon settlers began irrigation in 1847. Ranchers and miners in the West were also diverting water in the mid-1800s.

After being a constraint on growth for 200 years, water was much less so for the rest of the 19th century. Instead, fuel for the steam engine became the primary constraint. Wood and coal instead of waterpower fueled industrial expansion into the early 1900s. Also during this period, railroads rose to prominence as a method of transportation, thus making the country much less reliant on boats and barges and navigable streams and harbors. Water for drinking and water for waste disposal were the two uses that increased most rapidly to the beginning of the 20th century.

By the beginning of the 20th century, civilization had tainted most coastal waters and many inland streams. Rapid population growth of cities and increasing concentrations of industry combined to overtax the ability of the nation's water resources to meet all needs. Typhoid epidemics erupted in a number of cities along the East Coast around the turn of the century. The cause was finally determined to be contaminated drinking water. Practical methods of chlorinating drinking water had not yet been discovered. Rural and urban developments in the floodplain of major streams such as the Mississippi, Missouri, and Ohio Rivers, both contributed to the cause of flooding and incurred damages due to flooding. Flood control structures—dams and levees—were fragmentary. In the Midwest and West, many areas could not sustain settlement because insufficient water was available for crops or animal husbandry. Securing the coal and wood needed to fuel the economic engine of the U.S. led to resource extraction practices that fouled waters with sediment and acid. Land reclamation and forest regeneration practices had not yet been developed.

By the middle of the 20th century, the country had begun to remedy many water and related land resource problems. Local, state, and federal agencies led an assault

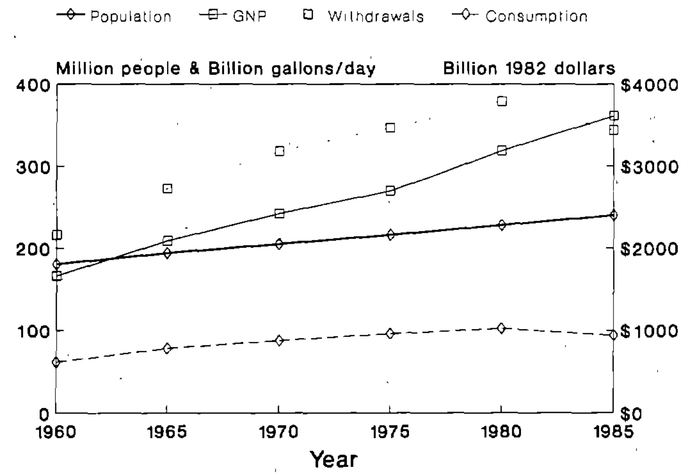


Figure 10.—Rates of increase in GNP, population, and water withdrawals, 1960–1985.

on the problems. Structural approaches to solving water resource problems were favored. The Army Corps of Engineers improved navigation and controlled flooding with locks, dams, dredging, levees, and other works. The Bureau of Reclamation built dams and irrigation structures to water the West. The Forest Service and SCS developed and installed land management practices to keep soil in place, thereby preserving clean water. The Tennessee Valley Authority began economic redevelopment of the southern Appalachians—a massive demonstration of how water resources could be better harnessed for economic development. Local and state governments installed water and waste treatment facilities to render potable supplies safe and remove suspended solids from waste flows.

The demands for water today stem largely from this history of developing water resources. The inertia created by using water resource development to drive economic development continues to affect demand for water today and will for years to come. Trends in water withdrawals and consumption through the 1960s and 1970s show an inexorable climb in total use, marching lockstep with increases in gross national product (GNP) and population (fig. 10).

But by the early 1970s it became clear that while prior developments had, to a great extent, solved problems of water flow volumes, much remained to be done about problems of water quality. Public Law 92–500 and subsequent amendments and related water quality legislation provided the added momentum needed to preserve pristine water quality where it existed and to clean up fouled water to fishable and swimmable levels. The legislation provided a major shift in the long-run trend of ever-increasing withdrawals and consumption. The added cost of waste treatment imposed by the legislation made water conservation and recycling much more cost-effective than it had been in the past. Recent water withdrawals and consumption information (Solley et al. 1988) shows that water quality legislation has also had a significant effect in retarding growth in demand for withdrawals and consumption (fig. 10).

This chapter reviews historical trends in water demand and projects those trends into the future. Water withdrawals and consumptive use are both referred to as "demand" in this chapter. In later chapters, demand analyses will use consumption because it is the more limiting form of water use.

Historical data on water withdrawals and consumption is summarized from USGS (MacKichan and Kammerer 1961, Murray 1968, Murray and Reeves 1972 and 1977, Solley et al. 1983, and Solley et al. 1988). Projections of withdrawals and consumption are presented for the years 2000 to 2040 based on USGS data from 1960 to 1985. Water demand projections made in other studies published since 1960 are reviewed and comparisons of data recently collected with previous projections are made.

HISTORICAL DATA ON WATER WITHDRAWALS AND CONSUMPTION

National trends in withdrawals and consumption.—The USGS reported estimates of water use in the United States at five-year intervals since 1950 (MacKichan 1951). The most recent data available is 1985 (Solley et al. 1988). Withdrawals in 1960 totaled 216 bgd and consumption was 61 bgd.[1] By 1985, withdrawals totaled 343 bgd and consumption 93 bgd, reflecting increases of 59% and 52% respectively (fig. 11).

National trends by water use.—Increases in total withdrawals and total consumption obscure interesting trends in the six major categories of water use and over time. Water uses examined in this report include thermoelectric steam cooling, irrigation, municipal central supplies, industrial self-supplies, domestic self-supplies, and livestock watering. Trends in freshwater withdrawals vary by use. Withdrawals for municipal central supplies rose 78% from 1960 to 1985 while withdrawals for industrial self-supplies dropped 21% (table 8).

Consumption trends also vary by use. Consumption by thermoelectric steam cooling rose 1840% from 1960

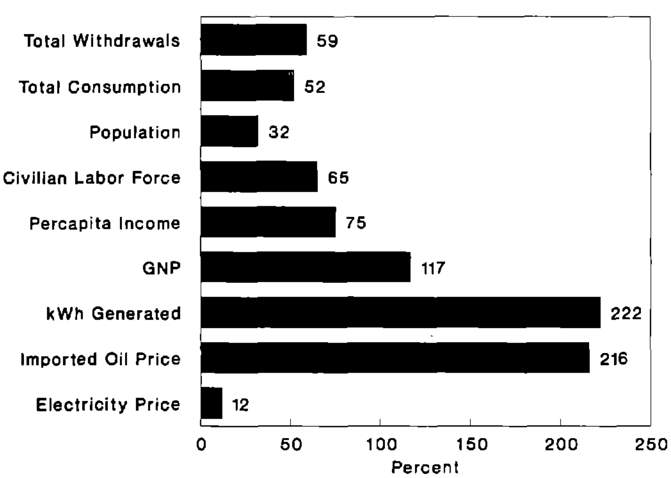


Figure 11.—Increases in withdrawals, consumption, and related variables from 1960 to 1985.

to 1985 while consumption by irrigation only rose 42% (table 9). Detailed tables of withdrawals and consumption by type of use are presented in Appendix A. Detailed discussion of trends by use category are presented later in this chapter when projections are discussed.

National trends by water source.—Withdrawal and consumption trends vary by source of water. From 1960 to 1985, groundwater withdrawals rose 81% and surface water withdrawals rose 53%; however, wastewater withdrawals declined 5%. The latter figure is particularly noteworthy because in the early 1970s, wastewater reuse was strongly encouraged. The reduction apparently only counts water withdrawn from conveyance structures after municipal wastewater treatment. One policy implemented by regulations arising from the Clean Water Act was to charge industries the full cost of treating industrial waste flows sent to municipal treatment plants. It now appears that industrial users adopted internal recycling strategies to reduce their waste flows and thus municipal waste treatment fees. Data showing industrial self-supplied withdrawals dropping 21% and consumption rising 39% are consistent with significant increases in internal recycling.

Regional trends in withdrawals and consumption.—Trends in freshwater withdrawals between 1960 and 1985 also varied among geographic regions (table 10). Withdrawals in the South and Rocky Mountains rose 89% and 75% respectively. This doubled the increases in the North and Pacific Coast, which were 40% and 32% respectively. Over this period, Censuses of Population and Manufacturing both reported population and industrial growth in the South and West and declines in the North. Water withdrawals were similarly affected. The lower percentage increase in withdrawals along the Pacific Coast reflects the fact that major increases in population and industry occurred in a water-short area (e.g. in Southern California) relying heavily on imports from other hydrologic basins.

Consumption trends by region show a different story. Consumption in the North increased 132%, far eclipsing increases in the South (68%), Pacific Coast (49%) and Rocky Mountains (37%). Because the North is more heavily industrialized than other parts of the United States, it shows a larger increase in consumption than the other regions. Irrigation is the primary component of consumption in the other three regions. There have been smaller percentage increases in consumption in irrigation than in the industrial sector.

PROJECTED DEMANDS FOR WATER

The projections from 2000 to 2040 presented here are the result of Forest Service analyses conducted especially for this Assessment. Projections *are not* the Forest Service interpretation of a "most likely" scenario. The projections *are* a statement of demand levels in 2040 if recent trends in demand for water continue. Projections of withdrawals and consumption are intended to suggest future demands if water resource management continues as it has from 1960 to 1987. However, some demand pro-

Table 8.—Total freshwater withdrawals (million gallons per day) in the United States for 1960 to 1985, by water use and source, with projections of demand to 2040

							Projections				
Water use and source	**1960**	**1965**	**1970**	**1975**	**1980**	**1985**	**2000**	**2010**	**2020**	**2030**	**2040**
Thermoelectric steam cooling											
Groundwater	920	1100	1400	1400	1600	610	700	700	690	680	680
Surface water	73100	90500	118300	129600	146800	129800	156700	174500	192200	209900	227600
Total Thermoelectric	74000	91600	119800	131000	148400	130400	157400	175200	192900	210600	228300
Irrigation											
Groundwater	30400	41600	45250	57100	61200	56300	55600	58300	60900	62650	64200
Surface water	54000	74400	81700	85000	90400	85800	86600	92900	99100	104210	109100
Wastewater	560	500	370	370	280	450	290	260	200	200	200
Total Irrigation	84900	116500	127300	142500	151900	142500	142500	151500	160200	167100	173400
Municipal central supplies											
Groundwater	6300	8100	9500	10800	11700	14600	20100	24100	28200	31600	33700
Surface water	14200	15700	17900	18800	22300	21900	30500	34600	38500	41640	43500
Total Municipal	20500	23800	27400	29600	34000	36500	50600	58700	66700	72300	77100
Industrial self-supplies											
Groundwater	6000	6800	8000	9700	10300	6100	5600	6400	7340	8310	9340
Surface water	27200	29700	31200	28600	28700	20200	21700	23600	25420	27220	28960
Wastewater	70	140	150	170	190	150	300	400	420	470	500
Total Industrial	33300	36600	39300	38500	39200	26450	27600	30400	33200	36000	38800
Domestic self-supplies											
Groundwater	1840	2200	2500	2670	3260	3250	4300	4800	5250	5600	5800
Surface water	160	120	120	130	180	60	80	60	40	30	30
Total Domestic	2000	2320	2620	2800	3340	3320	4380	4860	5290	5630	5830
Livestock watering											
Groundwater	825	1000	1070	1250	1200	3020	1500	1600	1690	1750	1780
Surface water	675	740	800	900	970	1450	1180	1260	1330	1380	1410
Total Livestock	1500	1740	1870	2150	2170	4470	2680	2860	3020	3130	3190
Total groundwater withdrawal	46285	60800	67720	82920	89260	83880	87800	95900	104070	110590	115500
Total surface water withdrawal	169335	211160	250020	263030	289350	259210	296760	326920	356590	384380	410600
Total wastewater withdrawal	630	640	520	540	470	600	590	660	620	670	700
U.S. Total Withdrawals	216200	272400	318300	346600	379000	343700	385200	423600	461300	494800	526600

NOTE—The sum of totals by use and by water source differ because of independent rounding of intermediate sums.

Source: Data for 1960 through 1985 from U.S. Geological Survey Circulars, except for 1985 irrigation numbers. These are from the Soil Conservation Service, modified by additional non-agricultural irrigation use. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

jections lead to environmental, social, and economic implications at odds with the nation's goals. Consequently, these demand projections are a description of what planners call the "without" condition; the basis for evaluating the impacts of possible changes in water resource management to better achieve environmental, social, and economic goals for the future.

In the course of analyzing demand data, it became clear that simple linear extrapolation of data from 1960 to 1985 did not fit as well as semi-logarithmic or logarithmic curve forms. Linear trends usually had the 1985 datum well beneath the trend line and the 1980 datum on or slightly beneath the line. The Water Resources Council (1978) projected that the *rate of increase in demand* from most uses would decline drastically by the year 2000 as a consequence of the Clean Water Act. They believed that water conservation and internal recycling would combine to hold demands in the year 2000 at about 90% of the 1975 level. The 1980 data were close enough to the 1975 data that one could not be certain whether the rate of increase in demand had begun to decline or if the 1980 data were but a momentary pause in the rate of increase. The 1985 data provide conclusive evidence that demand was strongly affected by legislation and regulations of the 1970s—in fact, there was about a decade's lag between changing national policy and the effects of the policy change becoming apparent. Because structural changes in waste treatment and water conservation required planning, design, and securing of funding after regulations were written and before construction could begin, a 10-year lag between the law's passage and the first clear evidence of changes in water use is reasonable.

Semi-logarithmic and logarithmic curve forms provided a better fit to the historical data than linear trends. The curves imply that conservation and recycling will continue to occur at levels mandated by 1970s legislation. Additional increments of waste treatment and

Table 9.—Total freshwater consumption (million gallons per day) in the United States for 1960 to 1985, by geographic area and use, with projections of consumption to 2040

Water use	1960	1965	1970	1975	1980	1985	Projections 2000	2010	2020	2030	2040
North											
Domestic self-supplies	427	517	513	356	594	595	482	494	504	511	515
Industrial self-supplies	1045	1351	1187	1177	1247	1656	2790	3155	3523	3891	4262
Irrigation	233	398	460	613	1278	1187	1417	1481	1543	1592	1637
Livestock watering	603	628	614	689	623	650	643	680	711	733	746
Municipal central supplies	1329	1735	1881	1749	1615	1618	2335	2575	2783	2931	3016
Thermoelectric steam cooling	53	87	106	630	1294	2865	5457	6539	7379	8483	9829
Total North	3691	4717	4762	5215	6651	8571	13124	14924	16443	18142	20005
South											
Domestic self-supplies	519	798	721	661	842	843	732	750	766	777	783
Industrial self-supplies	1524	1581	2220	2075	2781	1702	2378	2690	3003	3317	3633
Irrigation	9143	14913	12646	17564	16356	14701	17550	18349	19116	19717	20278
Livestock watering	416	472	540	680	769	992	925	977	1022	1054	1073
Municipal central supplies	1139	1301	1612	2323	2172	2176	3140	3464	3742	3942	4056
Thermoelectric steam cooling	96	228	568	1061	1536	1089	1739	2083	2351	2703	3132
Total South	12837	19294	18307	24364	24455	21503	26464	28312	29999	31509	32954
Rocky Mountains											
Domestic self-supplies	120	136	161	188	293	293	211	216	221	224	226
Industrial self-supplies	157	248	378	601	625	376	503	569	635	701	768
Irrigation	24073	30491	34755	34999	36242	31689	37836	39558	41212	42508	43717
Livestock watering	315	439	476	498	430	524	533	563	589	607	618
Municipal central supplies	495	584	756	857	1303	1305	1883	2077	2244	2364	2432
Thermoelectric steam cooling	48	83	126	207	369	303	482	578	652	750	869
Total Rocky Mountains	25208	31981	36651	37350	39260	34494	41449	43561	45553	47154	48631
Pacific Coast											
Domestic self-supplies	151	117	261	244	253	253	249	255	261	264	267
Industrial self-supplies	249	181	306	332	364	409	1044	1180	1318	1456	1594
Irrigation	18576	20095	25608	26745	29243	26211	30695	32091	33433	34484	35465
Livestock watering	103	82	82	84	80	207	211	223	233	240	244
Municipal central supplies	508	1517	1675	1737	2006	2010	2901	3199	3457	3641	3746
Thermoelectric steam cooling	27	18	24	40	42	96	86	103	117	134	155
Total Pacific Coast	19614	22010	27957	29182	31987	29186	35185	37052	38817	40220	41472
U.S. Total Consumption	61350	78002	87677	96111	102353	93755	116222	123850	130812	137025	143062

Source: Data for 1960 through 1985 from U.S. Geological Survey Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

recycling beyond that mandated by existing legislation are not assumed to occur in the future. Comparisons of projections in 2040 between linear and the two curve forms showed that, on average, demands are 15% to 20% lower for the curve forms than the linear form. The analyses suggest that is a reasonable expected gain from conservation and recycling.

The 1987 release of BMDP Statistical Software (Dixon et al. 1985) for personal computers was used to analyze data and perform projections. Standard BMDP diagnostics were used to evaluate statistical fit and significance. Projection equations and goodness-of-fit statistics are listed in Appendix B. The data consisted of historical water withdrawal and consumption information from USGS reports and demographic information forming the basic assumptions for this Assessment (table 11).

Projections were made by water use category at the national level. The projections were then disaggregated to water resource regions and Forest Service Regions based on the shares each region had of the 1985 total withdrawals and consumption. Where historical data suggested that regional shares were changing, a continuation of the rate of change was factored into the disaggregation process. Results are displayed in tables 8–10 and in Appendix A.

THERMOELECTRIC STEAM COOLING

Thermoelectric power is electricity generated using either fossil-fuel (coal, oil, or natural gas), renewable (wood or geothermal), or nuclear energy. No matter what the energy source, the principal method of generating electricity is to convert water into steam and then use steam pressure to propel the generator's turbine. Spent steam recondenses into hot water which must then be dealt with in some way. In nuclear reactors, the steam generation and recondensation process is typically a closed-loop process where the recondensed water is recycled back to the boiler. Cooling water is used to assist the recondensation process.

Table 10.—Total freshwater withdrawals (million gallons per day) in the United States from 1960 to 1985, by geographic area and water source, with projections of demand to 2040

Region and water source	1960	1965	1970	1975	1980	1985	Projections 2000	2010	2020	2030	2040
North											
Groundwater	5625	7130	8750	8920	9930	9395	12060	13840	15670	17225	18365
Surface water	70735	92000	107355	106975	110050	97785	117110	130450	143600	156350	168450
Wastewater	80	125	130	155	190	105	250	310	325	375	415
Total North	76440	99255	116235	116050	120170	107285	129420	144600	159595	173950	187230
South											
Groundwater	15570	21820	19165	23650	24040	24520	25795	28280	30790	32830	34390
Surface water	34635	42765	57415	68265	83295	70460	82360	91450	100400	109050	117300
Wastewater	30	5	20	65	70	175	100	110	100	105	105
Total South	50235	64590	76600	91980	107405	95155	108255	119840	131290	141985	151795
Rocky Mountains											
Groundwater	12690	15920	18675	27920	31140	29190	27515	29220	30890	32125	33120
Surface water	36420	47420	52740	53380	59745	57520	61475	66320	71075	75100	78850
Wastewater	90	125	170	155	35	55	70	75	65	60	60
Total Rocky Mountains	49200	63465	71585	81454	90920	86765	89060	95615	102030	107285	112030
Pacific Coast											
Groundwater	13400	15930	21130	22430	24150	20790	22430	24560	26720	28410	29625
Surface water	27545	28975	32510	34410	36260	33450	35815	38700	41525	43880	46000
Wastewater	430	385	200	170	175	260	165	165	135	130	120
Total Pacific Coast	41375	45290	53840	57010	60585	54500	58410	63425	68380	72420	75745
Total groundwater	46285	60800	67720	82920	89260	83800	87800	95900	104070	110590	115500
Total surface water	169335	211160	250020	263030	289350	259210	296760	326920	356590	384380	410600
Total wastewater	630	640	520	540	470	600	590	660	620	670	700
U.S. Total Withdrawals	216200	272400	318300	346600	379000	343700	385200	423600	461300	494800	526600

NOTE—The sum of totals by region and by water source differ because of independent rounding of intermediate sums.

Source: Data for 1960 through 1985 from U.S. Geological Survey Circulars, except for 1985 irrigation numbers. These are from the Soil Conservation Service, modified by additional non-agricultural irrigation use. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table 11.—Data used to project withdrawals and consumption

Variable	1955	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Population[1]	165.9	180.7	194.3	205.1	216.0	227.8	239.3	274.9	294.3	312.1	325.5	333.4
Civilian labor force[2]	65.02	69.63	74.45	82.77	93.77	106.94	115.46	142.54	159.16	175.09	192.26	211.86
Disposable income[3]	5.71	6.06	7.03	8.13	8.94	9.72	10.62	13.92	16.73	19.66	23.53	28.79
Gross national product[4]	1,494.9	1,665.3	2,087.6	2,416.2	2,695.0	3,187.1	3,607.5	5,402.0	7,031.3	9,166.1	11,956.7	15,626.0
Billion kWh generated[5]	-----	557.	791.	1,143.	1,318.	1,612.	1,794.	2,311.	2,765.	3,285.	3,760.	4,265.
Imported oil price[6]	-----	7.67	7.35	7.05	23.49	39.54	24.21	32.08	51.10	69.85	88.86	107.88
Electricity price[7]	-----	16.10	14.20	12.50	15.00	17.50	18.00	19.00	19.50	20.00	20.50	21.00

Notes:
[1]*Million people*
[2]*Million people*
[3]*Thousand 1982 constant dollars per capita*
[4]*Billion 1982 constant dollars*
[5]*Generation by fossil-fueled powerplants. Historical information from Energy Information Administration, projections based upon the historical linkage between GNP and electricity demand described in Department of Energy documents.*
[6]*Constant 1982 dollars per barrel, F.O.B. domestic refinery.*
[7]*Constant 1984 dollars per million BTUs*

Source: Darr (1989)

In fossil-fuel and geothermal power plants, the process is not always a closed loop. "Once-through" cooling was the norm until the early 1970s. Legislation then recognized that putting excess heat back into the aquatic environment was as damaging as putting excess nutrients or allowing suspended sediments into the streams. Excess heat is called *thermal pollution*. Today, power generation facilities use a variety of ways to get rid of waste heat to the atmosphere before piping cooled water back to the stream. Some plants use cooling towers or cooling ponds, relying upon evaporation to cool the water. These are often effective enough that the cooled water can be recycled through the plant. As recycling increases, the amount of water consumed through evaporation will increase.

Electricity generation in the United States has set a new record every year since the early 1940s except for 1982. In 1985, a new record of 2.47 trillion kiloWatt-hours (kWh) was set. Electricity generation from petroleum, natural gas, and hydroelectric power has continued to decline, while generation using coal, nuclear, and renewable resources has continued to rise (fig. 12) (Energy Information Administration 1986a). These changes continue the shifts in mix of fossil fuels that have been underway since the 1950s. The share of electricity generated by natural gas and petroleum has fallen from 37% in 1972 to only 16% in 1985. Generation using petroleum products peaked at 365 billion kWh in 1978 and declined to 100 billion kWh in 1985. Generation using natural gas peaked at 376 billion kWh in 1973 and has dropped to 292 billion kWh since then. The share generated by coal and nuclear fuel has risen over the same period from 47% to 72%. Generation using coal has increased more than 100% since 1970 and stood at 1,401 billion kWh in 1985. Nuclear power generated 384 billion kWh in 1985, a 1000% increase since 1971. The share of electricity generated by hydropower is also on the decline. Although outputs have remained essentially constant, subject to vagaries of the weather, the share has fallen because total generation increased. Hydroelectric power peaked at 332 billion kWh in 1982 but dry weather in recent years resulted in a decline to 282 billion kWh in 1985.

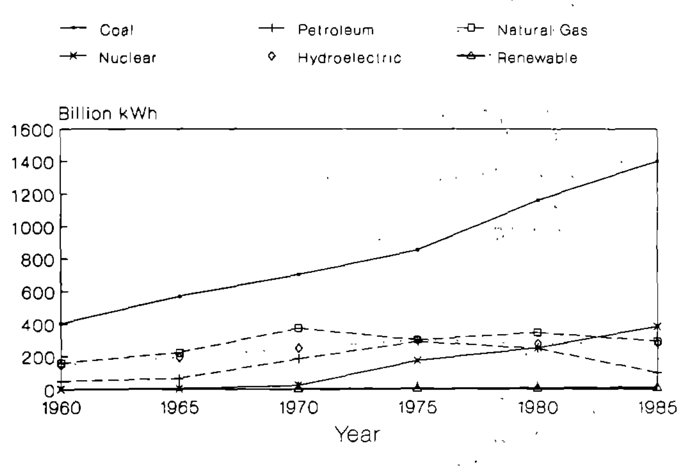


Figure 12.—Electricity net generation by fuel source, 1960-1985 (Energy Information Administration 1986a).

Choice of fuels varies across regions due to availability and transportation costs. The Northeast relies primarily upon nuclear and oil-fired units; the Pacific Coast on natural gas and hydropower. All other regions—especially those in the South and Southwest experiencing the largest rates of population and industrial growth—depend primarily on coal (Energy Information Administration 1986b).

A recent examination of electricity demand between 1953 and 1983 determined that a structural change did occur in 1973 following the Arab oil embargo (Energy Information Administration 1985). A more recent study (Cornett 1985) analyzed changes in demand in the early 1980s following the structural change. This analysis demonstrated that changes in demand were uneven across sectors of the economy and areas of the country. Less rapid growth in electricity use in the residential and commercial sectors can be explained mainly by conservation measures in response to higher electricity prices. Average growth of about 2.0% per year in residential electricity demand between 1980 and 1984 compares with average annual GNP growth of 2.7% for the same period. Average growth in commercial demand exceeded 4%. Industrial growth in electricity demand was down sharply during the last recession. Average annual growth in demand was only 0.8% per year—less than one-third the growth rate in GNP. If growth in residential and commercial demand for electricity remains moderate (as a result of slow growth in housing and commercial sectors) and growth in industrial output remains low, then the ratio of electricity-to-GNP growth rates could remain below 1.0—barely one-half the 1.8 average ratio for the 1953–1984 period. Cornett (1985) found that most of the change in residential and commercial demand for electricity in the early 1980s can be attributed to changes in real income. The change in industrial demand for electricity is attributed largely to changes in output associated with the recession. Cornett concluded that if recent sluggish output trends in housing construction, food, paper, chemicals, and primary metals sectors (the five biggest industrial users of electricity) continue, and if gains in energy efficiency continue because prices remain high, future electricity/GNP growth ratios will continue to remain below 1.0.

Cornett's outlook for electricity demand was amplified in the National Energy Policy Plan (Department of Energy 1985). Energy productivity (GNP per unit of energy consumed) rose 28% between 1974 and 1985—14% between 1981 and 1985, the greatest improvement in efficiency since World War II. This progress is continuing for all types of energy including electricity. Energy conservation has made a bigger contribution to reducing the need for new or imported energy resources than any change in fuels has accomplished (e.g. substituting coal for petroleum). The plan proclaimed coal as the fuel for America's future. It has become the main fuel for electric utilities. Modern coal-fired powerplants are cleaner than most older oil-fired plants. New technologies to burn coal are being developed that promise even higher efficiencies and environmental performance. The increased demand for coal will lead to more mining which has implications for mine-related water impacts.

Nuclear energy is now the second-largest source of electricity and provides 15% of the nation's needs. This is expected to rise to 20% by the turn of the century. Renewable energy resources (now primarily wood and water) contribute about 9% of the country's domestic energy production. This could rise to nearly 13% by the end of the century and to 15% by 2010 as more economical renewable energy technologies (e.g. wood, geothermal, solar, or wind) develop.

Future trends in energy consumption, particularly electricity consumption, suggest that efficiency increases will continue. The National Energy Policy Plan projects that it could take 20 to 30 years to gain full advantage of all the opportunities for efficiency that have been recognized in the industrial sector. The residential sector has shown a 40% drop in energy use per household since 1973 due largely to improved insulation, improved appliance efficiency, and changes in household behavior. Further, the average efficiency increase in energy-using capital goods will increase over time by an additional 20% to 50% through normal turnover of stock and implementation of more efficient technologies.

Given the assumptions of energy conservation outlined above, the nation will need between 100 and 300 gigawatts of new electrical generation capacity between now and the year 2000; over and above the 70 gigawatts under construction in late 1985. This new capacity will be needed to replace obsolete units as well as satisfy growth in electricity demand. The nation currently has some excess electrical generation capacity. Utilities are trying to stretch their capacity by improving operation and maintenance. They hope to boost utilization factors of generating units by 10% to 25%. More intensive use of existing capital will help postpone new construction but does not significantly reduce cooling water needs.

Another way of meeting power demands is to import energy. Power imports from Canada (principally hydropower) have grown six-fold since 1970. They are expected to double from the current 40 billion kWh level (2% of domestic demand) to 80 billion kWh by the year 2000 (3% of domestic demand). Between excess capacity and improving utilization, conservation, interconnection of power distribution networks, and imports from Canada, public utilities are attempting to stave off the need for construction of new powerplants.[2] However, by the turn of the century, significant expansions in construction programs of many utilities will inevitably occur to meet rising demand.

Current projections by the Department of Energy show demand for electricity growing in rough proportion to growth in the nation's economy for the foreseeable future. The question pertinent to this Assessment is the nature of the relationship because cooling water withdrawals are made in direct proportion to the number of kWh generated by fossil-fuel, nuclear, and wood-burning powerplants. All conclusions by the Department of Energy (1985) suggest that the historic tie between rate of growth in GNP and electricity demand has undergone a major structural change since the mid-1970s and that the ratio of growth in electricity generated to growth in GNP is likely to stay below 1.0 well into the next century. Efficiency gains reported and expected mean that the nation will use less electricity to produce increments of GNP in the future than in 1950s and 1960s. Consequently, this Assessment adopts the 0.8 ratio determined by the Department of Energy for the early 1980s and projects kWh as a linear function of the growth in GNP.

Water use and trends.—Thermoelectric powerplants furnish practically all of their own water; less than 1% is obtained from public supplies. In 1985, total water withdrawals for thermoelectric steam cooling totaled 187 bgd—a decrease of 11% from 1980. This total includes 130.4 bgd of freshwater and 56 bgd of saline water (saline water withdrawals and consumption are not studied in this Assessment). The 1985 freshwater withdrawal level is 12% less than the 1980 level and the same as withdrawals in 1975 even though the kWh generated have increased 36% since then (figs. 13–16; tables A.1, A.7, and A.13; figs. A.3 and A.4).

About 99% of withdrawals are used for condenser and reactor cooling of generators. About 4% of freshwater withdrawn is consumed, up from 2% in 1980, 1% in 1975 and 0.5% in 1970.

Thermoelectric steam cooling is the second largest withdrawal use next to irrigation. It has been the fastest growing use in recent years. Assumptions made about the continued increase in demand for electricity lead to projections of withdrawals that make it the largest use of water by 2040. Most of the increase in water use comes after 2000 when a large number of new power plants begin generation.

One of the largest withdrawal uses—thermoelectric steam cooling—is one of the smallest consumptive uses. Consumption has been rising rapidly, but from an extremely small base. Consumption is projected to double by 2010 and triple by 2040. However, even by 2040, consumption is still projected to be only 6% of withdrawals.

Potential for changes in the projections.—Because electrical demands are tied so closely to GNP increases, and because GNP growth rates show long-term increases, it would take a major economic disturbance to significantly alter these long-run withdrawal and consumption projections. The Arab oil embargo of the early 1970s was just such a disturbance and resulted in a structural change in the electricity/GNP long-term trend. Other potential events that could significantly alter withdrawals and consumption include additional major water quality legislation directed at thermal pollution, which would boost consumption and cut withdrawals, and the advent of practical uses for recently invented superconductor materials, which would reduce withdrawals.

IRRIGATION

Irrigation is the act of applying water to land to promote vegetation growth or obtain other benefits. In arid and semi-arid parts of the Rocky Mountains and Pacific Coast, irrigation is needed to raise most non-native

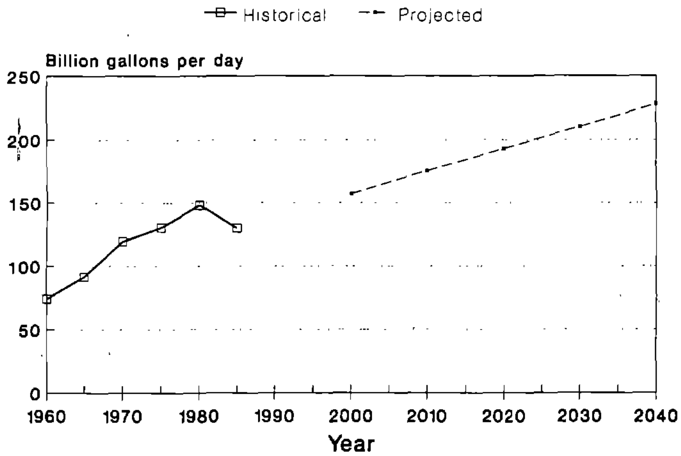


Figure 13.—Thermoelectric stream cooling, total freshwater withdrawals.

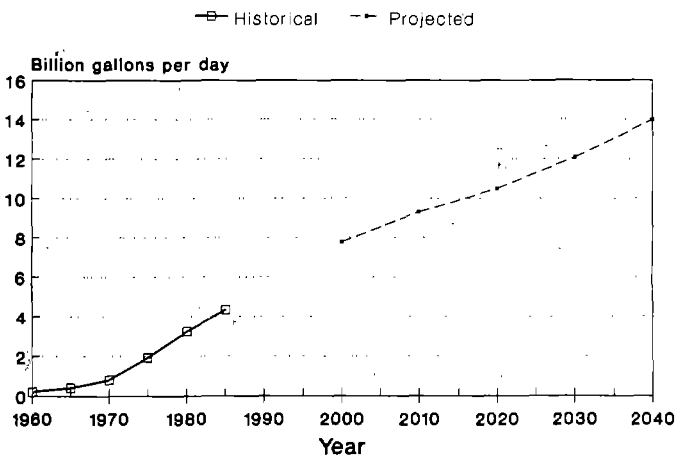


Figure 14.—Thermoelectric steam cooling, total freshwater consumption.

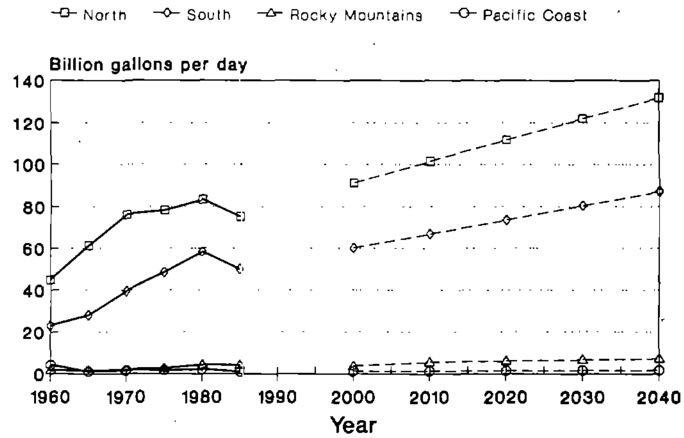


Figure 15.—Thermoelectric steam cooling, freshwater withdrawals by region.

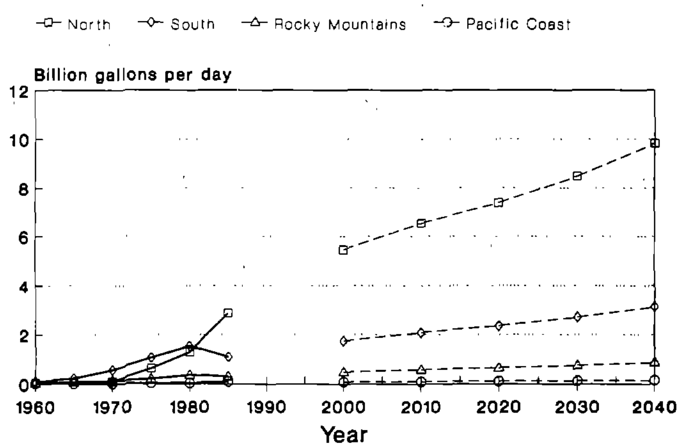


Figure 16.—Thermoelectric steam cooling, freshwater consumption by region.

vegetation. Agricultural, horticultural, and viticultural activities depend on regular applications of water at frequent intervals. In many Western areas, home, business, roadside, and recreation settings, turf and landscape plantings require irrigation too. Irrigation also promotes beautification in residential and business settings and helps keep buildings cooler.

Irrigation is often essential to recreation activities such as managing turf on golf courses and making snow for downhill skiing. In rural areas, irrigation of roadside plantings and property perimeters can assist in wildfire control by establishing a buffer of less-combustible vegetation. In the more humid North and South, irrigation also provides an increase in the number of plantings per year, yield per crop, and reduces the risk of losses during drought periods. High-valued crops such as fruits and vegetables are irrigated to maintain quality standards and some canners and processors will not buy non-irrigated produce. Irrigation is also used to reduce nursery and fruit losses to late spring and early fall frosts. Estimates of withdrawals and consumption of water for irrigation purposes vary greatly because of the many factors involved.

Most irrigation involves crops. If acres in crop production and water application rates can be determined, then some reliable estimates of withdrawals for irrigation can be made. Additional information about evapotranspiration must be known to reliably estimate consumption. This data is scarce. Different sources of irrigation information gather data in different ways, thus complicating the process of estimating acreage irrigated. For example, the Census of Agriculture conducted by the Department of Commerce reports land as irrigated only if irrigated in the year of the census. The Natural Resources Inventory conducted by the SCS every 5 years records land as irrigated if irrigated in the year of the survey or in two or more of the preceding four years. Irrigation trade associations publish statistics based upon other criteria. An extensive analysis of irrigation water requirements for croplands was conducted by Flickinger (1987) for the Appraisal.

Day and Horner (1987) present data on the history of irrigated agriculture. In 1889, 3.6 million acres (0.6%) of the 623 million acres of farmland in the U.S. were irrigated. All irrigated land was located in the arid and semi-arid West, principally California (1 million acres) and Colorado (0.9 million acres). In 1889, 54,000 farms were irrigating an average of 67 acres and each producing $11.50 per acre in crop value. Today, about 45 million acres of farmland are irrigated, an average of 210 acres per farm and producing about $530 per acre. Irrigated land area has grown continuously, except for several years during the Great Depression and during 1978–1984. The growth rate declined since the mid-1950s except for a brief increase from 1969 to 1978. The proportion of irrigated to non-irrigated farmland reached a record high of 5% in 1978 with approximately 50 million acres irrigated. Since then, irrigated acreage of farmland declined by about 11%. During the recession of 1982–1984, irrigated acreage declined 4.3 million acres.

A major factor behind the rapid expansion of western irrigation during 1880 to 1900 was the need for winter feed to sustain the growing cattle industry. Simple low-head dams and stream diversion structures were constructed to flood meadows and irrigate hay and other feed crops. Without winter feed, it is likely that millions of acres of rangeland would have been underused and the feed grain-livestock economy of the Great Plains might never have developed. Today, 60% of irrigated farmland is used to produce forage, roughage, and feed grain crops (corn, barley, oats, sorghum, hay, pasture, and silage) for livestock.

Wheat and rice production—food grains for humans—slowly gained importance as a component of irrigated farmland, rising from a 10% share in 1889 to a 17% share by 1982. As agricultural technology and transportation systems improved and as consumer demand for a wider variety of crops increased, irrigated land increasingly was devoted to what were initially known as "specialty crops". Today, this list includes cotton, sugarcane, peanuts, tobacco, soybeans, vegetables, and orchards. Twenty percent of farmland irrigated is used to grow these crops (Day and Horner 1987).

Day and Horner (1987) document how irrigation use differs among regions. The Pacific Coast and Rocky Mountain regions account for 85% of irrigated farmland in the U.S. About 12% of southern farmland is irrigated, principally the river delta areas in Arkansas, Louisiana, and Mississippi, where rice, cotton, and sugarcane are grown extensively, and in Florida where citrus and vegetables are widely grown. The rapid growth of irrigated farmland in the South is largely due to expansion in Georgia, now the eighth largest state for irrigated corn production (Bajwa et al. 1987). Irrigation is much less prevalent in the North, but supplemental irrigation is expanding rapidly in the Lake States and Corn Belt (Iowa, Missouri, Illinois, Indiana, and Ohio) as farmers learn how to augment rainfall to improve planting schedules and reduce weather risks. About 4% of the farmland in the North is irrigated.

The federal government played a large role in the development of irrigation in the western states. The Reclamation Act of 1902 established the Bureau of Reclamation in the Department of the Interior to facilitate settlement of the western States by developing irrigation water supplies. Since then, the Bureau has carried out an extensive program of dam and water distribution system construction and operation. In 1982, 10.9 million acres of land were irrigated with water from Bureau of Reclamation projects. This acreage produced about $7.3 billion in gross revenues. These figures represented about 20% of all irrigated farmland in the contiguous U.S. and about 30% of the value of all irrigated farmland outputs (Day and Horner 1987).

U.S. farmers use two basic types of irrigation water application systems—gravity and sprinkler. Gravity systems apply water using gated pipes, ditches with siphon tubes, overland flooding, and underground porous pipes (subirrigation). Gravity systems were used on 27.5 million acres of farmland in 1984 (Day and Horner 1987). Bajwa et al. (1987) reported that the farmland acreage irrigated by gravity systems dropped 12% between 1979 and 1984.

Sprinkler systems are the more modern of the two application systems and also more expensive. Sprinklers include different types of equipment delivering water under pressure. Hardware includes center pivot systems, side-roll units moved either mechanically or by hand, permanent sprinklers, moveable and permanently mounted guns, and drip systems. Sprinkler systems were used on 18.3 million acres of farmland in 1984 (Day and Horner 1987). Bajwa et al. (1987) reported that farmland acreage irrigated with sprinklers dropped 8% between 1979 and 1984.

A relatively new pressurized method currently included in the sprinkler figures is drip or trickle irrigation. This technique is very popular in orchards. Its use expanded by 161% between 1979 and 1984, but the total acreage irrigated with this method in 1984 was still less than 1 million acres. The major virtue of drip or trickle systems is less water use than conventional sprinkler systems. Major disadvantages of drip systems are they cannot be used to flush salts from saline soils and they are expensive.

Water use and trends.—Irrigation water withdrawals in 1985 totaled 142.5 bgd, a decline of 6% since 1980 (fig. 17). The 1985 level of withdrawals is equivalent to the 1975 level. Irrigation withdrawals in 1985 were larger than for any category of water use. Irrigation is by far the largest consumptive user. Consumption totaled 73.8 bgd in 1985, or 78% of the total consumption by all uses (fig. 18). It is this aspect of irrigation water use that has the most significance for current and projected future water use and development. Regional breakdowns of irrigation water withdrawals and consumption are shown in figures 19 and 20 and tables A.2, A.8, and A.14; and by source in figures A.5–A.7.

Irrigation water comes from wells, on-site surface sources, and surface sources provided by off-site suppliers such as irrigation districts and ditch companies. The principal source is from wells—56.3 bgd, or 68% of total groundwater withdrawals. Surface withdrawals amounted to 85.8 bgd in 1985, which is 33% of total national withdrawals. Bajwa et al. (1987) report that 3 of every 4 gallons from surface sources are provided by off-site suppliers. As discussed in Chapter 2, irrigators in the Great Plains rely heavily on groundwater withdrawals while irrigators in other parts of the Rocky Mountain and Pacific Coast regions rely heavily on off-farm suppliers.

Because both wells and on-farm surface water sources must be pumped to deliver water to crops, energy expenses of irrigating farmland can be quite high. Total energy expenses for irrigation pumping reached $1 billion in 1984. Average expenditures per acre grew by 60% from $20 per acre in 1979 to $32 per acre in 1984. This growth in energy costs occurred during the same period that farmland acreage irrigated fell by 11%. Viewed in this context, the rise in energy costs is even more dramatic. Five sources of energy are used to pump irrigation water—electricity, natural gas, liquid propane (LP) gas, diesel oil, and gasoline. Electricity dominates at 58%, natural gas is 19%, and diesel oil 17% of the irrigation pumping energy market. Since 1979, electricity usage grew in importance, natural gas declined, and diesel oil held steady (Bajwa et al. 1987).

Flickinger (1987) reported that water withdrawals by farmers for irrigating crops in 1982 was 129.6 bgd—about 87% of total irrigation withdrawals for that year. The fundamental difference between Flickinger and USGS estimates is that Flickinger carefully estimated withdrawals and consumption *only* for agricultural uses. USGS estimates include withdrawals for non-agricultural uses. In some water resource regions, Flickinger's estimates were larger than the 1982 estimate interpolated from USGS numbers. This Assessment concurs with Flickinger's estimates for agriculture and uses them as a base. In water resource regions where USGS estimates are larger than Flickinger's, USGS numbers are used to account for non-agricultural irrigation. The pattern of water resource regions where USGS estimates were higher fit the expectation of regions having significant non-agricultural irrigation. Thus, irrigation withdrawals and consumption numbers in this Assessment are somewhat larger than the irrigation estimates for 1985 by Solley et al. (1988).

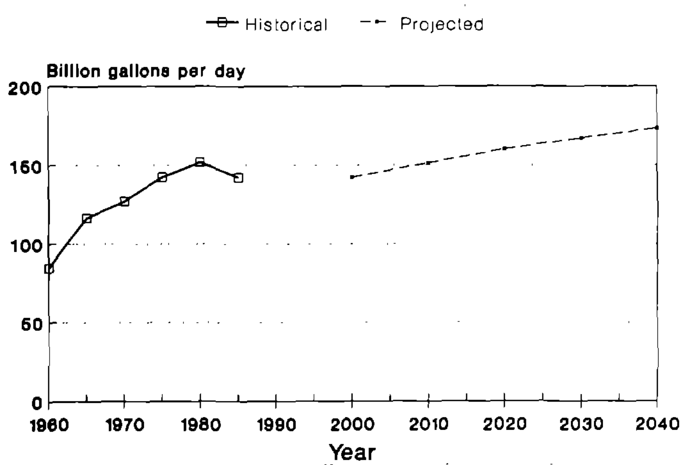


Figure 17.—Irrigation, total freshwater withdrawals.

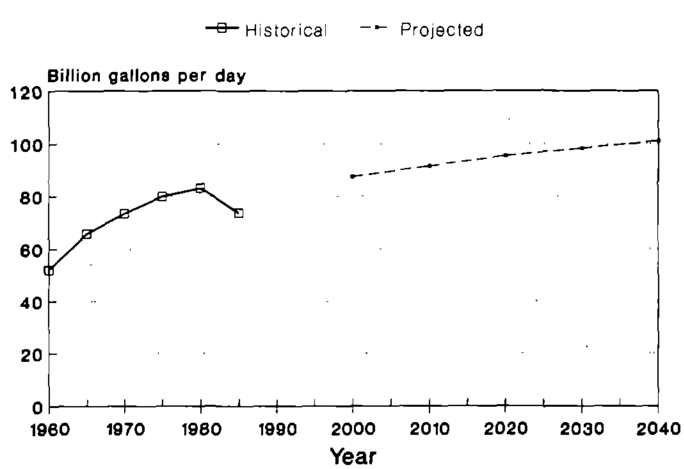


Figure 18.—Irrigation, total freshwater consumption.

Bajwa et al. (1987) contains detailed information on the farmland irrigation situation in each state including methods, sources, and expenses of irrigation and comparisons of the average value of farm capital for farms using irrigation compared to dryland production practices.

Potential for changes in the projections.—Irrigation water usage is projected to grow at a much slower rate over the next 50 years than over the previous 25 years. From 1960 to 1985, the average annual growth increase was 2.1%. From 2000 to 2040, the projected growth rate is 0.5%. A major reason is the continuing increase in pumping costs. Energy cost increases and aquifer declines increase pumping costs. Increased pumping costs reduce net return per acre, thus narrowing the advantage enjoyed by irrigated crop production over dryland crop production. The point has been reached in parts of the Southern Great Plains where net returns from irrigated crop production are lower than for dryland crop production. As soon as irrigation equipment is depreciated and paid for, many farmers stop irrigating. If crop prices rise, additional income may restore the cost advantage of using irrigation.

Bureau of Reclamation water pricing policies have come under scrutiny recently by interests seeking to reduce crop production subsidies. Irrigators are charged for water obtained from Bureau projects, but prices are user-favorable. If prices increase, then irrigation water use is expected to decline below projected levels. Also, a shift from irrigating low-valued crops such as alfalfa, hay, and pasturage would likely occur.

Technological advances in irrigation are expected to continue because of expected cost increases in pumping water. Chief among new technologies to be implemented soon are drip and trickle irrigation systems. These enable the farmer to control water applications much more precisely and have much lower losses to evaporation and excess runoff. It has been shown that evaporation loss from sprinklers is an exponential function of wind velocity and that in the southern plains, an average of 17% of the water passing through a standard sprinkler nozzle evaporates before reaching the target (Clark and Finley 1975). Other management practices could be employed to reduce energy and related irrigation costs (Gilley 1983). To the extent that such practices are adopted, projected withdrawal and consumption projections could reflect even less than a 0.5% growth per year, perhaps even an absolute reduction. The recent downturn in use (figs. 17–20) may be the beginning of a downward trend, but the 1990 water use estimates are needed for confirmation.

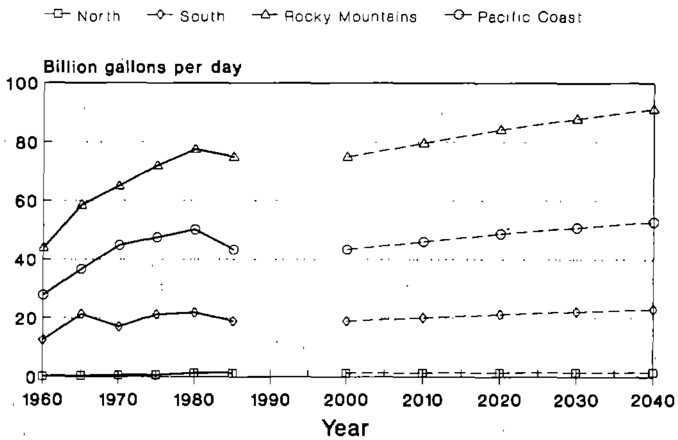


Figure 19.—Irrigation, freshwater withdrawals by region.

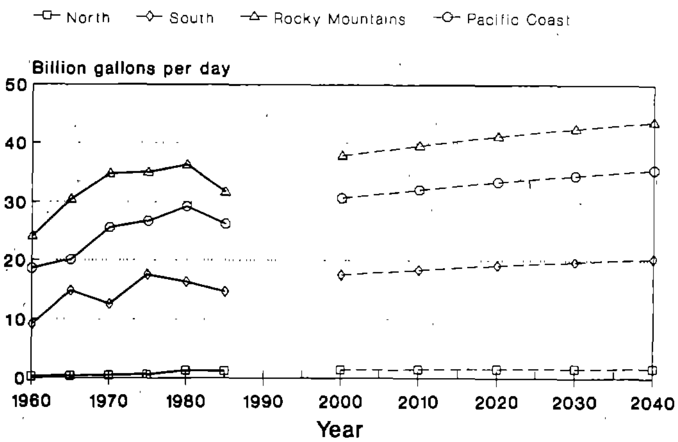


Figure 20.—Irrigation, freshwater consumption by region.

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

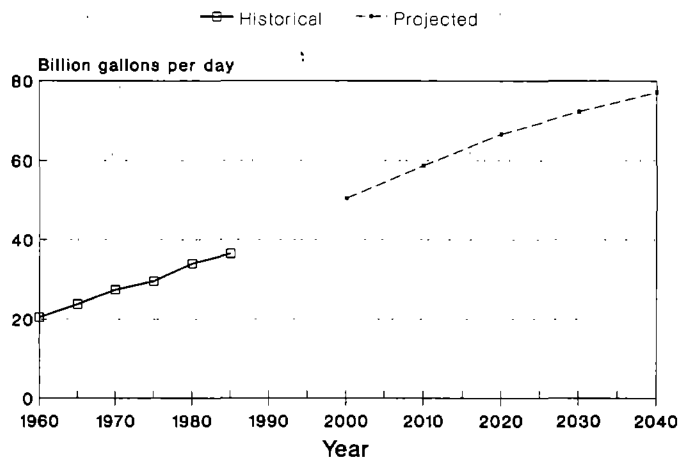


Figure 21.—Municipal supplies, total freshwater withdrawals.

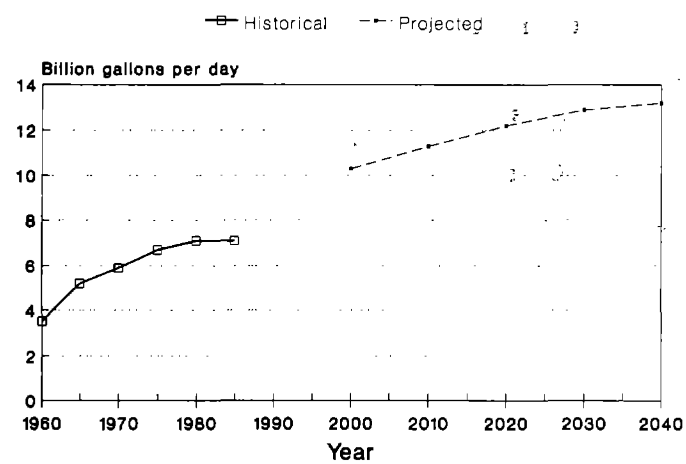


Figure 22.—Municipal supplies, total freshwater consumption.

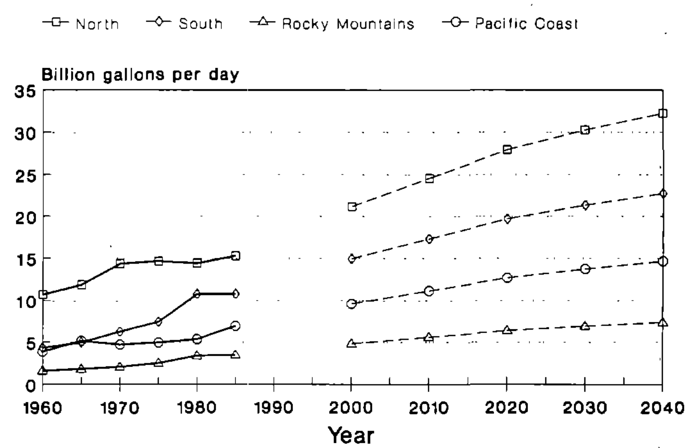


Figure 23.—Municipal supplies, freshwater withdrawals by region.

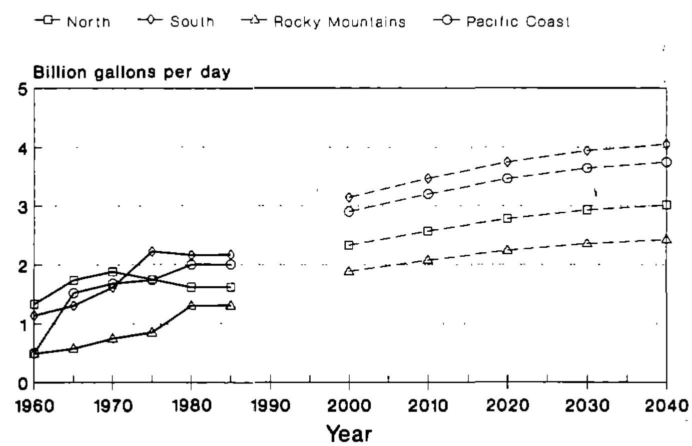


Figure 24.—Municipal supplies, freshwater consumption by region.

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

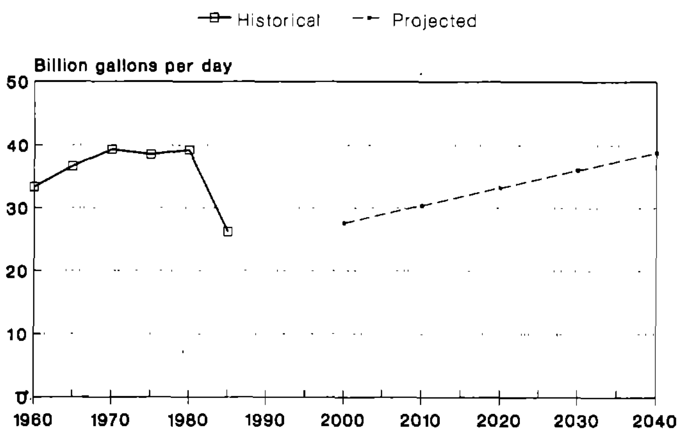


Figure 25.—Industrial self-supplied water, total freshwater withdrawals.

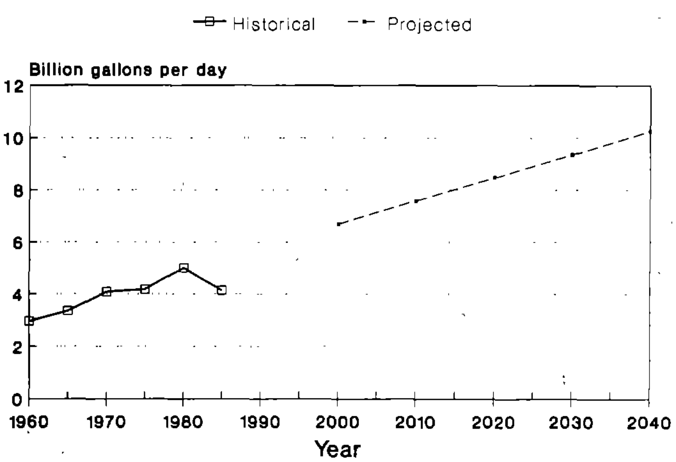


Figure 26.—Industrial self-supplied water, total freshwater consumption.

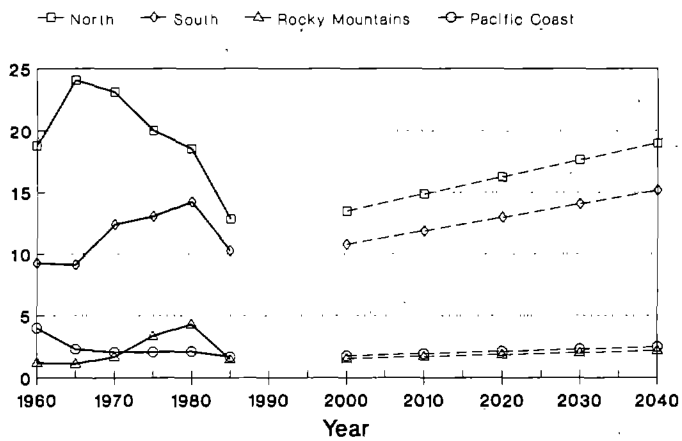


Figure 27.—Industrial self-supplied water, freshwater withdrawals by region.

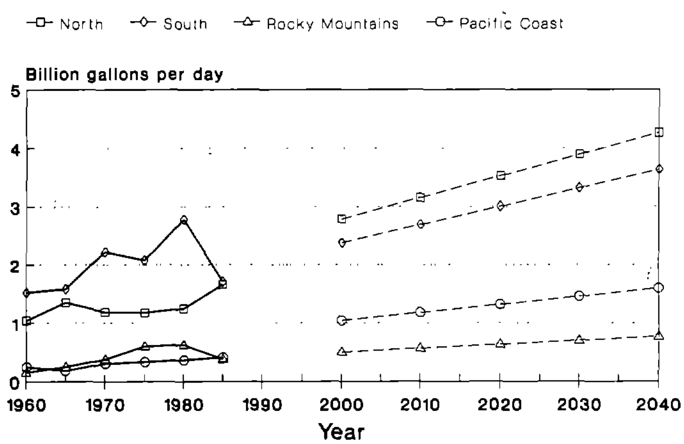


Figure 28.—Industrial self-supplied water, freshwater consumption by region.

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.

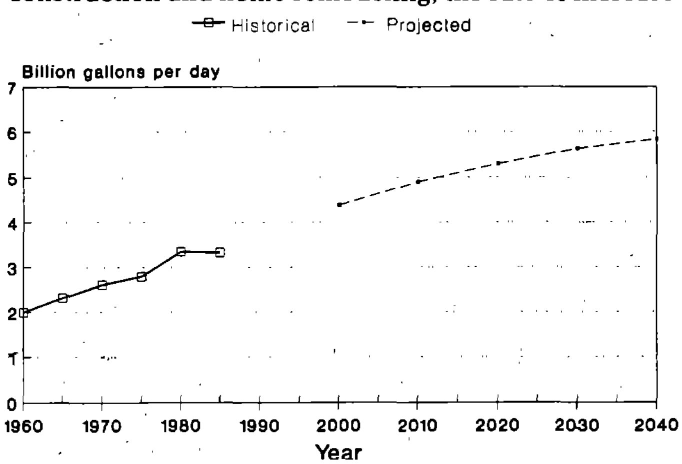


Figure 29.—Domestic self-supplied water, total freshwater withdrawals.

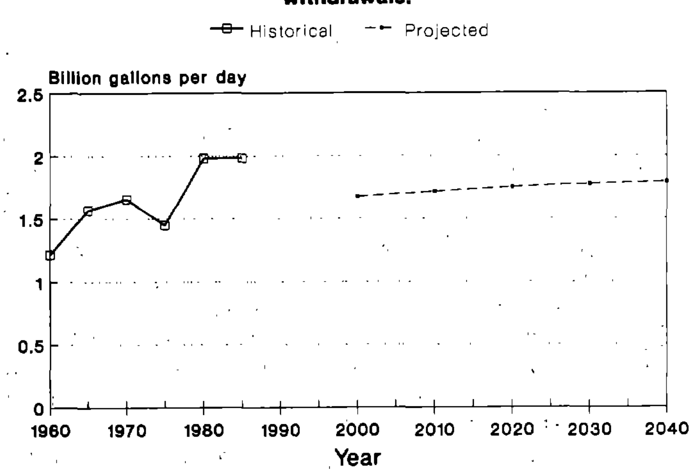


Figure 30.—Domestic self-supplied water, total freshwater consumption.

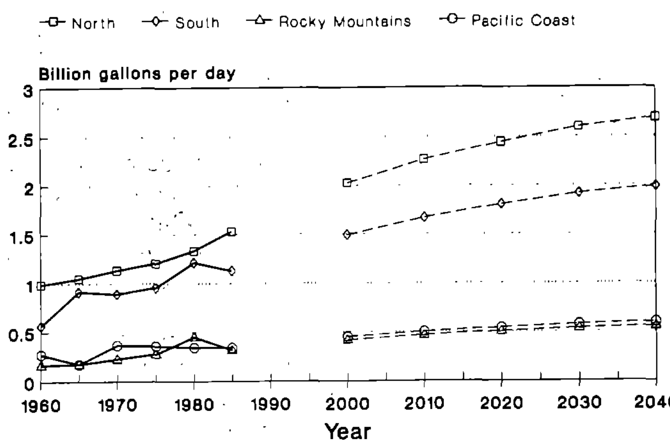


Figure 31.—Domestic self-supplied water, freshwater withdrawals by region.

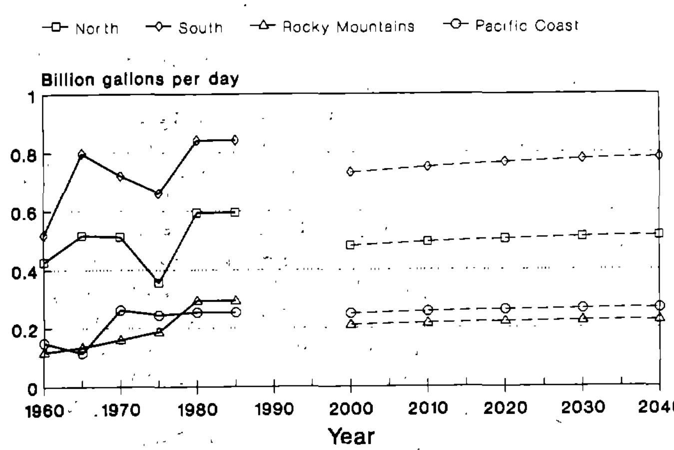


Figure 32.—Domestic self-supplied water, freshwater consumption by region.

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

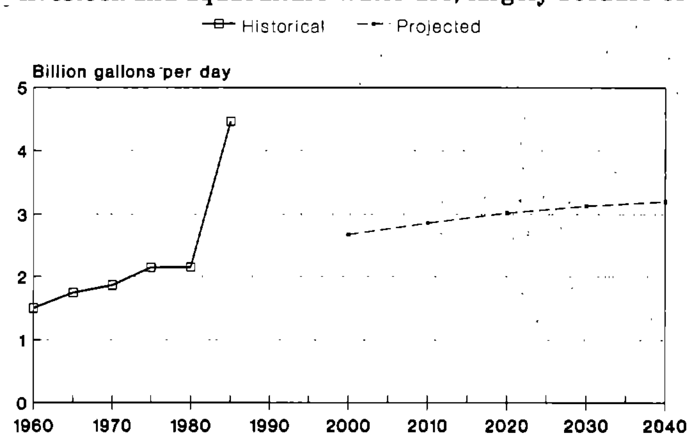


Figure 33.—Livestock watering, total freshwater withdrawals.

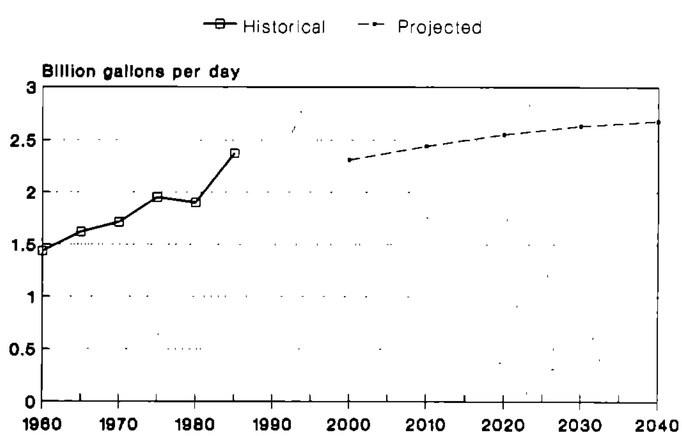


Figure 34.—Livestock watering, total freshwater consumption.

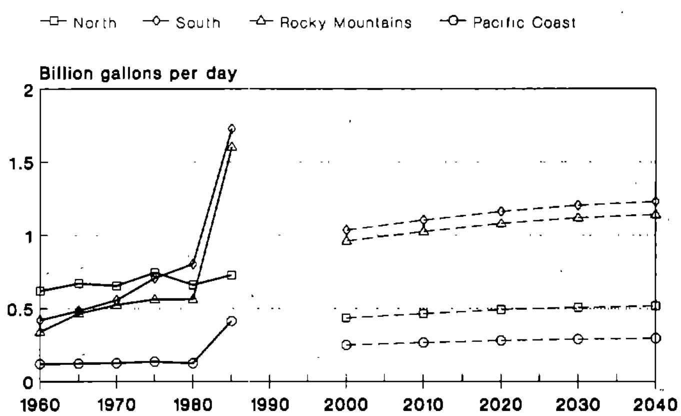


Figure 35.—Livestock watering, freshwater withdrawals by region.

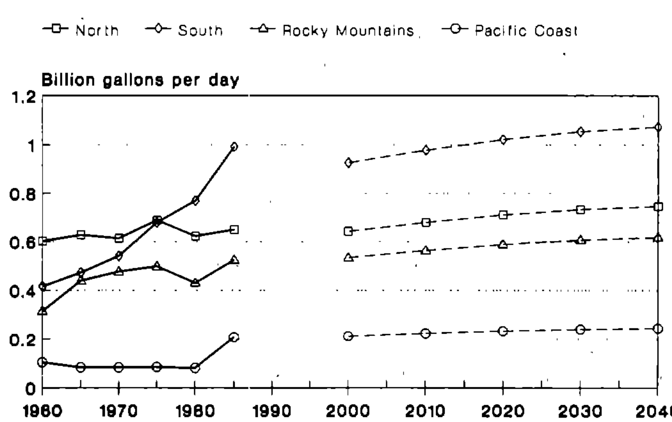


Figure 36.—Livestock watering, freshwater consumption by region.

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.

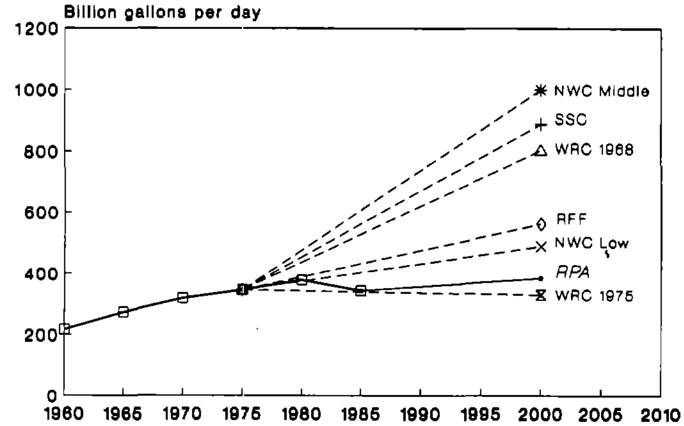


Figure 37.—Freshwater withdrawals, 1960-1985, with projections from other studies to the year 2000.

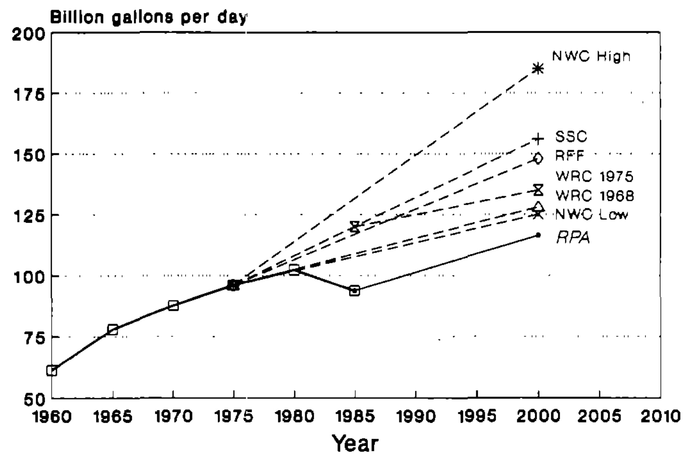


Figure 38.—Freshwater consumption, 1960-1085, with projections from other studies to the year 2000.

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.*

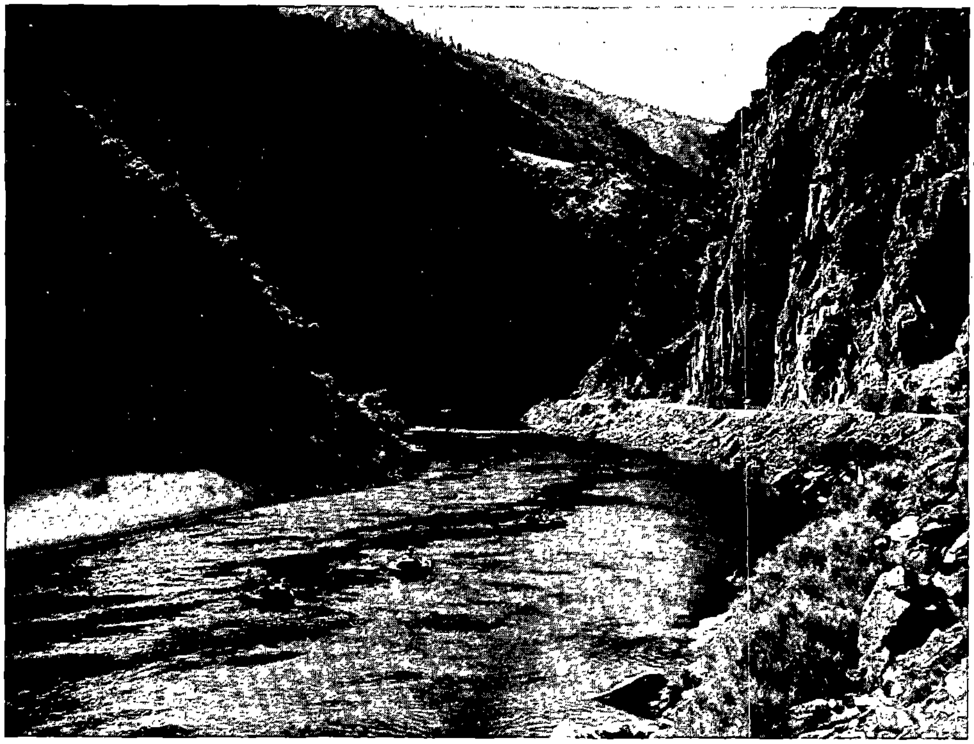
Source: After U.S. Forest Service (1981, table 7.10)

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.

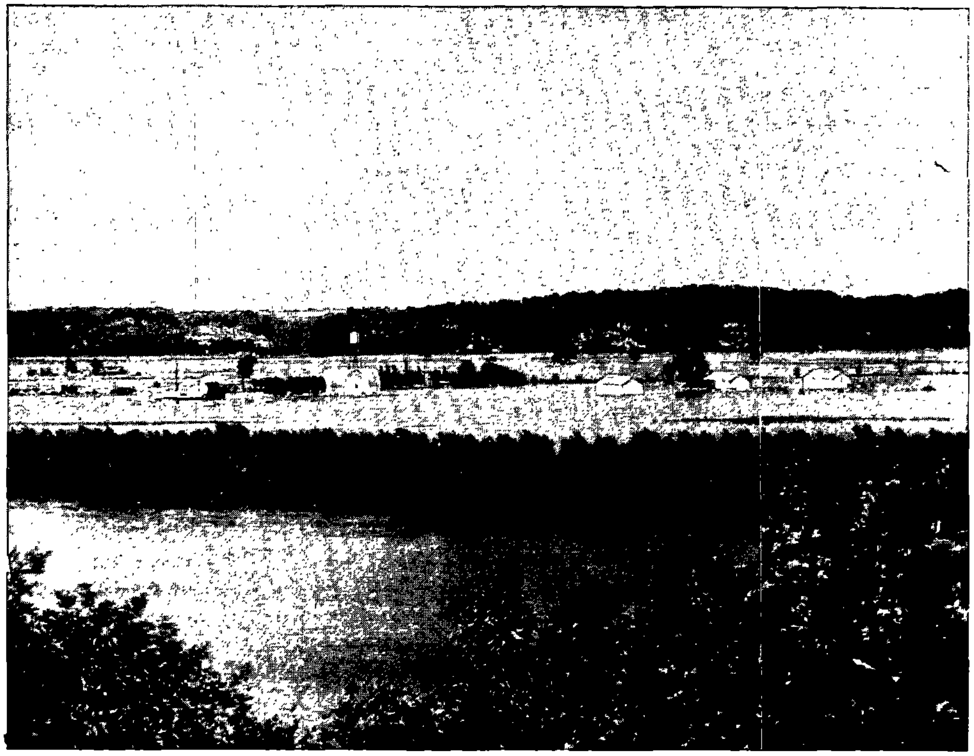
Despite increasing trends in annual flood damages,[4] there is no evidence that storms are increasing in magnitude or frequency. Increases in damages result from intensified development in flood-prone or flood-susceptible areas (Water Resources Council 1978) and from concentrating higher-valued agricultural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

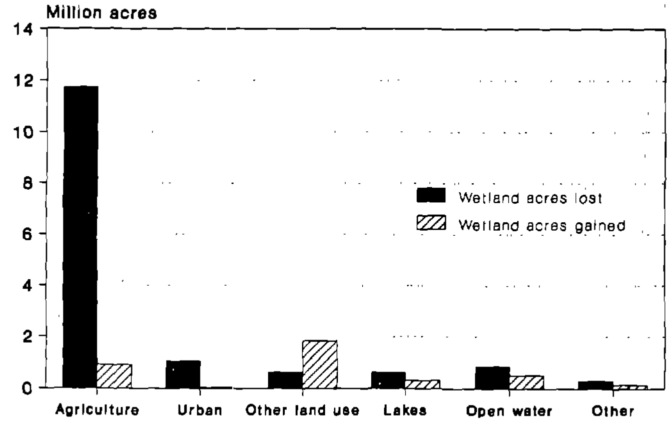


Figure 39.—Trends in the conversion of freshwater and saltwater wetlands, mid-1950s to mid-1970s (OTA 1984).

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.

CHAPTER 5: COMPARISON OF PROJECTED DEMAND AND SUPPLY SITUATIONS

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]		Average stream outflow[8]	Instream flow requirement[9]	Surplus or deficit[10]
						Agriculture	Non-agriculture			
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

		Surpluses or deficits[1]					
		Normal Expected Supplies; Projected Demands			Supplies Expected If Global Climate Changes; Projected Demands (see note)		
Water resource region	Rainfall Condition	-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 offstream 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 11 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.

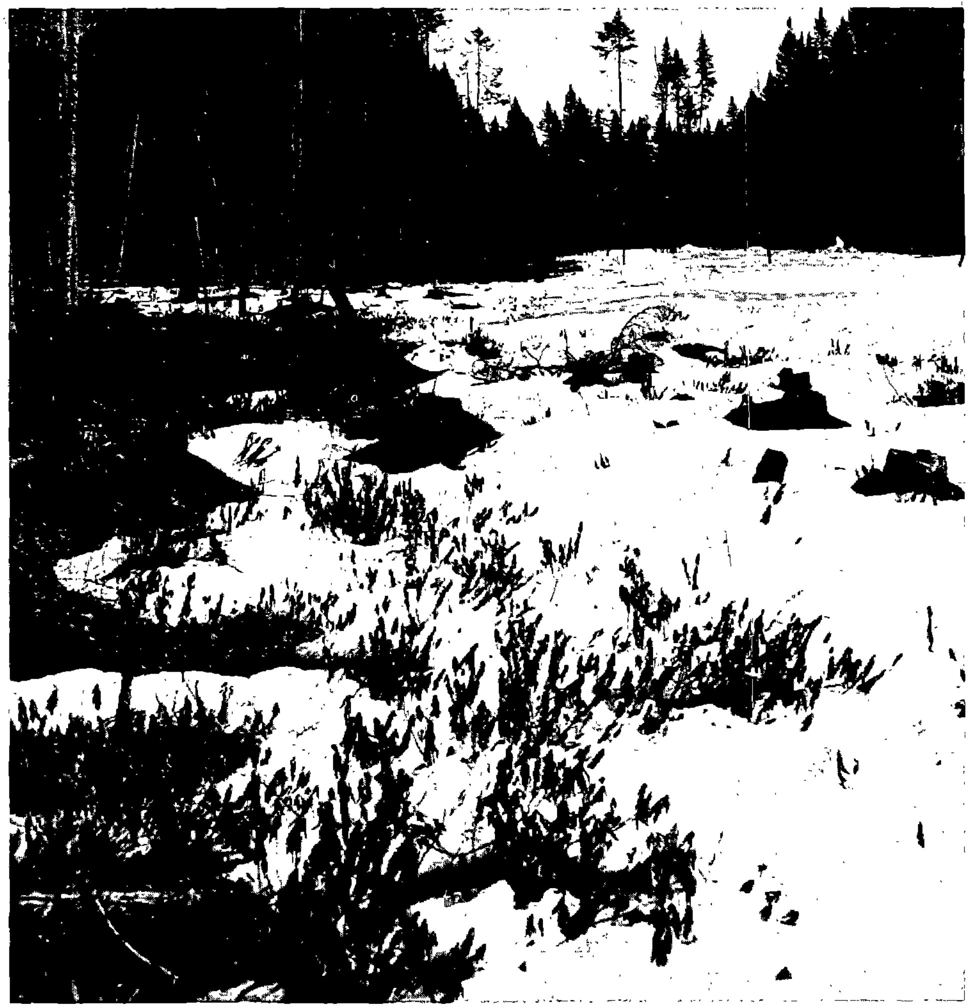
Projections indicate that the situation will worsen in proportion to increases in demands for offstream surface water use. In regions where water shortages are projected, many rivers originate on public lands, thus public land managers have opportunities to pursue management practices that augment instream 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. Midcycle 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. Decisionmakers 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.

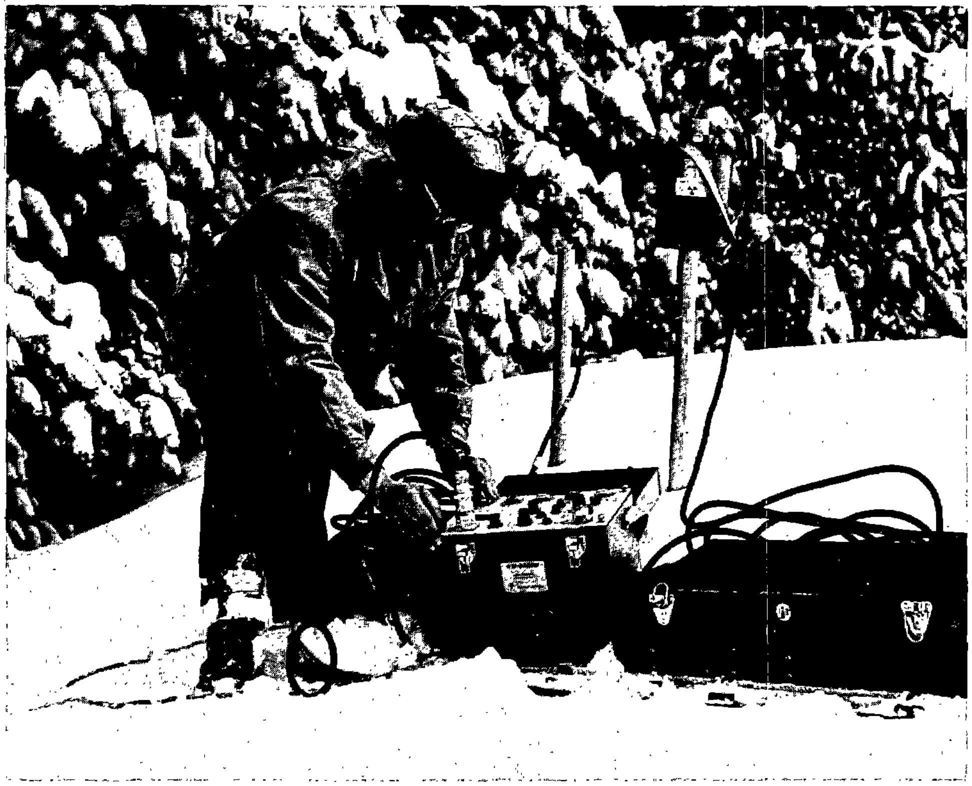
Some level of clear cutting will be necessary to provide patchy cover necessary to trap blowing snow. Thinning will also be needed to regulate the amount of shade and timing of snowmelt. At altitudes where cutting is needed, soils tend to be more fragile and unstable than at lower elevations. Consequently, 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 offsite. 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 adsorb readily onto soil colloids and does this affect chemical activity? If adsorbed, what are its effects on aquatic ecosystems washed into a stream? Many of these questions are asked about agricultural chemicals. Given the similarities between chemicals applied to forests, rangeland, and cropland, a comprehensive examination of nutrients and other chemicals and their effects on nonpoint-source pollution in various ecosystems should be performed.

Increasing complexity of problems such as acid deposition and chemical buildups in watersheds point to the value of long-term records. Thus, the value of research locations such as Hubbard Brook Experimental Forest, New Hampshire; Fraser Experimental Forest, Colorado; Coweeta Hydrologic Laboratory, North Carolina (50 years old); Crossett Experimental Forest, Arkansas (60 years old); and the Wind River Experimental Forest, Wyoming (70 years old) is better understood today. Today, the Forest Service maintains 84 experimental forests across the nation. However, the agency had a total of 113 experimental forests at one time or another this century; 16 were lost in the 1960s. If long-term records such as those available on the 84 experimental forests are allowed to lapse, the capability to answer difficult and complex forest related questions nay also be lost.

The final cumulative effect needing research is defining instream flows necessary to support various instream water uses in different situations. Each water withdrawal affects water volume in a stream and the suitability of that stream for fish and wildlife habitat and recreation. Considered alone, most proposed withdrawals or diversions are not large enough to cause significant impacts on suitability of instream flows. However, when all withdrawals and diversions are considered, the effects of one additional permit to withdraw or divert water may be substantial.

Land managers and owners are frequently asked to make judgments about levels of instream flows needed to avoid detrimental effects on instream water uses. Little information is available to guide these decisions. Research to develop procedures for quantifying and evaluating cumulative effects of withdrawals and diversions will be helpful in the long-term. Developing initial estimates of suitable flows needed under certain conditions could be most helpful in the short-term.

MAINTAINING LAND PRODUCTIVITY

Maintaining land productivity was mandated by the National Forest Management Act of 1976. The Forest Service's research mission could focus on soil productivity to help fulfill agency obligations under that act.

The objective of soil productivity research is to develop an ability to use site characteristics to predict the productivity of a site for a variety of resources. Work is underway to predict timber outputs from site characteristics. A major task is to define nutritional needs of major commercial timber species. For the most part, little is known about this subject. The most knowledge exists for loblolly pine, but many gaps still exist.

Relationships between soil productivity and agricultural crops are much better known than those between soil productivity and trees. Some results are available for forage from agricultural research. Interdisciplinary teams have been responsible for many advances in the agricultural field, particularly in plant breeding and seed development. A similar interdisciplinary approach may prove useful for soil productivity research in forested ecosystems. This team, having skills in genetics, silviculture, soil science, and ecological modeling could take advantage of the synergy among specialties. Not only must models be constructed, but validation methods also need to be developed.

NOTES

1. Providing technical and financial assistance to nonindustrial private forest landowners has been a Forest Service responsibility for many years. Providing assistance to rangeland owners is an SCS responsibility.

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The data displayed in these tables for 1960 to 1985 come from USGS Circulars on estimated water use (MacKichan and Kammerer 1961, Murray 1968, Murray and Reeves 1972, Murray and Reeves 1977, Solley et al. 1983, Solley et al. 1988). Projections of water use from 2000 to 2040 are Forest Service estimates based upon regression equations reported in Appendix B.

The demand statistics in these tables differ in two important ways from the demand statistics for water use reported in the Appraisal. First, statistics in this report include the most recent data; estimates of water use in 1985. The 1980 data were the latest used for making water demand projections in the Appraisal. Second, projections in this report are based on historical relationships among determinants of water demand and recent trends in how those relationships have changed. In contrast, Appraisal demand projections are based on assumed future changes in relationships among demand determinants. Consequently, the scenario projected in this report is a continuation of recent trends while that projected in the Appraisal is the *most likely* scenario based on the assumed future changes in demand determinants and their relationships.

Tables A.1 to A.6 summarize freshwater withdrawals by use. Each table shows the amount of water withdrawn by water source (groundwater, surface water, and wastewater, where applicable) by water resource region. Wastewater withdrawal data are only available for irrigation and industrial use. Water resource regions were defined by the Water Resources Council (fig. A.1). Regions divide the continental U.S. into 18 major hydrologic basins. Data are also shown for Alaska, Hawaii, and the Caribbean.

Tables A.7 to A.12 summarize freshwater withdrawals by use and water source and present information by Forest Service Region. Administration of the National Forest System is decentralized by 9 Regions (fig. A.2). Water withdrawal and consumption information by state were obtained from USGS and were then combined into Forest Service Regions. For display purposes, Forest Service Regions were further aggregated into four geographic regions—North, South, Rocky Mountains, and Pacific Coast. The North is the Eastern Region. The South is the Southern Region, including Puerto Rico and the Virgin Islands. The Rocky Mountains contain the Northern, Rocky Mountain, Southwestern, and Intermountain Regions. The Pacific Coast contains the California (including Hawaii), Pacific Northwest, and Alaskan Regions.

Tables A.13 to A.18 summarize consumption by use for Forest Service Regions and water resource regions. Consumption data is not available by water source.

Figures A.3–A.16 illustrate trends in withdrawals by water use category and by source, groundwater versus surface water.

Figure A.1.—Water resource regions

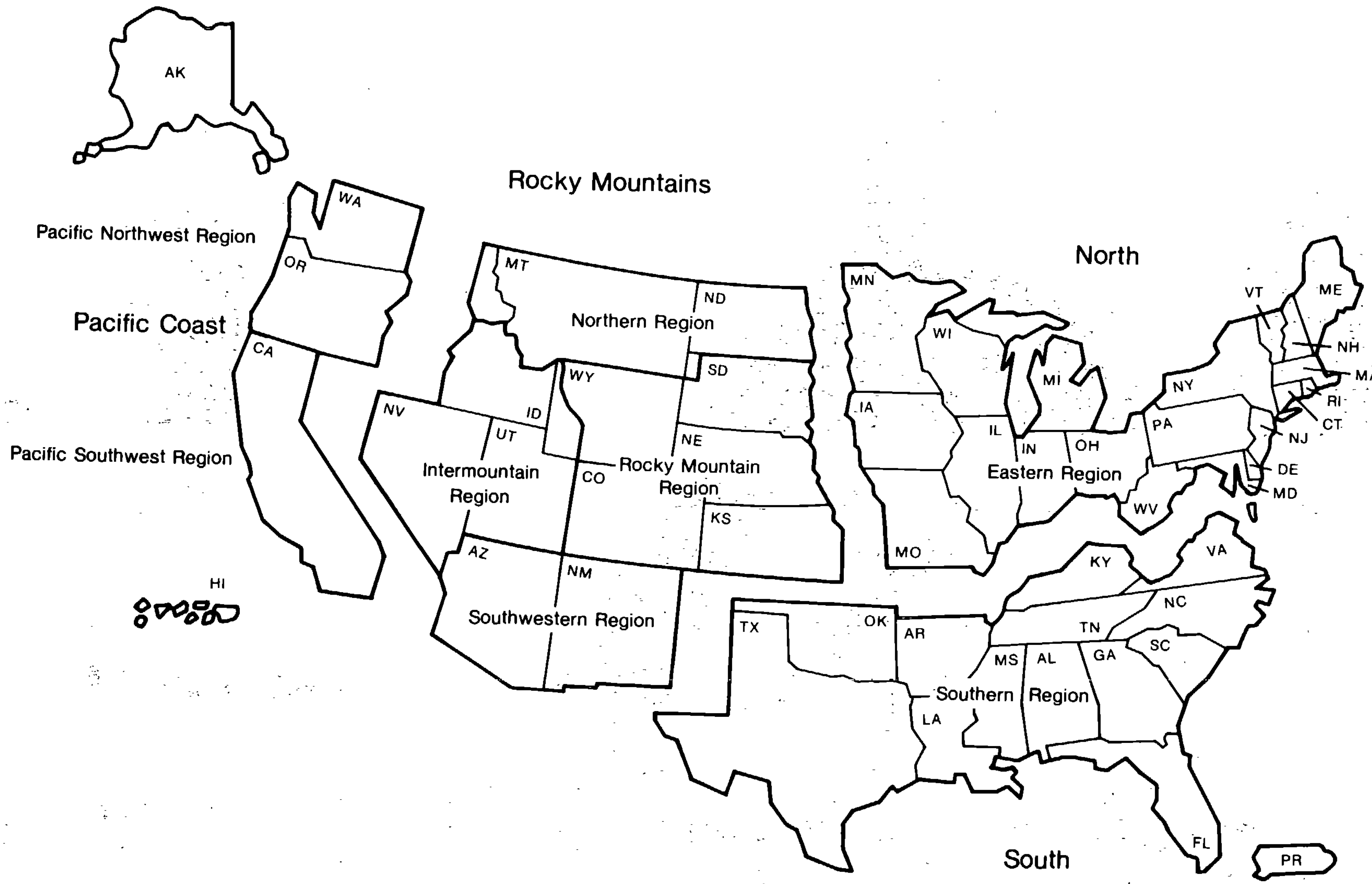

Figure A.2.—Assessment and Forest Service Regions.

Table A.1.—Freshwater withdrawals (million gallons per day) for thermoelectric steam cooling use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	6	0	1	1	1	0	0	0	0	0	0
Mid-Atlantic	3	8	100	170	110	44	60	59	59	58	58
South Atlantic-Gulf	17	17	32	91	88	35	33	33	33	32	32
Great Lakes	0	0	38	64	30	12	21	21	20	20	20
Ohio	19	40	54	32	52	21	22	22	21	21	21
Tennessee	0	0	0	0	0	0	0	0	0	0	0
Upper Mississippi	7	9	290	34	13	5	53	53	52	52	51
Lower Mississippi	21	76	66	27	54	21	23	23	23	22	22
Souris-Red-Rainy	3	1	1	0	1	0	0	0	0	0	0
Missouri Basin	5	61	310	310	48	19	106	104	103	102	102
Arkansas-White-Red	37	42	46	56	70	28	27	27	27	26	26
Texas-Gulf	301	320	51	32	30	12	18	18	17	17	17
Rio Grande	179	190	15	22	15	6	8	8	8	8	8
Upper Colorado	0	0	0	0	0	0	0	0	0	0	0
Lower Colorado	18	19	44	38	45	18	20	20	20	19	19
Great Basin	0	0	4	4	5	2	2	2	2	2	2
Pacific Northwest	0	0	0	7	5	2	2	2	2	2	2
California	290	300	300	380	890	352	248	245	242	240	239
Alaska	0	1	1	2	8	3	2	2	2	2	2
Hawaii	14	31	82	140	130	51	56	55	54	54	54
Caribbean	0	0	0	0	3	1	0	0	0	0	0
Total Groundwater	920	1115	1435	1410	1598	633	703	694	686	679	676
Surface Water											
New England	620	870	1900	1900	2300	2041	2456	2734	3012	3289	3567
Mid-Atlantic	8100	10300	15000	14000	15000	13312	16019	17830	19641	21452	23262
South Atlantic-Gulf	8400	10900	15000	18000	19000	16861	20291	22585	24879	27173	29466
Great Lakes	17500	20000	26000	25000	27000	23961	28835	32095	35354	38614	41872
Ohio	16000	20000	27000	27000	30000	26623	32039	35661	39283	42904	46525
Tennessee	5600	5900	6100	8700	9300	8253	9932	11055	12178	13300	14423
Upper Mississippi	8200	13000	12000	13000	16000	14199	17087	19019	20951	22882	24813
Lower Mississippi	930	1800	4000	6000	7700	6833	8223	9153	10083	11012	11941
Souris-Red-Rainy	0	64	140	190	53	47	57	63	69	76	82
Missouri Basin	2200	2200	3000	3900	8100	7188	8650	9628	10606	11584	12562
Arkansas-White-Red	3130	1700	1900	2800	9900	8786	10573	11768	12963	14158	15353
Texas-Gulf	1877	2600	4700	7600	950	843	1015	1129	1244	1359	1473
Rio Grande	123	170	6	5	2	2	2	2	3	3	3
Upper Colorado	118	120	100	160	140	124	150	166	183	200	217
Lower Colorado	2	2	3	110	45	40	48	53	59	64	70
Great Basin	76	170	130	78	120	106	128	143	157	172	186
Pacific Northwest	7	5	26	29	23	20	25	27	30	33	36
California	140	660	1200	1100	1100	976	1175	1308	1440	1573	1706
Alaska	86	1	68	18	22	20	23	26	29	31	34
Hawaii	12	41	46	32	9	8	10	11	12	13	14
Caribbean	4	0	0	0	0	0	0	0	0	0	0
Total Surface Water	73125	90503	118319	129622	146764	130243	156738	174457	192176	209893	227606
Total Withdrawals											
New England	626	870	1901	1901	2301	2030	2442	2716	2991	3266	3541
Mid-Atlantic	8103	10308	15100	14170	15110	13329	16035	17838	19642	21446	23249
South Atlantic-Gulf	8417	10917	15032	18091	19088	16838	20256	22535	24813	27092	29370
Great Lakes	17500	20000	26038	25064	27030	23844	28684	31911	35137	38364	41591
Ohio	16019	20040	27054	27032	30052	26510	31891	35478	39066	42653	46240
Tennessee	5600	5900	6100	8700	9300	8204	9869	10979	12089	13200	14310
Upper Mississippi	8207	13009	12290	13034	16013	14126	16993	18904	20816	22727	24639
Lower Mississippi	951	1876	4066	6027	7754	6840	8229	9154	10080	11005	11931
Souris-Red-Rainy	3	65	141	190	54	48	57	64	70	77	83
Missouri Basin	2205	2261	3310	4210	8148	7188	8647	9619	10592	11565	12537
Arkansas-White-Red	3167	1742	1946	2856	9970	8795	10580	11770	12960	14151	15341
Texas-Gulf	2208	2920	4751	7632	980	864	1040	1157	1274	1391	1508
Rio Grande	272	360	21	27	17	15	18	20	22	24	26
Upper Colorado	117	120	100	160	140	123	149	165	182	199	215
Lower Colorado	21	21	47	148	90	79	96	106	117	128	138
Great Basin	76	170	134	82	125	110	133	148	162	177	192
Pacific Northwest	7	5	26	36	28	25	30	33	36	40	43
California	430	960	1500	1480	1990	1755	2112	2349	2587	2824	3062
Alaska	86	2	69	20	30	26	32	35	39	43	46
Hawaii	26	72	128	172	139	123	148	164	181	197	214
Caribbean	4	0	0	0	3	3	3	4	4	4	5
Total Withdrawals	74045	91618	119754	131032	148362	130876	157441	175151	192862	210572	228282

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.2.—Freshwater withdrawals (million gallons per day) for irrigation use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	0	10	20	12	8	6	6	6	7	7	7
Mid-Atlantic	48	82	77	150	97	74	73	76	80	82	84
South Atlantic-Gulf	322	1200	1300	1300	2000	1520	1501	1576	1645	1692	1733
Great Lakes	15	24	37	44	180	137	135	142	148	152	156
Ohio	3	6	8	10	88	67	66	69	72	74	76
Tennessee	2	1	2	2	3	2	2	2	2	3	3
Upper Mississippi	27	60	69	100	350	266	263	276	288	296	303
Lower Mississippi	590	1100	2000	3300	4800	3649	3602	3782	3947	4061	4159
Souris-Red-Rainy	0	2	8	26	46	35	35	36	38	39	40
Missouri Basin	2226	2700	4500	8800	11000	8362	8256	8667	9046	9306	9532
Arkansas-White-Red	2260	8000	5900	7900	8400	6386	6304	6619	6908	7107	7279
Texas-Gulf	6346	5800	5000	6000	3900	2965	2927	3073	3207	3300	3380
Rio Grande	2954	2700	2000	1900	1600	1216	1201	1261	1316	1354	1386
Upper Colorado	11	14	53	60	81	62	61	64	67	69	70
Lower Colorado	3189	4000	3900	4400	3900	2965	2927	3073	3207	3300	3380
Great Basin	760	890	760	1000	1000	760	751	788	822	846	867
Pacific Northwest	2900	3300	3000	4500	5100	3877	3828	4019	4194	4315	4419
California	8200	11000	16000	17000	18000	13684	13509	14183	14802	15229	15598
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	380	590	550	430	460	350	345	362	378	389	399
Caribbean	170	93	67	140	140	106	105	110	115	118	121
Total Groundwater	30403	41572	45251	57074	61153	56292	55575	58347	60894	62649	64167
Surface Water											
New England	10	16	60	45	45	46	46	49	53	55	58
Mid-Atlantic	33	40	50	84	150	152	154	165	176	185	193
South Atlantic-Gulf	476	2000	1100	1700	1800	1824	1842	1977	2108	2216	2320
Great Lakes	31	41	53	56	120	122	123	132	141	148	155
Ohio	9	18	27	24	60	61	61	66	70	74	77
Tennessee	12	7	4	5	4	4	4	4	5	5	5
Upper Mississippi	16	25	35	42	29	29	30	32	34	36	37
Lower Mississippi	260	860	1200	1600	2900	2939	2968	3185	3396	3571	3737
Souris-Red-Rainy	13	23	4	16	18	18	18	20	21	22	23
Missouri Basin	11019	13000	14000	20000	18000	18240	18424	19767	21081	22163	23198
Arkansas-White-Red	2340	2200	2300	2100	2400	2432	2457	2636	2811	2955	3093
Texas-Gulf	806	1300	1100	1000	1600	1621	1638	1757	1874	1970	2062
Rio Grande	2294	3700	3500	2900	2700	2736	2764	2965	3162	3324	3480
Upper Colorado	5948	6400	7800	3700	7400	7499	7574	8126	8667	9112	9537
Lower Colorado	1952	2100	2600	3100	3700	3749	3787	4063	4333	4556	4768
Great Basin	4400	3900	5100	5000	4900	4965	5016	5381	5739	6033	6315
Pacific Northwest	16000	23000	24000	24000	24000	24320	24566	26356	28109	29551	30930
California	7800	15000	18000	19000	20000	20266	20472	21963	23424	24626	25775
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	540	570	680	520	450	456	461	494	527	554	580
Caribbean	110	160	73	120	180	182	184	198	211	222	232
Total Surface Water	54069	74360	81686	85012	90456	85767	86635	92947	99129	104215	109080
Wastewater											
New England	0	1	0	0	0	0	0	0	0	0	0
Mid-Atlantic	1	0	0	0	0	0	0	0	0	0	0
South Atlantic-Gulf	0	0	0	0	0	0	0	0	0	0	0
Great Lakes	0	0	0	0	30	49	31	28	24	21	19
Ohio	0	0	0	0	0	0	0	0	0	0	0
Tennessee	0	0	0	0	0	0	0	0	0	0	0
Upper Mississippi	0	0	0	0	0	0	0	0	0	0	0
Lower Mississippi	0	0	0	0	0	0	0	0	0	0	0
Souris-Red-Rainy	0	0	0	0	0	0	0	0	0	0	0
Missouri Basin	24	0	88	80	2	3	2	2	2	1	1
Arkansas-White-Red	15	0	6	2	15	24	16	14	12	11	9
Texas-Gulf	9	5	14	31	55	89	57	51	44	39	35
Rio Grande	33	18	17	20	0	0	0	0	0	0	0
Upper Colorado	0	0	0	0	0	0	0	0	0	0	0
Lower Colorado	2	57	5	58	6	10	6	6	5	4	4
Great Basin	48	51	53	5	4	6	4	4	3	3	3
Pacific Northwest	0	3	6	9	17	28	18	16	14	12	11
California	430	400	120	160	150	244	156	138	121	107	95
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	0	0	57	0	0	0	0	0	0	0	0
Caribbean	0	0	0	0	0	0	0	0	0	0	0
Total Wastewater	562	535	366	365	279	453	290	257	225	199	176
Total Withdrawals											
New England	10	27	80	57	53	42	42	45	47	49	51
Mid-Atlantic	82	122	127	234	247	238	238	253	268	279	290
South Atlantic-Gulf	798	3200	2400	3000	3800	3656	3656	3888	4111	4286	4449
Great Lakes	46	65	90	100	330	478	478	508	537	560	582
Ohio	12	24	35	34	148	101	101	107	114	118	123
Tennessee	14	8	6	7	7	18	18	19	20	21	22
Upper Mississippi	43	85	104	142	379	532	532	566	598	624	647
Lower Mississippi	850	1960	3200	4900	7700	6500	6499	6912	7309	7620	7910
Souris-Red-Rainy	13	25	12	42	64	159	159	169	179	186	193
Missouri Basin	13269	15700	18588	28880	29002	26465	26463	28144	29759	31024	32206
Arkansas-White-Red	4615	10200	8206	10002	10815	9869	9868	10495	11097	11569	12010
Texas-Gulf	6537	7105	6114	7031	5555	8744	8743	9299	9832	10250	10641
Rio Grande	5905	6418	5517	4820	4300	3924	3924	4173	4412	4600	4775
Upper Colorado	5613	6414	7853	3760	7481	6827	6826	7260	7676	8003	8307
Lower Colorado	5388	6157	6505	7558	7606	6941	6940	7381	7804	8136	8446
Great Basin	5208	4841	5913	6005	5904	5388	5388	5730	6059	6316	6557
Pacific Northwest	18900	26303	27006	28509	29117	26570	26568	28255	29877	31147	32333
California	16430	26400	34120	36160	38150	34813	34810	37021	39146	40810	42364
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	920	1160	1287	950	910	830	830	883	934	973	1011
Caribbean	280	253	140	260	320	417	417	443	469	489	507
Total Withdrawals	84933	116467	127303	142451	151888	142512	142500	151551	160248	167063	173423

Source: Data for 1960 through 1980 from USGS Circulars. In addition to the irrigation of crops, this data also includes irrigation of recreational facilities (e.g. golf courses and ski slopes) and other uses (e.g. landscape plantings) if water source is self-supplied. Data for 1985 from the Soil Conservation Service, modified by additional nonagricultural irrigation use. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.3.—Freshwater withdrawals (million gallons per day) for municipal central supplies in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	170	260	330	280	330	421	565	679	795	890	949
Mid-Atlantic	670	890	1100	1300	1100	1402	1885	2263	2650	2966	3163
South Atlantic-Gulf	810	990	1300	1500	1900	2422	3256	3910	4577	5124	5464
Great Lakes	363	400	700	460	440	561	754	905	1060	1187	1265
Ohio	400	510	620	700	730	930	1251	1502	1758	1969	2099
Tennessee	73	71	64	79	89	113	153	183	214	240	256
Upper Mississippi	410	570	870	1200	1100	1402	1885	2263	2650	2966	3163
Lower Mississippi	210	270	390	470	610	777	1045	1255	1469	1645	1754
Souris-Red-Rainy	15	15	20	22	27	34	46	56	65	73	78
Missouri Basin	316	340	430	490	530	675	908	1091	1277	1429	1524
Arkansas-White-Red	265	310	250	370	320	408	548	658	771	863	920
Texas-Gulf	449	510	590	670	800	1020	1371	1646	1927	2157	2301
Rio Grande	141	160	180	280	240	306	411	494	578	647	690
Upper Colorado	12	19	28	26	23	29	39	47	55	62	66
Lower Colorado	148	230	250	320	370	472	634	761	891	998	1064
Great Basin	130	110	160	190	400	510	685	823	964	1079	1150
Pacific Northwest	350	410	460	460	530	675	908	1091	1277	1429	1524
California	1300	1900	1600	1700	1900	2422	3256	3910	4577	5124	5464
Alaska	8	12	24	35	23	29	39	47	55	62	66
Hawaii	74	100	120	170	180	229	308	370	434	485	518
Caribbean	7	19	34	59	75	96	129	154	181	202	216
Total Groundwater	6321	8096	9520	10781	11717	14933	20077	24110	28225	31597	33697
Surface Water											
New England	870	950	1100	1100	1200	1170	1638	1858	2071	2239	2341
Mid-Atlantic	3160	3140	4100	4000	4300	4193	5870	6659	7423	8023	8387
South Atlantic-Gulf	970	990	1400	1700	1900	1853	2594	2942	3280	3545	3706
Great Lakes	3000	3400	3700	2700	3500	3413	4778	5420	6042	6530	6827
Ohio	1100	1300	1500	1500	1500	1463	2048	2323	2589	2799	2926
Tennessee	240	180	240	250	320	312	437	496	552	597	624
Upper Mississippi	600	580	690	1800	820	800	1119	1270	1415	1530	1599
Lower Mississippi	170	230	220	280	310	302	423	480	535	578	605
Souris-Red-Rainy	18	21	25	26	30	29	41	46	52	56	59
Missouri Basin	510	630	590	720	850	829	1160	1316	1467	1586	1658
Arkansas-White-Red	360	420	490	570	1200	1170	1638	1858	2071	2239	2341
Texas-Gulf	490	460	550	690	2200	2145	3003	3407	3798	4105	4291
Rio Grande	100	94	130	74	74	72	101	115	128	138	144
Upper Colorado	37	34	30	51	100	98	137	155	173	187	195
Lower Colorado	73	66	140	190	350	341	478	542	604	653	683
Great Basin	140	160	160	190	410	400	560	635	708	765	800
Pacific Northwest	840	840	830	710	730	712	996	1130	1260	1362	1424
California	1400	2100	1800	2000	2200	2145	3003	3407	3798	4105	4291
Alaska	15	20	35	46	30	29	41	46	52	56	59
Hawaii	11	8	12	11	15	15	20	23	26	28	29
Caribbean	62	120	170	230	280	273	382	434	483	522	546
Total Surface Water	14166	15743	17912	18838	22319	21765	30466	34562	38527	41643	43532
Total Withdrawals											
New England	1040	1210	1430	1380	1530	1650	2265	2621	2971	3251	3466
Mid-Atlantic	3830	4030	5200	5300	5400	5822	7995	9250	10487	11473	12232
South Atlantic-Gulf	1780	1980	2700	3200	3800	4097	5626	6509	7380	8074	8608
Great Lakes	3363	3800	4400	3160	3940	4248	5833	6749	7652	8371	8925
Ohio	1500	1810	2120	2200	2230	2404	3302	3820	4331	4738	5052
Tennessee	313	251	304	329	409	441	606	701	794	869	926
Upper Mississippi	1010	1150	1560	3000	1920	2070	2843	3289	3729	4079	4349
Lower Mississippi	380	500	610	750	920	992	1362	1576	1787	1955	2084
Souris-Red-Rainy	33	36	45	48	57	61	84	98	111	121	129
Missouri Basin	826	970	1020	1210	1380	1488	2043	2364	2680	2932	3126
Arkansas-White-Red	625	730	740	940	1520	1639	2250	2604	2952	3230	3443
Texas-Gulf	935	970	1140	1360	3000	3235	4442	5139	5826	6374	6796
Rio Grande	245	254	310	354	314	339	465	538	610	667	711
Upper Colorado	41	53	58	77	123	133	182	211	239	261	279
Lower Colorado	229	296	390	510	720	776	1066	1233	1398	1530	1631
Great Basin	270	270	320	380	810	873	1199	1387	1573	1721	1835
Pacific Northwest	1190	1250	1290	1170	1260	1359	1865	2158	2447	2677	2854
California	2700	4000	3400	3700	4100	4421	6070	7023	7962	8711	9288
Alaska	23	32	59	81	53	57	78	91	103	113	120
Hawaii	85	108	132	181	195	210	289	334	379	414	442
Caribbean	69	139	204	289	355	383	526	608	689	754	804
Total Withdrawals	20487	23839	27432	29619	34036	36699	50392	58301	66100	72316	77100

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A 4.—Freshwater withdrawals (million gallons per day) for industrial self-supplied use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	130	140	180	200	180	81	111	128	147	166	187
Mid-Atlantic	630	700	1000	630	580	261	438	505	579	656	737
South Atlantic-Gulf	1140	1300	1500	1900	1800	809	1031	1188	1362	1542	1734
Great Lakes	421	360	300	300	630	283	244	281	322	365	410
Ohio	600	890	750	740	1300	585	553	638	731	828	930
Tennessee	230	49	45	140	97	44	56	64	74	84	94
Upper Mississippi	480	620	630	690	650	292	390	450	516	584	657
Lower Mississippi	450	470	980	950	1000	450	581	670	767	869	977
Souris-Red-Rainy	5	7	5	2	4	2	2	3	3	3	4
Missouri Basin	183	270	360	400	380	171	226	261	299	338	380
Arkansas-White-Red	310	400	250	290	320	144	170	197	225	255	287
Texas-Gulf	352	340	390	340	240	108	192	222	254	288	323
Rio Grande	78	75	110	84	16	7	42	48	55	62	70
Upper Colorado	5	8	12	28	23	10	12	14	16	19	21
Lower Colorado	75	110	170	210	160	72	107	123	141	160	180
Great Basin	110	65	85	120	130	58	66	77	88	99	112
Pacific Northwest	400	400	620	2100	2300	1034	995	1147	1314	1489	1674
California	300	480	410	390	430	193	244	281	322	365	410
Alaska	12	7	8	0	6	3	3	3	4	4	5
Hawaii	110	65	160	97	9	4	53	61	70	79	89
Caribbean	29	38	40	72	85	38	39	45	52	58	66
Total Groundwater	6050	6794	8005	9683	10340	4650	5555	6405	7339	8314	9345
Surface Water											
New England	1100	1100	1100	1300	1300	898	907	987	1064	1139	1212
Mid-Atlantic	2830	3200	5600	3700	2900	2003	2990	3255	3508	3755	3995
South Atlantic-Gulf	1970	1600	2100	2600	4100	2832	2157	2348	2530	2709	2882
Great Lakes	7200	8700	8300	6900	5100	3523	4978	5416	5837	6249	6647
Ohio	6600	7700	5100	5200	3700	2556	3431	3735	4025	4309	4584
Tennessee	1200	1000	1300	1500	2000	1382	1176	1281	1380	1477	1572
Upper Mississippi	1200	1000	1100	1100	2600	1796	1176	1281	1380	1477	1572
Lower Mississippi	940	2100	3100	3300	3200	2211	2353	2561	2760	2955	3144
Souris-Red-Rainy	80	98	73	31	5	3	27	29	31	34	36
Missouri Basin	280	180	160	120	300	207	142	155	167	179	190
Arkansas-White-Red	681	440	370	630	530	366	375	408	440	471	501
Texas-Gulf	819	570	1000	330	280	193	395	430	463	496	527
Rio Grande	11	8	97	9	0	0	26	28	30	33	35
Upper Colorado	28	30	52	63	560	387	165	180	194	208	221
Lower Colorado	25	27	42	58	86	59	46	50	53	57	61
Great Basin	200	140	130	120	370	256	152	165	178	191	203
Pacific Northwest	1700	1400	1100	1300	1400	967	931	1014	1093	1170	1244
California	64	85	48	55	58	40	39	43	46	50	53
Alaska	70	95	100	90	120	83	76	83	89	95	102
Hawaii	33	51	100	94	36	25	56	61	66	71	75
Caribbean	130	140	180	98	30	21	75	82	89	95	101
Total Suface Water	27161	29664	31152	28598	28675	19810	21673	23591	25425	27218	28955
Wastewater											
New England	0	0	0	0	0	0	0	0	0	0	0
Mid-Atlantic	70	130	130	150	160	120	266	312	359	406	453
South Atlantic-Gulf	0	0	0	0	0	0	0	0	0	0	0
Great Lakes	0	0	0	0	0	0	0	0	0	0	0
Ohio	0	0	0	0	0	0	0	0	0	0	0
Tennessee	0	0	0	0	0	0	0	0	0	0	0
Upper Mississippi	0	0	0	0	0	0	0	0	0	0	0
Lower Mississippi	0	0	0	0	0	0	0	0	0	0	0
Souris-Red-Rainy	0	0	0	0	0	0	0	0	0	0	0
Missouri Basin	0	0	0	0	0	0	0	0	0	0	0
Arkansas-White-Red	0	2	5	4	0	0	5	6	7	8	9
Texas-Gulf	0	2	1	5	0	0	4	4	5	6	6
Rio Grande	0	4	0	0	0	0	0	0	0	0	0
Upper Colorado	0	0	0	0	0	0	0	0	0	0	0
Lower Colorado	0	1	0	7	12	9	11	13	15	18	20
Great Basin	0	0	0	1	1	1	1	1	2	2	2
Pacific Northwest	0	0	0	0	0	0	0	0	0	0	0
California	1	1	4	2	9	7	9	11	12	14	15
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	0	0	9	0	10	8	11	13	15	18	20
Caribbean	0	0	0	0	0	0	0	0	0	0	0
Total Wastewater	71	140	149	169	192	144	308	362	416	471	525
Total Withdrawals											
New England	1230	1240	1280	1500	1480	928	996	1097	1199	1300	1401
Mid-Atlantic	3460	3900	6600	4330	3480	2182	3369	3712	4054	4397	4739
South Atlantic-Gulf	3110	2900	3600	4500	5900	3699	3273	3606	3939	4272	4604
Great Lakes	7621	9060	8600	7200	5730	3592	5034	5546	6057	6569	7081
Ohio	7200	8590	5850	5940	5000	3135	3926	4325	4724	5123	5522
Tennessee	1430	1049	1345	1640	2097	1315	1188	1309	1430	1551	1671
Upper Mississippi	1680	1620	1730	1790	3250	2038	1583	1744	1905	2066	2227
Lower Mississippi	1390	2570	4080	4250	4200	2633	2930	3227	3525	3823	4121
Souris-Red-Rainy	85	105	78	33	9	6	28	31	34	37	39
Missouri Basin	463	450	520	520	680	426	402	443	484	525	566
Arkansas-White-Red	991	840	620	920	850	533	559	616	672	729	786
Texas-Gulf	1168	910	1390	670	520	326	603	665	726	787	849
Rio Grande	106	83	207	93	16	10	74	81	89	96	104
Upper Colorado	29	38	64	91	583	365	173	190	208	225	243
Lower Colorado	104	137	212	268	246	154	170	187	204	222	239
Great Basin	310	205	215	240	500	313	223	246	269	291	314
Pacific Northwest	2100	1800	1720	3400	3700	2320	2062	2272	2482	2691	2901
California	364	565	458	445	488	306	325	358	391	424	457
Alaska	82	102	108	90	126	79	76	83	91	99	107
Hawaii	143	116	260	191	45	28	116	128	140	151	163
Caribbean	159	178	220	170	115	72	118	130	142	154	166
Total Withdrawals	33225	36458	39157	38281	39015	24460	27228	29996	32764	35532	38300

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.5.—Freshwater withdrawals (million gallons per day) for domestic self-supplied use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	37	95	94	110	130	129	171	191	209	223	231
Mid-Atlantic	260	270	340	380	430	428	566	632	691	738	764
South Atlantic-Gulf	320	540	460	510	720	717	948	1058	1158	1235	1279
Great Lakes	290	260	270	280	270	269	356	397	434	463	480
Ohio	190	240	240	280	290	289	382	426	466	497	515
Tennessee	57	64	51	42	61	61	80	90	98	105	108
Upper Mississippi	160	190	200	190	290	289	382	426	466	497	515
Lower Mississippi	50	63	110	77	94	94	124	138	151	161	167
Souris-Red-Rainy	10	13	19	24	23	23	30	34	37	39	41
Missouri Basin	98	94	110	130	210	209	277	309	338	360	373
Arkansas-White-Red	69	98	88	100	130	129	171	191	209	223	231
Texas-Gulf	30	33	80	100	120	119	158	176	193	206	213
Rio Grande	9	10	20	25	33	33	43	49	53	57	59
Upper Colorado	1	4	6	6	15	15	20	22	24	26	27
Lower Colorado	1	10	24	36	37	37	49	54	59	63	66
Great Basin	14	26	37	28	32	32	42	47	51	55	57
Pacific Northwest	39	95	220	220	230	229	303	338	370	394	409
California	190	81	120	120	130	129	171	191	209	223	231
Alaska	5	6	4	6	11	11	14	16	18	19	20
Hawaii	6	0	0	0	4	4	5	6	6	7	7
Caribbean	2	1	0	2	5	5	7	7	8	9	9
Total Groundwater	1838	2193	2493	2666	3265	3251	4300	4800	5250	5600	5800
Surface Water											
New England	2	5	2	2	1	0	1	1	0	0	0
Mid-Atlantic	2	1	2	2	2	1	1	1	1	0	0
South Atlantic-Gulf	0	0	2	2	0	0	0	0	0	0	0
Great Lakes	10	10	7	4	3	1	2	1	1	1	1
Ohio	31	41	33	25	21	10	11	9	6	4	4
Tennessee	1	0	1	0	0	0	0	0	0	0	0
Upper Mississippi	17	16	6	8	10	5	5	3	2	2	2
Lower Mississippi	5	1	0	1	1	0	1	0	0	0	0
Souris-Red-Rainy	0	0	0	0	0	0	0	0	0	0	0
Missouri Basin	15	12	11	14	22	10	9	7	5	4	4
Arkansas-White-Red	5	6	6	7	25	12	9	7	4	3	3
Texas-Gulf	0	0	0	0	0	0	0	0	0	0	0
Rio Grande	0	0	1	1	1	0	1	0	0	0	0
Upper Colorado	14	2	1	1	43	20	13	10	7	5	5
Lower Colorado	0	0	0	0	0	0	0	0	0	0	0
Great Basin	2	1	1	1	4	2	1	1	1	1	1
Pacific Northwest	30	6	29	34	32	15	17	12	8	6	6
California	17	9	9	9	9	4	5	3	2	2	2
Alaska	1	2	2	3	0	0	1	0	0	0	0
Hawaii	2	0	0	0	0	0	0	0	0	0	0
Caribbean	9	4	3	18	3	1	5	3	2	2	2
Total Surface Water	163	116	116	132	177	83	80	60	40	30	30
Total Withdrawals											
New England	39	100	96	112	131	127	167	186	202	241	222
Mid-Atlantic	262	271	342	382	432	418	550	615	665	707	732
South Atlantic-Gulf	320	540	462	512	720	697	916	1025	1109	1178	1220
Great Lakes	300	270	277	284	273	264	347	389	420	447	462
Ohio	221	281	273	305	311	301	396	443	479	509	527
Tennessee	58	64	52	42	61	59	78	87	942	100	103
Upper Mississippi	177	206	206	198	300	291	382	427	462	491	508
Lower Mississippi	55	64	110	78	95	92	121	135	146	155	161
Souris-Red-Rainy	10	13	19	24	23	22	29	33	35	38	39
Missouri Basin	113	106	121	144	232	225	295	330	357	379	393
Arkansas-White-Red	74	104	94	107	155	150	197	221	239	254	263
Texas-Gulf	33	33	80	100	120	116	153	171	185	196	203
Rio Grande	10	10	21	26	34	33	43	48	52	56	58
Upper Colorado	6	6	7	7	58	56	74	83	89	95	98
Lower Colorado	10	10	24	36	37	36	47	53	57	61	63
Great Basin	16	27	38	29	36	35	46	51	55	59	61
Pacific Northwest	69	101	249	254	262	254	333	373	403	429	444
California	207	90	129	129	139	135	177	198	214	227	235
Alaska	6	8	6	9	11	11	14	16	17	18	19
Hawaii	8	0	0	0	4	4	5	6	6	7	7
Caribbean	11	5	3	20	8	8	10	11	12	13	14
Total Withdrawals	2005	2309	2609	2798	3442	3334	4380	4900	5300	5630	5830

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.6.—Freshwater withdrawals (million gallons per day) for livestock watering use in the United States from 1960 to 1985, by water resource region, with projections of demand to 2040

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	7	6	7	4	4	10	6	7	7	7	8
Mid-Atlantic	38	37	46	68	79	196	83	88	93	96	98
South Atlantic-Gulf	63	79	110	150	130	322	167	179	188	195	199
Great Lakes	64	57	62	60	64	159	80	85	90	93	95
Ohio	58	54	58	78	63	156	85	91	96	99	101
Tennessee	10	16	11	9	12	30	14	15	15	16	16
Upper Mississippi	200	260	200	200	220	546	266	284	299	310	316
Lower Mississippi	18	22	22	25	17	42	27	29	31	32	33
Souris-Red-Rainy	11	14	12	13	10	25	15	16	17	17	18
Missouri Basin	182	210	270	300	270	670	360	385	405	420	428
Arkansas-White-Red	56	60	66	86	85	211	102	109	114	118	121
Texas-Gulf	10	53	71	85	78	193	100	107	113	117	119
Rio Grande	8	38	17	18	26	64	26	28	29	30	31
Upper Colorado	1	2	6	6	2	5	6	6	7	7	7
Lower Colorado	9	16	18	32	12	30	27	28	30	31	32
Great Basin	10	23	35	38	34	84	46	49	52	53	54
Pacific Northwest	21	24	18	28	21	52	29	31	32	33	34
California	57	34	38	42	36	89	50	53	56	58	59
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	1	1	1	6	5	12	5	5	6	6	6
Caribbean	1	1	1	1	15	37	7	8	8	8	9
Total Groundwater	825	1007	1069	1249	1183	2934	1501	1603	1688	1749	1783
Surface Water											
New England	6	6	5	5	5	11	7	7	8	8	8
Mid-Atlantic	26	23	33	27	32	69	41	44	46	48	49
South Atlantic-Gulf	67	68	51	96	110	239	114	122	129	134	136
Great Lakes	28	22	24	25	20	43	31	33	35	36	37
Ohio	69	80	84	110	90	195	126	135	142	148	151
Tennessee	28	21	20	28	29	63	34	36	39	40	41
Upper Mississippi	91	56	60	63	51	111	77	82	87	90	92
Lower Mississippi	23	23	33	23	25	54	36	38	41	42	43
Souris-Red-Rainy	10	6	2	3	4	9	4	4	5	5	5
Missouri Basin	137	160	170	180	120	261	208	223	235	244	249
Arkansas-White-Red	86	93	120	140	150	326	182	194	205	213	217
Texas-Gulf	8	37	42	51	120	261	94	101	107	111	113
Rio Grande	6	31	20	20	6	13	20	22	23	24	24
Upper Colorado	8	9	12	9	91	198	50	53	56	58	59
Lower Colorado	3	3	10	17	5	11	14	15	16	17	17
Great Basin	11	6	6	10	12	26	12	13	14	15	15
Pacific Northwest	38	35	34	25	34	74	41	44	47	48	49
California	25	50	54	58	50	109	72	77	81	84	86
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	2	3	6	0	0	0	3	3	3	3	3
Caribbean	3	5	8	8	15	33	14	15	16	16	16
Total Surface Water	675	737	794	898	969	2104	1179	1261	1332	1383	1411
Total Withdrawals											
New England	13	12	12	9	9	21	13	14	15	15	16
Mid-Atlantic	64	60	79	95	111	260	124	132	140	145	148
South Atlantic-Gulf	130	147	161	246	240	562	282	301	317	329	335
Great Lakes	92	79	86	85	84	197	111	119	125	130	132
Ohio	127	134	142	188	153	358	210	224	237	245	250
Tennessee	38	37	31	37	41	96	47	51	53	55	57
Upper Mississippi	291	316	260	263	271	634	346	369	389	403	412
Lower Mississippi	41	45	55	48	42	98	63	67	71	74	75
Souris-Red-Rainy	21	20	14	16	14	33	19	20	22	22	23
Missouri Basin	319	370	440	480	390	913	570	609	642	666	679
Arkansas-White-Red	142	153	186	226	235	550	282	301	317	329	335
Texas-Gulf	18	90	113	136	198	463	195	208	219	227	232
Rio Grande	14	69	37	38	32	75	47	50	52	54	55
Upper Colorado	8	11	18	15	93	218	55	59	62	64	65
Lower Colorado	14	19	28	49	17	40	41	44	46	48	49
Great Basin	21	29	41	48	46	108	59	63	66	69	70
Pacific Northwest	59	59	52	53	55	129	70	74	78	81	83
California	82	84	92	100	86	201	121	129	136	141	144
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	3	4	7	6	5	12	8	8	9	9	9
Caribbean	4	6	9	9	30	70	21	22	24	24	25
Total Withdrawals	1501	1744	1863	2147	2152	5038	2683	2864	3020	3131	3195

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.7.—Freshwater withdrawals (million gallons per day) for thermoelectric steam cooling use in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	3	1	1	2	2	1	1	1	1	1	1
Rocky Mountain	26	79	341	347	89	65	72	71	71	70	69
Southwestern	23	23	49	52	51	43	48	47	47	46	46
Intermountain	0	1	7	14	12	17	19	19	19	19	18
Pacific Southwest	303	330	383	521	1020	95	106	104	103	102	102
Pacific Northwest	0	0	0	0	0	1	1	1	1	1	1
Southern	530	618	167	172	208	201	223	220	217	215	214
Eastern	36	62	486	300	208	206	229	226	223	221	220
Alaskan	0	1	1	2	8	4	5	5	5	5	5
Total Groundwater	920	1115	1435	1410	1598	633	703	694	686	679	676
Surface Water											
Northern	65	136	413	780	1101	958	1153	1284	1414	1544	1675
Rocky Mountain	1526	984	1095	1119	2842	2873	3457	3848	4239	4630	5020
Southwestern	51	16	22	132	103	69	83	92	102	111	121
Intermountain	128	198	175	136	192	74	89	99	109	119	129
Pacific Southwest	152	697	1254	1131	1110	416	500	557	614	670	727
Pacific Northwest	3698	5	26	29	23	439	528	588	648	707	767
Southern	22571	27311	39400	48258	58076	49796	59926	66700	73475	80249	87021
Eastern	44849	61154	75865	78019	83295	75592	90970	101254	111538	121821	132101
Alaskan	86	1	68	18	22	26	31	35	38	42	45
Total Surface Water	73125	90503	118319	129622	146764	130243	156738	174457	192176	209893	227606
Total Withdrawals											
Northern	68	137	414	781	1103	959	0	1284	1413	1543	1673
Rocky Mountain	1552	1063	1437	1465	2931	2938	3534	3932	4329	4727	5124
Southwestern	74	39	71	184	154	112	135	150	165	180	195
Intermountain	128	199	182	150	204	91	110	122	135	147	159
Pacific Southwest	455	1027	1639	1651	2131	511	614	684	753	822	891
Pacific Northwest	3698	5	26	29	23	440	529	588	648	707	767
Southern	23101	27929	39565	48432	58284	49996	60145	66910	73676	80441	87207
Eastern	44883	61217	76349	78321	83502	75798	91184	101441	111698	121955	132212
Alaskan	86	2	69	20	30	30	36	41	45	49	53
Total Withdrawals	74045	91618	119754	131032	148362	130876	157441	175151	192862	210572	228282

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

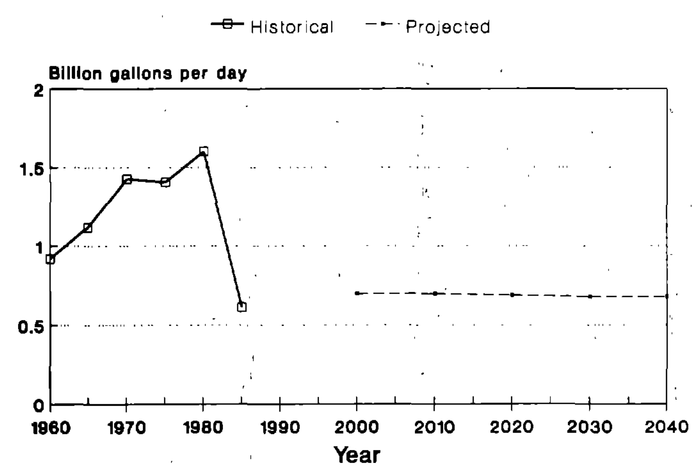

Figure A.3.—Thermoelectric steam cooling, fresh groundwater withdrawals.

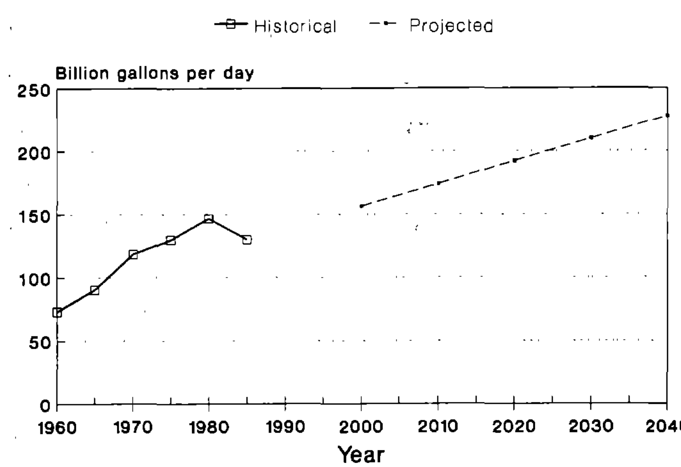

Figure A.4.—Thermoelectric steam cooling, fresh surface water withdrawals.

Table A.8.—Freshwater withdrawals (million gallons per day) for irrigation use in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	541	626	551	929	1085	878	867	910	950	977	1001
Rocky Mountain	4077	5170	7534	12564	15037	12127	11972	12569	13118	13496	13823
Southwestern	3910	5100	5100	5500	5300	3670	3623	3804	3970	4084	4183
Intermountain	2442	3058	2469	3802	4341	3783	3735	3921	4092	4210	4312
Pacific Southwest	8880	11590	16550	17430	18460	11436	11290	11853	12371	12727	13036
Pacific Northwest	660	740	980	1150	1110	1100	1086	1140	1190	1224	1254
Southern	9819	15429	12054	15300	14759	12645	12484	13107	13679	14073	14414
Eastern	127	280	296	429	862	857	846	888	927	953	977
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Groundwater	30403	41572	45251	57074	61153	56292	55575	58347	60894	62649	64167
Surface Water											
Northern	6977	9314	10634	13771	12864	12128	12250	13143	14017	14736	15424
Rocky Mountain	11521	15999	17695	14652	17969	17310	17485	18759	20007	21033	22015
Southwestern	2620	3500	3900	4400	5400	4670	4717	5061	5398	5674	5939
Intermountain	11823	15653	16967	16231	15551	20364	20570	22069	23537	24745	25900
Pacific Southwest	9940	14580	17680	18520	19450	21070	21283	22834	24353	25602	26797
Pacific Northwest	7900	9300	9500	10400	11100	9550	9647	10349	11038	11604	12146
Southern	2706	5909	4956	5884	7034	6174	6236	6691	7136	7502	7852
Eastern	110	140	217	256	435	430	434	466	497	522	546
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Surface Water	54069	74360	81686	85012	90456	85767	86635	92947	99129	104215	109080
Wastewater											
Northern	0	0	0	1	3	0	1	1	1	1	1
Rocky Mountain	39	0	86	80	2	5	23	20	18	16	14
Southwestern	0	78	22	54	3	29	23	20	18	16	14
Intermountain	48	52	59	9	13	17	10	9	8	7	6
Pacific Southwest	430	400	177	160	150	253	149	132	116	102	90
Pacific Northwest	0	3	3	4	4	5	3	3	3	2	2
Southern	34	0	15	53	70	119	64	57	50	44	39
Eastern	10	1	0	0	30	26	15	13	11	10	9
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Wastewater	562	535	366	365	279	453	290	257	225	199	176
Total Withdrawals											
Northern	7518	9940	11186	14701	13952	13006	13005	13831	14624	15246	15827
Rocky Mountain	15637	21169	25316	27295	33008	29441	29439	31309	33105	34513	35827
Southwestern	6530	8678	9022	9954	10703	8369	8368	8900	9411	9811	10184
Intermountain	14313	18763	19495	20041	19905	24164	24162	25696	27171	28327	29405
Pacific Southwest	19250	26570	34407	36110	38060	32759	32757	34837	36836	38403	39865
Pacific Northwest	8560	10043	10483	11554	12214	10655	10654	11330	11981	12490	12966
Southern	12559	21338	17025	21237	21863	18938	18936	20139	21294	22200	23045
Eastern	247	421	513	685	1327	1312	1312	1395	1475	1538	1597
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Withdrawals	84933	116467	127303	142451	151888	142512	142500	151551	160248	167063	173423

Source: Data for 1960 through 1980 from USGS Circulars. In addition to the irrigation of crops, this data also includes irrigation of recreational facilities (e.g. golf courses and ski slopes) and other uses (e.g. landscape plantings) if water source is self-supplied. Data for 1985 from the Soil Conservation Service, modified by additional nonagricultural irrigation use. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.9.—Freshwater withdrawals (million gallons per day) for municipal central supplies in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	82	66	75	94	113	135	182	218	256	286	305
Rocky Mountain	350	353	419	471	466	550	740	889	1040	1165	1242
Southwestern	184	261	322	443	488	583	784	941	1102	1234	1316
Intermountain	221	256	313	345	593	538	723	868	1016	1137	1213
Pacific Southwest	1276	1995	1730	1884	2072	4202	5649	6784	7942	8891	9482
Pacific Northwest	371	311	359	337	365	422	567	681	798	893	952
Southern	1796	2185	2626	3182	3811	4471	6011	7219	8451	9460	10089
Eastern	2053	2657	3652	3989	3786	3991	5366	6443	7543	8444	9006
Alaskan	8	12	24	35	23	41	55	66	77	87	93
Total Ground Water	6321	8096	9520	10781	11717	14933	20077	24110	28225	31597	33697
Surface Water											
Northern	115	95	116	121	132	143	200	227	253	273	286
Rocky Mountain	418	532	500	637	813	911	1275	1447	1613	1743	1822
Southwestern	66	71	136	147	281	261	365	414	462	499	522
Intermountain	183	193	200	265	533	374	523	594	662	716	748
Pacific Southwest	1410	2068	1810	2018	2216	1461	2045	2320	2586	2795	2922
Pacific Northwest	789	775	769	662	670	948	1327	1505	1678	1814	1896
Southern	2531	2801	3630	4258	6986	6322	8850	10039	11191	12096	12645
Eastern	8640	9187	10716	10683	10658	11310	15831	17960	20020	21639	22621
Alaskan	15	20	35	46	30	35	49	56	62	67	70
Total Surface Water	14166	15743	17912	18838	22319	21765	30466	34562	38527	41643	43532
Total Withdrawals											
Northern	177	160	191	215	244	278	382	442	501	548	584
Rocky Mountain	768	885	919	1108	1279	1462	2007	2322	2633	2880	3071
Southwestern	250	330	457	590	770	844	1159	1341	1520	1663	1773
Intermountain	403	447	512	609	1127	912	1252	1448	1642	1796	1915
Pacific Southwest	2684	4054	3536	3900	4290	5663	7776	8996	10200	11159	11897
Pacific Northwest	1160	1087	1128	1000	1035	1370	1881	2176	2468	2700	2878
Southern	4326	4978	6253	7439	10798	10794	14821	17147	19441	21269	22676
Eastern	10696	11867	14378	14677	14439	15301	21010	24308	27559	30151	32146
Alaskan	23	32	59	81	53	76	104	121	137	150	160
Total Withdrawals	20487	23839	27432	29619	34036	36699	50392	58301	66100	72316	77100

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

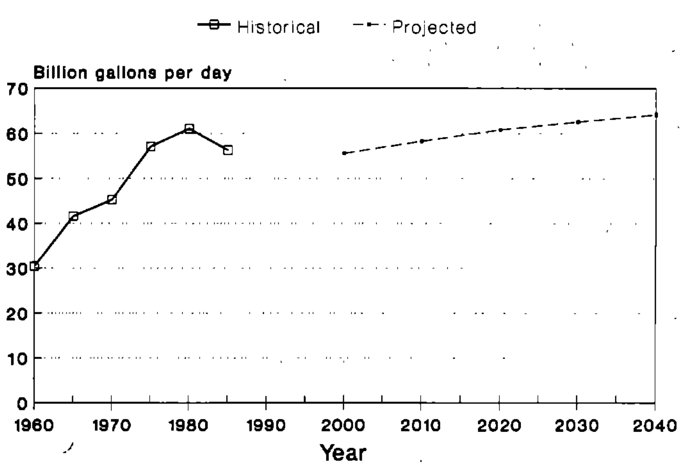

Figure A.5.—Irrigation, fresh groundwater withdrawals.

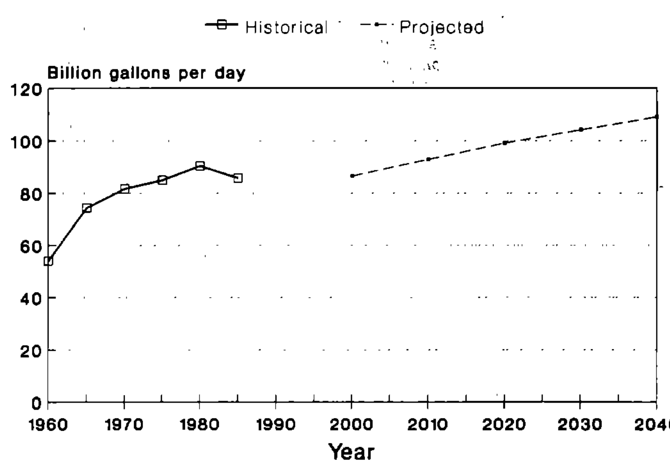

Figure A.6.—Irrigation, fresh surface water withdrawals.

Table A.10.—Freshwater withdrawals (million gallons per day) for industrial self-supplied use in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	57	48	114	446	497	76	91	104	120	136	152
Rocky Mountain	230	210	342	385	332	156	186	215	246	279	313
Southwestern	79	171	222	254	147	68	82	94	108	122	137
Intermountain	175	155	373	1625	1804	187	223	257	295	334	375
Pacific Southwest	415	542	569	485	430	420	502	579	663	751	844
Pacific Northwest	211	298	260	209	230	159	190	219	251	284	320
Southern	2747	2621	3268	3716	3646	1872	2236	2578	2954	3346	3761
Eastern	2124	2743	2849	2563	3248	1704	2036	2348	2690	3048	3425
Alaskan	12	7	8	0	6	8	10	11	13	14	16
Total Groundwater	6050	6794	8005	9683	10340	4650	5555	6405	7339	8314	9345
Surface Water											
Northern	193	112	149	120	108	40	44	48	51	55	58
Rocky Mountain	221	181	187	198	827	146	160	174	188	201	214
Southwestern	20	26	38	25	20	8	9	10	10	11	12
Intermountain	233	212	260	277	564	38	42	46	49	53	56
Pacific Southwest	76	102	128	136	81	121	132	144	155	166	177
Pacific Northwest	3234	1242	998	1130	1245	674	737	803	865	926	985
Southern	6473	6454	9089	9262	10524	7711	8437	9183	9897	10595	11271
Eastern	16641	21241	20202	17360	15187	10965	11996	13058	14073	15066	16027
Alaskan	71	94	100	90	120	106	116	126	136	146	155
Total Surface Water	27161	29664	31152	28598	28675	19810	21673	23591	25425	27218	28955
Wastewater											
Northern	0	0	0	0	0	0	0	0	0	0	0
Rocky Mountain	0	0	0	0	0	0	0	0	0	0	0
Southwestern	0	0	0	0	2	5	4	5	6	6	7
Intermountain	0	1	0	8	11	0	12	14	16	18	20
Pacific Southwest	1	1	13	2	19	3	15	17	20	22	25
Pacific Northwest	0	0	0	0	0	1	0	0	0	1	1
Southern	0	7	6	9	0	55	39	46	53	60	66
Eastern	70	131	130	150	160	81	238	280	322	364	406
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Wastewater	71	140	149	169	192	144	308	362	416	471	525
Total Withdrawals											
Northern	250	160	264	567	605	116	129	142	155	168	181
Rocky Mountain	454	391	528	584	1161	302	336	370	405	439	473
Southwestern	101	197	260	280	167	76	85	94	102	111	120
Intermountain	411	366	634	1907	2366	225	251	276	302	327	353
Pacific Southwest	498	644	697	623	510	541	602	663	724	786	847
Pacific Northwest	3437	1540	1258	1339	1480	833	927	1022	1116	1210	1304
Southern	9247	9075	12358	12979	14203	9583	10667	11752	12836	13921	15005
Eastern	18745	23985	23052	19912	18488	12670	14103	15537	16971	18405	19838
Alaskan	83	101	108	90	126	114	127	140	153	166	179
Total Withdrawals	33225	36458	39157	38281	39105	24460	27228	29996	32764	35532	38300

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.11.—Freshwater withdrawals (million gallons per day) for domestic self-supplied use in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	23	27	32	44	82	48	61	68	74	79	81
Rocky Mountain	71	80	97	110	168	105	134	148	162	172	178
Southwestern	37	10	38	56	64	64	81	90	98	104	108
Intermountain	24	46	47	54	73	80	101	112	122	130	134
Pacific Southwest	202	79	120	120	133	131	168	184	201	213	221
Pacific Northwest	18	74	203	189	169	168	213	236	258	274	283
Southern	542	888	869	928	1238	1115	1416	1568	1709	1815	1877
Eastern	915	984	1083	1160	1327	1531	1945	2153	2347	2492	2578
Alaskan	5	6	4	6	11	9	11	13	14	15	15
Total Groundwater	1838	2193	2493	2666	3265	3251	4131	4573	4985	5293	5475
Surface Water											
Northern	1	0	2	1	1	0	0	0	0	0	0
Rocky Mountain	4	9	7	7	68	3	5	5	5	5	5
Southwestern	3	2	1	1	1	1	2	2	2	2	2
Intermountain	3	2	2	4	6	2	3	3	3	3	3
Pacific Southwest	22	9	9	9	10	30	47	47	47	47	47
Pacific Northwest	30	5	26	30	30	10	15	15	15	15	15
Southern	22	25	17	29	14	16	25	25	25	25	25
Eastern	77	63	50	47	47	20	31	31	31	31	31
Alaskan	1	2	2	3	0	1	1	1	1	1	1
Total Surface Water	163	116	116	132	177	83	129	129	129	129	129
Total Withdrawals											
Northern	25	27	34	45	83	48	68	76	83	89	92
Rocky Mountain	76	89	104	117	235	109	152	170	187	200	207
Southwestern	41	12	39	57	65	65	91	102	113	120	125
Intermountain	27	48	49	58	79	82	115	128	141	150	156
Pacific Southwest	224	87	129	129	143	161	225	252	277	296	307
Pacific Northwest	46	78	229	219	199	178	248	278	306	326	338
Southern	567	912	887	958	1253	1131	1582	1772	1946	2077	2154
Eastern	994	1047	1133	1207	1374	1550	2169	2429	2668	2847	2953
Alaskan	6	8	6	9	11	10	14	15	17	18	18
Total Withdrawals	2005	2309	2609	2798	3442	3334	4664	5224	5737	6123	6351

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

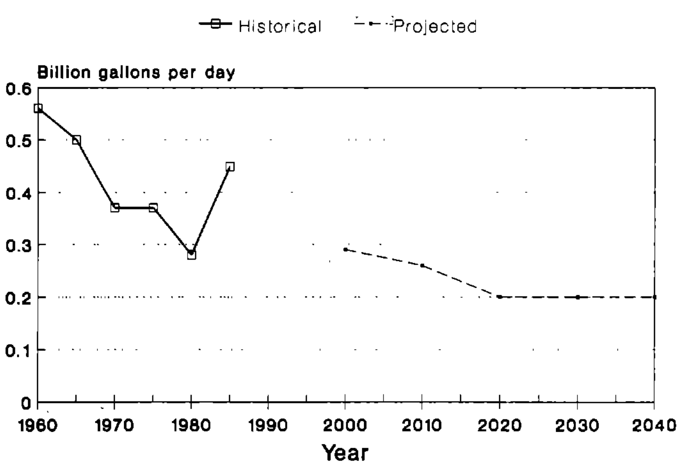

Figure A.7.—Irrigation, wastewater withdrawals.

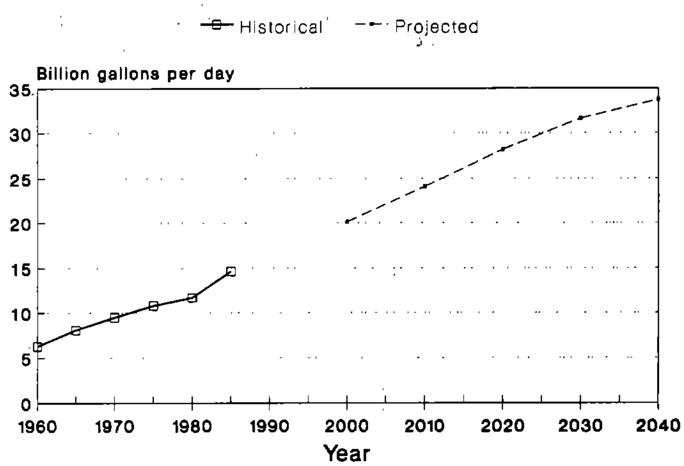

Figure A.8.—Municipal supplies, fresh groundwater withdrawals.

Table A.12.—Freshwater withdrawals (million gallons per day) for livestock watering use in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	17	35	36	42	36	258	132	141	149	154	157
Rocky Mountain	136	167	208	236	225	179	92	98	103	107	109
Southwestern	19	42	32	43	20	36	18	20	21	21	22
Intermountain	16	38	45	55	43	851	436	465	490	507	517
Pacific Southwest	58	35	39	48	42	42	21	23	24	25	25
Pacific Northwest	11	13	7	7	11	25	13	14	14	15	15
Southern	180	220	277	346	326	992	507	542	571	591	603
Eastern	388	456	426	472	479	541	277	296	311	322	329
Alaskan	0	0	0	0	0	10	5	5	6	6	6
Total Groundwater	825	1007	1069	1249	1183	2934	1501	1603	1688	1749	1783
Surface Water											
Northern	49	40	27	28	26	45	31	33	35	36	37
Rocky Mountain	72	91	119	99	173	126	211	225	238	247	252
Southwestern	9	37	40	44	12	75	14	15	16	17	17
Intermountain	21	17	18	16	29	30	36	38	40	42	43
Pacific Southwest	26	51	59	59	51	162	61	66	69	72	74
Pacific Northwest	26	24	21	21	21	813	25	27	29	30	30
Southern	243	263	281	359	475	542	577	618	652	677	691
Eastern	230	215	228	272	183	165	223	239	252	262	267
Alaskan	0	0	0	0	0	146	0	0	0	0	0
Total Surface Water	675	737	794	898	969	2104	1179	1261	1332	1383	1411
Total Withdrawals											
Northern	66	75	63	70	61	303	162	173	182	189	192
Rocky Mountain	209	258	328	335	399	305	162	173	183	190	194
Southwestern	27	79	72	87	32	111	59	63	67	69	70
Intermountain	37	56	63	70	72	881	469	501	528	548	559
Pacific Southwest	84	86	98	108	93	204	108	116	122	127	129
Pacific Northwest	37	37	28	28	32	838	446	476	502	521	531
Southern	421	485	558	705	803	1534	817	872	920	953	973
Eastern	620	670	654	744	660	706	376	401	423	439	448
Alaskan	0	0	0	0	0	156	83	89	93	97	99
Total Withdrawals	1501	1744	1863	2147	2152	5038	2683	2864	3020	3131	3195

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

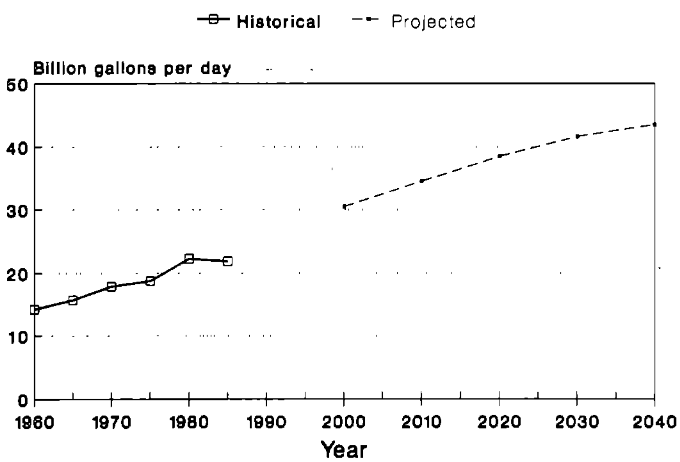

Figure A.9.—Municipal supplies, fresh surface water withdrawals.

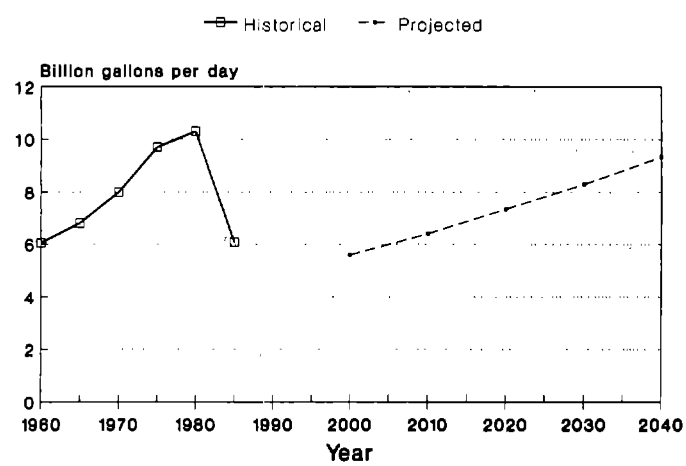

Figure A.10.—Industrial self-supplied water, fresh groundwater withdrawals.

Table A.13.—Freshwater consumption (million gallons per day) for thermoelectric steam cooling use in the United States for 1960 to 1985 by Water Resource region and Forest Service region, with projections of demand to 2040

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	1	3	3	98	21	31	50	60	68	78	91
Mid-Atlantic	15	27	35	140	260	389	623	747	843	969	1122
South Atlantic-Gulf	7	11	120	210	270	404	647	775	875	1006	1165
Great Lakes	12	11	14	52	93	139	223	267	301	348	401
Ohio	33	17	50	280	520	778	1246	1493	1685	1937	2245
Tennessee	0	8	64	59	20	30	48	57	65	75	86
Upper Mississippi	4	27	23	98	290	434	695	833	940	1080	1252
Lower Mississippi	-19	20	190	290	400	598	959	1149	1296	1490	1727
Souris-Red-Rainy	2	1	1	1	1	1	2	3	3	4	4
Missouri Basin	12	31	34	68	350	523	839	1005	1134	1304	1511
Arkansas-White-Red	29	54	82	95	410	613	982	1177	1329	1527	1770
Texas-Gulf	52	140	100	380	360	538	863	1034	1167	1341	1554
Rio Grande	4	11	17	20	11	16	26	32	36	41	47
Upper Colorado	8	18	22	60	130	194	312	373	421	484	561
Lower Colorado	7	15	36	47	49	73	117	141	159	183	212
Great Basin	2	2	6	6	6	9	14	17	19	22	26
Pacific Northwest	0	0	0	9	2	3	5	6	6	7	9
California	17	18	24	32	41	61	98	118	133	153	177
Alaska	0	0	0	1	0	0	0	0	0	0	0
Hawaii	0	0	0	0	0	0	0	0	0	0	0
Caribbean	0	1	0	5	6	9	14	17	19	22	26
U.S. Total	224	415	821	1947	3240	4846	7764	9303	10499	12070	13985
Forest Service region											
Northern	2	2	1	20	26	41	66	79	89	102	118
Rocky Mountain	22	46	53	77	197	113	181	216	244	281	325
Southwestern	20	31	59	74	106	96	154	184	208	239	277
Intermountain	4	4	13	36	39	51	82	98	111	128	148
Pacific Southwest	17	18	24	32	41	26	41	50	56	65	75
Pacific Northwest	10	0	0	7	1	25	40	48	54	62	72
Southern	96	228	568	1061	1536	1085	1739	2083	2351	2703	3132
Eastern	53	87	106	630	1294	3406	5457	6539	7379	8483	9829
Alaskan	0	0	0	1	0	3	5	6	7	8	9
Total Consumption	224	415	821	1947	3240	4846	7764	9303	10499	12070	13985

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

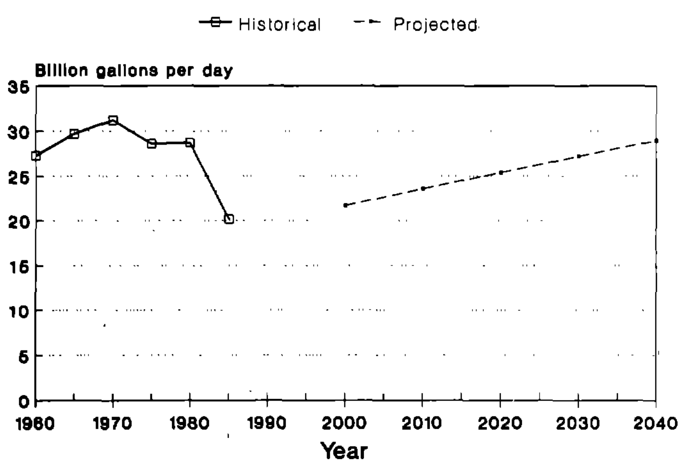

Figure A.11.—Industrial self-supplied water, fresh surface water withdrawals.

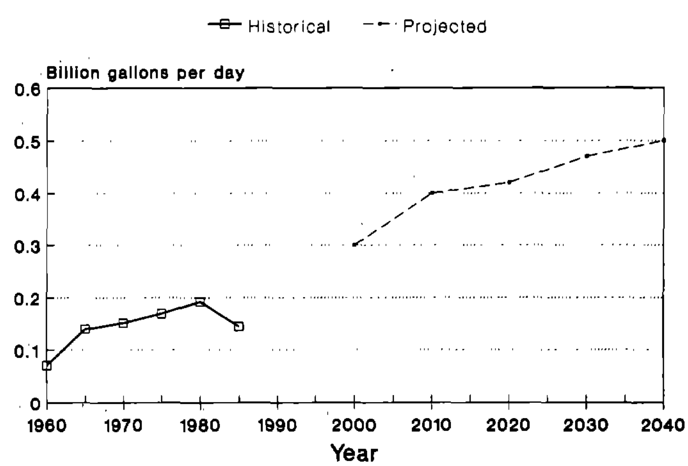

Figure A.12.—Industrial self-supplied water, wastewater withdrawals.

Table A.14.—Freshwater consumption (million gallons per day) for irrigation use in the United States for 1960 to 1985 by water resource region and Forest Service region, with projections of demand to 2040

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	7	26	64	57	52	46	55	57	60	61	63
Mid-Atlantic	82	122	120	200	240	212	253	264	275	284	292
South Atlantic-Gulf	797	1400	1500	1500	2300	2028	2421	2531	2637	2720	2797
Great Lakes	45	64	87	94	330	291	347	363	378	390	401
Ohio	12	24	35	32	150	132	158	165	172	177	182
Tennessee	14	8	7	7	7	6	7	8	8	8	9
Upper Mississippi	44	77	95	140	370	326	389	407	424	438	450
Lower Mississippi	660	1200	2200	4000	4800	4232	5053	5283	5504	5677	5838
Souris-Red-Rainy	9	17	12	41	60	53	63	66	69	71	73
Missouri Basin	6946	9800	12000	14000	15000	13225	15790	16509	17199	17740	18245
Arkansas-White-Red	3390	7700	6000	8000	8200	7229	8632	9025	9402	9698	9974
Texas-Gulf	4798	5500	4900	6500	4900	4320	5158	5393	5618	5795	5960
Rio Grande	3402	3900	3000	3200	2100	1851	2211	2311	2408	2484	2554
Upper Colorado	3505	3200	4000	1500	2000	1763	2105	2201	2293	2365	2433
Lower Colorado	3395	3100	4700	5700	4300	3791	4527	4732	4930	5085	5230
Great Basin	3300	3000	2900	3400	3500	3086	3684	3852	4013	4139	4257
Pacific Northwest	8000	10000	10000	9900	11000	9698	11580	12106	12612	13009	13379
California	13000	16000	21000	21000	23000	20278	24212	25313	26371	27201	27975
Alaska	0	0	1	0	0	0	0	0	0	0	0
Hawaii	370	530	750	500	610	538	642	671	699	721	742
Caribbean	250	230	98	150	200	176	211	220	229	237	243
U.S. Total	52026	65898	73469	79921	83119	73282	87498	91479	95303	98301	101098
Forest Service region											
Northern	3471	5750	6663	3901	4109	3041	3631	3796	3955	4079	4196
Rocky Mountain	9193	12029	14586	16513	17656	15997	19101	19970	20804	21459	22069
Southwestern	4224	4436	5882	6812	5706	4439	5301	5542	5773	5955	6124
Intermountain	7186	8276	7624	7773	8770	8211	9804	10250	10679	11015	11328
Pacific Southwest	14453	15659	21044	21537	23636	18818	22469	23491	24473	25243	25961
Pacific Northwest	4124	4436	4564	5209	5606	6889	8225	8600	8959	9241	9504
Southern	9143	14913	12646	17564	16356	14699	17550	18349	19116	19717	20278
Eastern	233	398	460	613	1278	1187	1417	1481	1543	1592	1637
Alaskan	0	0	1	0	0	0	0	0	0	0	0
Total Consumption	52026	65898	73469	79921	83119	73282	87498	91479	95303	98301	101098

Source: Data for 1960 through 1980 from USGS Circulars. In addition to the irrigation of crops this data also includes irrigation of recreational facilities (e.g. golf courses and ski slopes) and other uses (e.g. landscape plantings) if water source is self-supplied. Data for 1985 from the Soil Conservation Service, modified by additional nonagricultural irrigation use. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

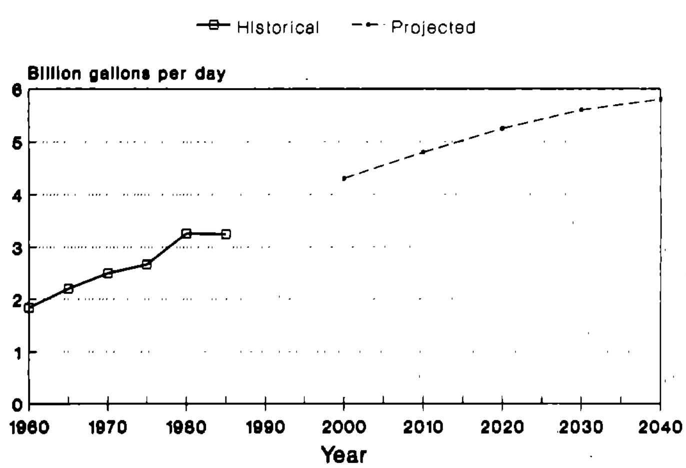

Figure A.13.—Domestic self-supplied water, fresh groundwater withdrawals.

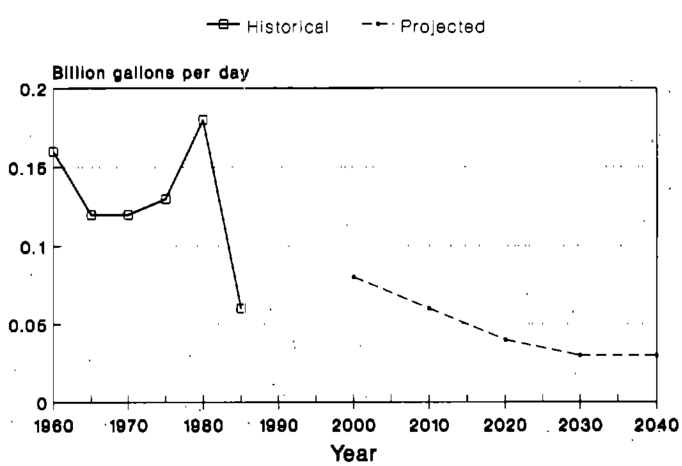

Figure A.14.—Domestic self-supplied water, fresh surface water withdrawals.

Table A.15.—Freshwater consumption (million gallons per day) for municipal central supplies in the United States for 1960 to 1985 by water resource region and Forest Service region, with projections of demand to 2040

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	150	160	190	180	150	130	217	239	258	272	280
Mid-Atlantic	452	681	750	760	710	615	1027	1132	1223	1289	1326
South Atlantic-Gulf	300	360	590	930	780	676	1128	1244	1344	1416	1457
Great Lakes	400	520	500	410	310	269	448	494	534	563	579
Ohio	190	230	270	240	240	208	347	383	414	436	448
Tennessee	60	46	36	40	44	38	64	70	76	80	82
Upper Mississippi	130	160	190	170	180	156	260	287	310	327	336
Lower Mississippi	110	200	240	310	400	347	578	638	689	726	747
Souris-Red-Rainy	9	11	19	20	22	19	32	35	38	40	41
Missouri Basin	212	240	250	290	360	312	521	574	620	653	672
Arkansas-White-Red	196	260	250	330	310	269	448	494	534	563	579
Texas-Gulf	396	350	380	560	550	477	795	877	948	998	1027
Rio Grande	124	110	150	190	140	121	202	223	241	254	261
Upper Colorado	10	14	19	26	41	36	59	65	71	74	77
Lower Colorado	110	150	190	240	390	338	564	622	672	708	728
Great Basin	67	69	140	140	310	269	448	494	534	563	579
Pacific Northwest	150	210	260	230	290	251	419	463	500	526	542
California	370	1300	1400	1500	1700	1473	2458	2711	2929	3086	3175
Alaska	0	7	11	4	33	29	48	53	57	60	62
Hawaii	25	38	46	55	60	52	87	96	103	109	112
Caribbean	11	21	43	42	75	65	108	120	129	136	140
U.S. Total	3472	5137	5924	6667	7095	6149	10259	11316	12226	12878	13250
Forest Service region											
Northern	74	61	91	87	99	86	143	158	171	180	185
Rocky Mountain	191	241	235	275	348	302	503	555	600	632	650
Southwestern	123	161	227	283	438	380	634	699	755	795	818
Intermountain	108	121	202	212	417	362	603	665	719	757	779
Pacific Southwest	395	1324	1455	1557	1757	1522	2540	2802	3027	3188	3280
Pacific Northwest	113	186	209	176	217	188	313	345	373	393	404
Southern	1139	1301	1612	2323	2172	1882	3140	3464	3742	3942	4056
Eastern	1329	1735	1881	1749	1615	1399	2335	2575	2783	2931	3016
Alaskan	0	7	11	4	33	29	48	53	57	60	62
Total Consumption	3472	5137	5924	6667	7095	6149	10259	11316	12226	12878	13250

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

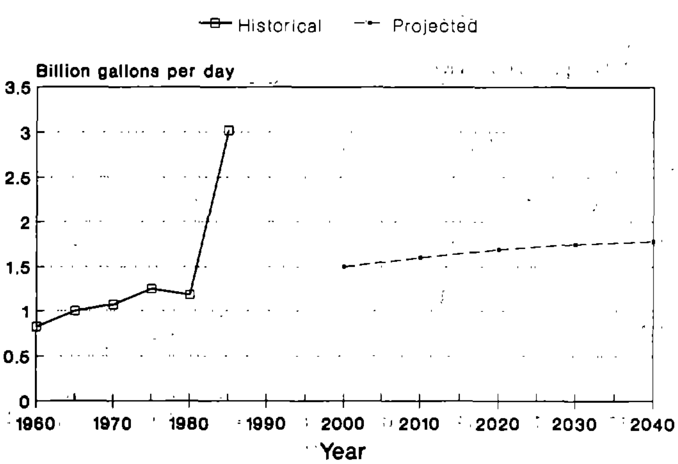

Figure A.15.—Livestock watering, fresh groundwater withdrawals.

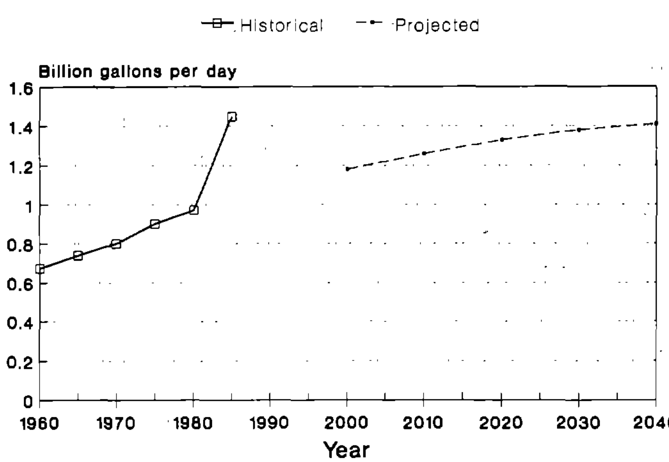

Figure A.16.—Livestock watering, fresh surface water withdrawals.

Table A.16.—Freshwater consumption (million gallons per day) for industrial self-supplied use in the United States for 1960 to 1985 by water resource region and Forest Service region, with projections of demand to 2040

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	84	79	96	64	66	72	88	100	112	123	135
Mid-Atlantic	460	470	330	340	280	307	375	424	473	523	573
South Atlantic-Gulf	430	260	540	540	1100	1204	1473	1665	1859	2054	2249
Great Lakes	280	360	450	370	370	405	495	560	625	691	757
Ohio	310	410	260	360	420	460	562	636	710	784	859
Tennessee	240	170	72	120	220	241	295	333	372	411	450
Upper Mississippi	36	58	75	98	170	186	228	257	287	317	348
Lower Mississippi	380	450	780	810	740	810	991	1120	1251	1382	1513
Souris-Red-Rainy	7	2	6	5	6	7	8	9	10	11	12
Missouri Basin	55	71	65	52	77	84	103	117	130	144	157
Arkansas-White-Red	185	330	210	270	330	361	442	500	558	616	675
Texas-Gulf	239	350	580	290	350	383	469	530	592	653	716
Rio Grande	31	46	97	55	13	14	17	20	22	24	27
Upper Colorado	5	8	21	27	63	69	84	95	106	118	129
Lower Colorado	32	51	100	190	150	164	201	227	254	280	307
Great Basin	9	36	62	63	100	109	134	151	169	187	204
Pacific Northwest	91	83	150	310	350	383	469	530	592	653	716
California	80	110	170	180	190	208	254	288	321	355	389
Alaska	0	4	4	0	1	1	1	2	2	2	2
Hawaii	13	4	4	4	0	0	0	0	0	0	0
Caribbean	7	10	18	37	20	22	27	30	34	37	41
U.S. Total	2974	3362	4090	4185	5016	5492	6715	7594	8478	9365	10257
Forest Service region											
Northern	32	24	28	50	57	33	41	46	51	57	62
Rocky Mountain	54	71	113	119	165	172	211	238	266	294	322
Southwestern	28	92	137	221	125	159	194	220	245	271	297
Intermountain	43	61	100	211	278	47	57	65	72	80	87
Pacific Southwest	95	114	175	183	191	679	830	939	1048	1158	1268
Pacific Northwest	154	64	126	149	171	159	194	220	245	271	297
Southern	1524	1581	2220	2075	2781	1945	2378	2690	3003	3317	3633
Eastern	1045	1351	1187	1177	1247	2282	2790	3155	3523	3891	4262
Alaskan	0	4	4	0	1	16	19	22	24	27	29
Total Consumption	2974	3362	4090	4185	5016	5492	6715	7594	8478	9365	10257

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.17.—Freshwater consumption (million gallons per day) for domestic self-supplied use in the United States for 1960 to 1985 by water resource region and Forest Service region, with projections of demand to 2040

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	31	84	47	36	63	46	48	49	50	51	51
Mid-Atlantic	86	88	130	100	110	106	112	115	117	119	120
South Atlantic-Gulf	310	490	360	340	440	357	375	385	392	398	401
Great Lakes	96	100	78	61	74	67	70	72	73	74	75
Ohio	140	200	180	140	200	163	171	175	179	182	183
Tennessee	54	61	31	25	39	30	31	32	33	33	33
Upper Mississippi	73	100	130	48	190	115	121	124	127	128	130
Lower Mississippi	52	58	100	68	67	74	77	79	81	82	83
Souris-Red-Rainy	7	14	19	11	23	17	17	18	18	19	19
Missouri Basin	89	85	96	110	170	118	124	127	129	131	132
Arkansas-White-Red	70	96	84	97	120	94	99	102	104	105	106
Texas-Gulf	29	33	80	100	120	94	99	101	103	105	106
Rio Grande	6	7	13	17	18	15	16	16	17	17	17
Upper Colorado	2	2	3	3	17	7	8	8	8	8	8
Lower Colorado	6	5	17	27	27	22	23	24	24	25	25
Great Basin	8	15	13	6	14	10	11	11	11	12	12
Pacific Northwest	23	75	200	180	200	182	191	196	200	202	204
California	120	51	73	76	84	73	77	79	80	81	82
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	6	0	0	0	3	1	1	1	1	1	1
Caribbean	9	4	3	4	2	3	3	3	3	3	3
U.S. Total	1217	1568	1657	1449	1981	1592	1675	1716	1751	1776	1791
Forest Service region											
Northern	12	24	29	40	75	45	47	49	50	50	51
Rocky Mountain	68	80	88	97	152	106	111	114	116	118	119
Southwestern	31	8	24	37	39	31	33	34	35	35	35
Intermountain	9	23	19	14	27	19	20	20	21	21	21
Pacific Southwest	133	50	71	74	85	72	76	78	79	81	81
Pacific Northwest	18	67	190	169	168	165	173	178	181	184	185
Southern	519	798	721	661	842	696	732	750	766	777	783
Eastern	427	517	513	356	594	458	482	494	504	511	515
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Consumption	1217	1568	1657	1449	1981	1592	1675	1716	1751	1776	1791

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.18.—Freshwater consumption (million gallons per day) for livestock watering use in the United States for 1960 to 1985 by water resource region and Forest Service region, with projections of demand to 2040

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	13	11	12	9	9	11	11	12	12	12	13
Mid-Atlantic	58	51	65	76	86	103	105	110	116	119	121
South Atlantic-Gulf	127	140	150	240	240	287	292	308	323	333	338
Great Lakes	85	72	82	78	77	92	94	99	103	107	109
Ohio	130	130	140	170	140	168	170	180	188	194	197
Tennessee	38	36	30	32	40	48	49	51	54	55	56
Upper Mississippi	290	300	250	250	270	323	328	347	363	374	381
Lower Mississippi	41	44	55	47	41	49	50	53	55	57	58
Souris-Red-Rainy	21	19	15	16	14	17	17	18	19	19	20
Missouri Basin	301	360	410	440	380	455	462	488	511	527	536
Arkansas-White-Red	139	150	180	220	230	275	280	295	309	319	324
Texas-Gulf	16	89	110	140	190	227	231	244	255	263	268
Rio Grande	13	68	36	37	26	31	32	33	35	36	37
Upper Colorado	7	10	17	14	22	26	27	28	30	30	31
Lower Colorado	12	16	28	47	11	13	13	14	15	15	16
Great Basin	19	16	21	20	17	20	21	22	23	24	24
Pacific Northwest	55	55	47	47	49	59	60	63	66	68	69
California	66	45	50	54	47	56	57	60	63	65	66
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	2	3	7	5	5	6	6	6	7	7	7
Caribbean	4	6	8	9	7	8	8	9	9	9	9
U.S. Total	1437	1621	1713	1951	1901	2276	2311	2442	2555	2635	2681
Forest Service region											
Northern	65	74	61	67	60	98	100	105	110	114	116
Rocky Mountain	196	251	304	307	314	271	275	291	304	314	319
Southwestern	22	78	71	86	18	59	60	63	66	68	69
Intermountain	32	36	39	38	38	96	98	103	108	112	114
Pacific Southwest	68	47	56	59	51	157	160	169	176	182	185
Pacific Northwest	35	35	26	25	29	50	51	54	56	58	59
Southern	416	472	540	680	769	911	925	977	1022	1054	1073
Eastern	603	628	614	689	623	633	643	680	711	733	746
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Consumption	1437	1621	1713	1951	1901	2276	2311	2442	2555	2635	2681

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

APPENDIX B: DEMAND EQUATIONS

INTRODUCTION

Demand equations were estimated using the 1987 release of *BMDP for the Personal Computer*, which executes the same routines outlined by Dixon et al. (1985). The stepwise regression routine was used to explore possible independent variables (table 11) for each dependent variable and transformation. Further analyses were performed using multiple linear regression.

Several different curve forms were tested for fit against the data. The prior assumption was that a logarithmic curve form was the most appropriate, given the emphasis on recycling and conservation engendered by legislation of the early 1970s. Semilogarithmic ($Y = \ln a + b \ln X$) and double logarithmic ($\ln Y = \ln a + b \ln X$; shown below as $\exp[c + b \ln x]$ where $c = \ln a$) curve forms were explored in preference to linear forms. The *BMDP Data Manager for the Personal Computer* (Engelman et al. 1986) was used to perform the natural logarithm transformations of dependent and independent variables.

Unless otherwise specified, F statistics listed are for equations with a single explanatory variable and a time series of six data points (1960 to 1985 inclusive). The critical values for $F_{1,5}$ are 4.06, 6.61, and 16.3 for 10%, 5%, and 1%, respectively.

THERMOELECTRIC STEAM COOLING

EQUATIONS

Total freshwater withdrawals =
$$\exp[7.6658 + 0.5656 \ln kWh] \quad R^2 = .93 \quad F = 51.6$$

Groundwater withdrawals = No significant equations

Fresh surface water withdrawals =
$$\exp[7.6241 + 0.5701 \ln kWh] \quad R^2 = .94 \quad F = 60.0$$

Freshwater consumption =
$$-10642 - 3.2887\ kWh + 182.446\ \text{civilian labor force} \quad R^2 = .98 \quad F = 91.2$$

DISCUSSION

Because no significant equations emerged for groundwater withdrawals, demand for fresh groundwater withdrawals was estimated as the difference between total freshwater withdrawals and fresh surface water withdrawals. Saline surface water (oceans and estuaries) is an alternative source of water for thermoelectric steam cooling. Because those utilities using groundwater are usually located in arid areas far removed from coastal sites where saline surface sources are available, saline surface sources were ignored for purposes of estimating groundwater withdrawals.

Billion kWh of power generated was selected as the best independent variable for projecting steam cooling withdrawals and consumption. The double exponential form suggests that conservation and recycling will continue to grow, but at a decreasing rate. Billion kWh were projected based upon the GNP relationships identified by the U.S. Department of Energy and the GNP projections from the basic assumptions for this Assessment.

IRRIGATION

EQUATIONS

Total freshwater withdrawals =
$$-227076 + 50465.68 \ln kWh \quad R^2 = .88 \quad F = 30.2$$

Groundwater withdrawals =
$$-94490 + 20168.35 \ln kWh \quad R^2 = .66 \quad F = 7.9$$

Fresh surface water withdrawals =
$$-133814 + 30414.04 \ln kWh \quad R^2 = .94 \quad F = 67.3$$

Wastewater withdrawals =
$$1736 - 186.71 \ln kWh \quad R^2 = 57.8 \quad F = 5.5$$

Freshwater consumption =
$$-84411 + 22194.83 \ln kWh \quad R^2 = .79 \quad F = 14.8$$

DISCUSSION

The wastewater withdrawals equation has an F statistic that is significant at the 7% level. Because wastewater withdrawals represent only 0.2% of the total demand for irrigation water in 1985, this level of significance was judged acceptable for projecting irrigation withdrawals. No other form or independent variable gave better results.

Billion kWh was selected as the most relevant independent variable to explain irrigation withdrawals and consumption. Electricity is the primary energy source used to pump water from aquifers and surface sources and pressurize sprinkler water delivery systems.

MUNICIPAL SUPPLIES

EQUATIONS

Total freshwater withdrawals =
$$\exp[-1.1803 + 2.138 \ln \text{population}] \quad R^2 = .987 \quad F = 235.4$$

Groundwater withdrawals =

$$\exp[-5.1671 + 2.6840 \ln \text{population}]$$
$$R^2 = .976 \quad F = 120.9$$

Fresh surface water withdrawals =

$$\exp[-0.0643 + 1.8497 \ln \text{population}]$$
$$R^2 = .971 \quad F = 98.9$$

Freshwater consumption =

$$-76821 + 15504.6 \ln \text{population}$$
$$R^2 = .95 \quad F = 72.8$$

DISCUSSION

Population is the most relevant independent variable for explaining changes in municipal withdrawals and consumption. Municipal supplies also serve some commercial and industrial facilities but usage by these firms is largely for people-related purposes so population growth remains relevant.

INDUSTRIAL SELF-SUPPLIED WATER USE

EQUATIONS

No demand equations were statistically significant.

Freshwater consumption =

$$-21953 + 3335.4 \ln \text{GNP}$$
$$R^2 = .989 \quad F = 374.7$$

DISCUSSION

GNP was expected to be the most relevant independent variable for projecting industrial self-supplied water use. But regression equations could not be developed with GNP or any other independent variable in the data set that explained a significant portion of the variation in industrial self-supplied water withdrawals. Although GNP continued to grow at nearly the same rate as during the 1960s and 1970s, water pollution legislation and policy changes forced changes in withdrawals independent of continued growth in GNP. The change in withdrawals was so abrupt and happened so recently that statistically defensible projections of industrial self-supplied use cannot yet be made. Consequently, projections were based on simple time trends.

Projections assume that a major adjustment in water use occurred in the 1980s. Further, that industrial self-supplied use will soon resume growing at about 95% of the annual rate of growth between 1960 and 1980—roughly 275 mgd per year. This total rate of increase was disaggregated into 130 mgd per year in fresh surface water withdrawals, 90 mgd per year in groundwater withdrawals, and 54 mgd per year in wastewater withdrawals.

The consumption equation, however, explains virtually all the variation in consumption and is highly significant.

DOMESTIC SELF-SUPPLIED WATER USE

EQUATIONS

Total freshwater withdrawals =

$$-2535 + 28.089 \text{ population}$$
$$R^2 = .94 \quad F = 58.8$$

Groundwater withdrawals =

$$-2838 + 25.916 \text{ population}$$
$$R^2 = .96 \quad F = 104.$$

Fresh surface water withdrawals = no significant independent variable

DISCUSSION

Population was selected as the most relevant independent variable for explaining variation in rural domestic water withdrawals. The statistical analysis of fresh surface water withdrawals produced no significant independent variables, merely a highly significant intercept term. Consequently, surface water withdrawal estimates were computed as the difference between the projected total and projected groundwater withdrawals.

Statistical analyses of freshwater consumption yielded no significant equations. R-squared for the equations tested varied between .03 and .35 and the best F-statistic had a probability value of about .08. Thus, a combination of time and population trends were used to project freshwater consumption (fig. 30).

LIVESTOCK WATERING USE

EQUATIONS

Total freshwater withdrawals =

$$-12200 + 2650 \ln \text{population}$$
$$R^2 = .96 \quad F = 72.8$$

Groundwater withdrawals =

$$-6619 + 1446.32 \ln \text{population}$$
$$R^2 = .87 \quad F = 19.53$$

Fresh surface water withdrawals =

$$-5581 + 1203.68 \ln \text{population}$$
$$R^2 = .95 \quad F = 53.6$$

Freshwater consumption =

$$-8467 + 1919.02 \ln \text{population}$$
$$R^2 = .90 \quad F = 26.5$$

DISCUSSION

The 1985 livestock water withdrawal and consumption estimates are significantly different from previous estimates because aquaculture water use (fish farming) is included for the first time (fig. 33). Defining aquaculture as part of livestock water use is a major structural change in the data series. To eliminate effects of the structural change when estimating regression equations, 1985 estimates were not used. Consequently, the equations are based only on the data from 1960 to 1980 and projections ignore future aquaculture water withdrawals and consumption.

Population was selected as the most relevant independent variable because it stands as a surrogate for red meat consumption. The basic assumption for red meat consumption for this Assessment was to hold per capita red meat consumption constant over the projection period. A similar case could be made for assuming per capita consumption of dairy products is constant over the projection period. Because per capita consumptions are constant, growth in the demand for animal products becomes a function of population.

Aquaculture water usage was relatively low from 1960 to 1980. Some states included aquaculture in the industrial self-supplied category; others in the livestock category. Between 1980 and 1985, the volume of water used in aquaculture grew rapidly as consumers ate more fish and poultry instead of beef and pork. Thus, USGS decided to standardize how states reported aquaculture water use declaring it an element of livestock use. This change in definition probably also contributed to difficulties in estimating industrial self-supplied water use equations. Sufficient data may be available by 1998 so the next RPA analysis of the water situation can include aquaculture in its livestock water projections.

APPENDIX C: SUMMARY OF STATE WATER QUALITY LAWS AFFECTING FORESTRY OPERATIONS

Significant features of water quality legislation are given, by region, in the tables that follow: South—Table C.1; North—table C.2; Rocky Mountain region—table C.3; and Pacific Coast region—table C.4 (source: Haines and Siegel (1988)).

Table C.1—Significant features of water quality legislation in the South

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Alabama	Water Pollution Control Act. Ala. Code, Sec. 22-22-1 to 14. Enacted 1971; amended 1973, 1979, 1982.	Alabama Water Improvement Commission.	Pollutants harmful to fish or wildlife, or constituting a public hazard are subject to regulation. Commission granted permit issuing authority for control of discharges of such pollutants into waterways. Commission may issue cease-and-desist orders and commence civil actions to enjoin actual or threatened violations.	Civil: $100 to $10,000 fine per day of violation of a Commission rule or order. Criminal: $2,500 to $25,000 per day of violation and/or imprisonment for up to one year. Penalty may be doubled on second conviction. Payment of costs of damage, and restocking of fish and wildlife	No reference to silvicultural discharges or wastes from timber transport or harvesting. Law probably applicable to nonpoint pollution if damage to fish or wildlife clearly attributable.	Coastal Preservation Act (Ala. Code, Sec. 9-7-14 to 9-7-22) Activities permitted include planting and harvesting of trees including normal road construction.
Arkansas	Water and Air Pollution Control Act. Ark. Stat. Ann. Sec. 82-1901 to 1991. Enacted 1949; amended 15 times, 1953 to 1985.	Department of Pollution Control and Ecology (under authority of Arkansas Pollution Control Commission).	Department given broad authority to issue permits and orders, and to promulgate rules and standards, with respect to prohibited pollutants. Department can initiate civil action to force compliance with orders and standards.	Civil: up to $5,000 fine per day of violation plus payment of administrative expenses and damages. Criminal: violation considered misdemeanor. Up to $10,000 and/or one year in prison per day of violation.	Definition of pollution and Department's vested powers sufficiently broad to apply to nonpoint sources. Prohibited pollutants include decayed wood, sawdust, shavings, bark and sand. One member of the State Pollution Control Commission must be from the State Forestry Commission.	Stream Obstruction Statutes (Ark. Stat. Ann. Sec. 41-4052 and Sec. 41-4066 to 41-4067) prohibit obstructing any improved drainage project or any natural drain with trees, tree tops or limbs. Tree Removal in Riparian Areas (Sec. 41-4068 to 41-4069) prohibits removal of trees growing below normal high water mark of any navigable river or stream.
Florida	Air and Water Pollution Control Act. Fla. Stat. Ann. Sec. 403.011 to 403.291. Enacted 1971; amended 1972, 1974,1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985.	Department of Environmental Regulation.	Department given broad powers to develop water pollution abatement programs. Department must issue permits for all pollutant discharges pursuant to federal administrative requirements. Department may issue orders and seek injunctive relief against violations. Exception: Water owned entirely by one person excluded from Department control unless affecting other properties or water	Civil: up to $10,000 fine per day of violation. Criminal: Violation considered first degree misdemeanor. Fine of $2,500 to $25,000 and/or one year in prison per day of violation. False statement or misrepresentation: up to $10,000 and/or six months in prison. Department can initiate civil action to establish liability and recover damages, including those for fish mortality.	Powers granted to Department are sufficiently broad to include regulatory authority over nonpoint pollution from land management activities.	Warren Henderson Wetlands Protection Act of 1984 (Fla. Stat. Ann. T.29 Sec. 403.91 to 403.929) empowers Florida's five water management districts to regulate silvicultural activities which divert or impede normal water flow. Some districts require permits, others notification and/or merely compliance with standards.
Georgia	Water Quality Control Act. Ga. Code Ann. Chap. 12-5-20 to 12-5-53. Enacted 1971; amended 1972, 1974, 1977, 1978, 1982, 1983, 1986.	Division of Environmental Protection, within Department of Natural Resources (under authority of Georgia Water Quality Control Board).	Water Quality Control Board has broad authority to promulgate rules and regulations to control water pollution. Division of Environmental Protection can issue permits for both point and nonpoint discharges; can also issue stop orders. Statute applies to all waters except those entirely confined and retained on the property of a single ownership. All aspects of the program are to be consistent with the Federal Water Pollution Control Act.	Civil: up to $25,000 fine per day of violation. Criminal: violation considered misdemeanor. Fine of $2,500 to $25,000 per day of violation and/or one year in prison. Penalty doubled for repeated offense. False misrepresentation: felony; up to $10,000 and/or two years in prison. Assessment of civil liability for damages.	Division of Environmental Protection has explicit authority to issue permits for discharge of nonpoint pollutants. 1978 amendment to Water Quality Control Act provides for state administration of Federal Water Pollution Control Act Section 404 permit program.	
Kentucky	Environmental Protection Law. Ky., Rev Stat., Sec. 224 005 to 224.997 Enacted 1972; amended 1974, 1978, 1980, 1982, 1984.	Bureau of Environmental Protection within the Department of Natural Resources and Environmental Protection.	Department has broad authority to issue water quality rules and regulations; and to issue discharge permits in accordance with Federal Water Pollution Control Act guidelines. Department may initiate court action against violations. Exceptions: exemptions may be granted for up to one year if discharge is not likely to have a measurable impact on water quality and/or compliance would produce undue hardship without equal or greater benefit to the public.	Civil: up to $10,000 fine per day of violation. Criminal: violation considered misdemeanor; fine of $1,000 to $15,000 and/or imprisonment for up to one year per day of violation. Payment of costs of damage, and restocking of fish and wildlife.	Legislative authority broad enough to cover nonpoint pollution at discretion of Department. Department required to monitor environment for more effective and efficient control practices.	Kentucky Wild Rivers Act (Ky. Rev. Stat., Sec. 146.200 to 146.350) permits only selective cutting of timber within boundaries of designated wild river areas. Stream Obstruction Statute (151.310 to 151.320) prohibits the deposit of any matter which disturbs the flow of water in streams without a permit.

Louisiana	Water Control Law. La. Rev. Stat. 30:1073 and 30:1091–1097. Enacted 1979; amended 1980, 1983, 1984 1987.	Department of Environmental Quality and the Office of Water Resources (OWR)	The OWR is empowered to develop a general water protection plan and to regulate and restrain the discharge of pollution into waters. The Department establishes standards and guidelines; promulgates rules and regulations; and issues permits for the control of water pollution. Commission may initiate civil liability action.	No penalties may be imposed for unintentional pollution in connection with production of agricultural products. Commission may recover civil damages. Violations polluting waters with substance which is not likely to endanger human life or health is a misdemeanor; punishable by a fine of up to $25,000/ day of violation and/or up to one year imprisonment. Polluting with a substance which could endanger human life or health is a felony punishable by a fine of up to $100,000/day and/or 10 years imprisonment. Civil penalties are up to $25,000/day of violation. Up to $50,000/day for failure to take corrective action after compliance order is issued.	Legislative authority broad enough to cover nonpoint pollution at discretion of Department. Specifically empowers the Department to develop a nonpoint source management program. Law includes a provision prohibiting persons engaged in logging operations from leaving trees or treetops in navigable waters. Administrative regulations exempt silvicultural operations from permit requirements.	State and Local Coastal Resources Management Act of 1978 (La. Rev. Stat., Sec. 49.213.1 to 49:13.22). Permits are not required for silvicultural activities when forest practices used consistently in the past are employed An experimental or unconventional practice might require a permit. Natural and Scenic River System Act (Sec. 56:1841–1849.2) permits only selective cutting within 100 feet of scenic rivers Requires removal of tree tops from rivers.
Mississippi	Air and Water Pollution Control Act. Miss. Code, Sec. 49–17–1 to 49–17–53. Enacted 1966; amended 1968, 1971, 1972, 1973, 1977, 1978, 1980, 1981, 1985.	Commission of Natural Resources under authority of Bureau of Pollution Control of Department of Natural Resources.	Commission empowered to develop standards and programs for prevention, abatement and control of water pollution. A separate permit board issues permits for the discharge of contaminants. Commission can issue cease-and-desist orders during an emergency.	Civil: up to $25,000 fine per day of violation. Criminal: $2,500 to $25,000 per day of violation. Commission can initiate civil action to recover actual damages.	Commission's powers are broad enough to be applied to nonpoint sources of pollution.	Stream Obstruction Law (Miss. Code Sec. 97–15–41) prohibits the felling of trees or leaving logs in excess of six inches in diameter or tree tops in a running stream.
North Carolina	Water and Air Resources Acts. N.C. Gen. Stat. Sec. 143–214. Enacted 1951; amended 1957, 1959, 1967, 1969, 1973, 1975, 1977, 1979, 1983, 1985.	Department of Natural Resources and Community Development under authority of Environmental Management Commission.	Commission has broad powers over water pollution, is authorized to issue permits for discharge of pollutants, and can issue orders directed at a violator after a hearing is held.	Civil: up to $10,000 fine per day of violation. Criminal: violation considered misdemeanor; fine of up to $15,000 per day of violation, not to exceed a total of $200,000 for each 30- day period, and/or imprisonment for up to six months. Commission can initiate civil action to recover actual damages	Sawdust and wood shavings are listed as potential pollutants in the law. Nonpoint pollutants are covered under the statute's definition of water pollution which includes "alterations resulting from the concentration or increase of natural pollutants caused by man-related activities".	Stream Obstruction statutes (N.C. Gen. Stat , Sec. 77–13 and 77–14) prohibit the felling of any tree, or the leaving of slash, stumpage, sawdust, shavings, etc. in any stream so as to obstruct drainage.
Oklahoma	Pollution Control Coordinating Act. Okla. Stat. Title 82, Sec. 931 to 942. Enacted 1968; amended 1971, 1974, 1976, 1981, 1983. Pollution Remedies Law, Okla. Stat. Title 82, Sec. 926.1 to 926.13. Enacted 1972, amended 1981.	Water Resources Board under authority of Pollution Control Coordinating Board.	Department has executive authority over all state agencies administering pollution programs. Definition of pollution is broad and includes those substances potentially injurious to aesthetic sensibilities. Exception: law does not apply to waters entirely in one ownership unless affecting another's property or water.	Criminal: willful violation of any promulgated order is considered misdemeanor, punishable by maximum fine of $200 to $10,000 per day of violation and/or up to six months imprisonment. Civil penalty: up to $10,000. Civil liability for damages lies with those responsible for violation.	Broad authority granted to Department of Pollution Control and Water Resources Board covers nonpoint source pollution.	
South Carolina	Pollution Control Act. Code Laws S.C. Title 48, Sec. 48–1–10 to 48–1–350. Enacted 1971; amended 1973, 1974, 1975, 1978, 1980.	Department of Health and Environmental Control.	Department charged with responsibility of administering all state programs under Federal Water Pollution Control Act. Department has permit issuing authority, and can promulgate rules and regulations. Can issue orders and initiate legal proceedings to force compliance. Exception: no civil or criminal liabilities to be imposed for violations caused by acts of God, war, strike, riot, or catastrophe.	Civil: fine not to exceed $10,000 per day of violation. Criminal: Violation considered misdemeanor; punishable by fine of from $500 to $25,000 per day of violation and/or imprisonment for up to two years. Department can initiate civil liability proceedings to recover costs of damage.	The statute addresses the term "pollutant" in its broadest sense, thereby presumably covering all nonpoint sources Statute specifically lists decayed wood, sawdust, shavings, bark and sand as potential pollutants.	Stream Obstruction statute (Code Laws S.C. Title 49, Sec. 1–20) prohibits streambank damage or obstructing waterways with felled timber. Scenic Rivers Act (Title 51, Sec. 5–120) prohibits timber harvesting within designated distances of Class 1 streams on state controlled lands. Stream Cleaning Act (Title 49, Sec. 1–30) requires landowners to clean out the streams adjacent to their properties twice a year and to keep them free of obstructions which would interrupt the flow of sand and water.

Table C.1—Significant features of water quality legislation in the South—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Tennessee	Water Quality Control Act. Tenn. Code Ann. Sec. 69-3-101 to 69-3-121. Enacted 1971; amended 1972, 1973, 1977, 1979, 1981, 1982, 1984, 1985.	Division of Water Quality Control (within Department of Public Health) under authority of Water Quality Control Board.	Department of Public Health has broad authority to control water pollution, through regulations issued by Division of Water Quality Control. Nonpoint pollution caused by agricultural and forestry activities are exempt from regulation. Department of Public Health may issue cease-and-desist orders, and order corrective action.	Civil: up to $10,000 fine per day of violation. Criminal. violation is considered misdemeanor; punishable by fine of $50 to $25,000 per day of violation. Willful noncompliance, falsification of records, or misrepresentation considered felony and punishable by fine up to $25,000 and/or two years imprisonment. Department of Public Health can assess civil damages.	Pollution caused by agricultural or forestry activities subject to regulation only if point source involved. Statute specifically lists decayed wood, sawdust, silt, shavings, bark and rock as potential pollutants (subject to regulation if point source).	Scenic Rivers Act of 1968 (Tenn. Code Ann. Sec. 11-13-102 to 11-13-117). Commercial timber harvest is prohibited in protected river areas within conservation or public use easement.
Texas	Water Quality Act. Texas Code Ann., Water Code, Title 2, Sec. 5.001 to 5.357 and 26.001 to 26.225. Enacted in 1977; amended 1981, 1985.	State Water Commission and State Water Development Board under the Department of Water Resources.	Water Commission may grant authority to local governments to issue permits for discharge of waste into water. Commission itself can also issue rules, regulations and orders to control water quality.	Civil: $50 to $10,000 fine per day of violation. Criminal: $10 to $10,000 per day for violation of a rule or regulation.	The statute specifically covers agricultural waste, presumably including residues from forestry activities. Statute specifically lists decayed wood; sawdust, shavings; bark; runoff from irrigation; and rainfall runoff from cultivated or uncultivated rangeland, pastureland and farmland that may impair water quality.	Stream Obstruction Act (Texas Code Ann. Sec. 5.096) prohibits obstruction of navigable streams by cutting and felling of trees.
Virginia	Water Control Law. Code Va., Sec. 62.1-44.2 to 62.1-44.42. Enacted 1973; amended 1974, 1976, 1977, 1978, 1980, 1981, 1984, 1985, 1986.	Water Control Board.	After conducting a hearing, Board can issue special order to prohibit pollution, and also seek injunctive relief against violations.	Civil: not to exceed fine of $10,000 per day of violation. Criminal: $100 to $25,000 per day of violation. Civil action for damages may be initiated by Board if fish are killed as result of pollutant discharge	Legislation is broad enough to cover nonpoint pollution. Statute specifically lists decayed wood, sawdust, shavings and bark as potential pollutants.	Sec. 62.1-194 of the Virginia Code prohibits depositing timber or like material into any waters of the state. Sec. 62.1-194.2 of the Code prohibits placing treetops or logs which obstruct the movement of fish or boats for more than one week in rivers or streams. Scenic Rivers Act (Sec. 10-167 to 10-175). Permitted activities on rivers or river segments are designated on an individual basis. Forestry uses have not been restricted to date. Act specifies that the continuance of forestry activities on designated rivers is encouraged. Wetlands Act (Sec. 62.1-13.1 to 62.1-13.20) specifically permits the harvesting of forest products in wetlands.

Table C.2—Significant features of water quality legislation in the North

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Connecticut	Water Pollution Control Act. Conn. Gen Stat. Ann. Title 22a Sec. 416 to 471. Enacted 1958; amended 17 times, 1967 to 1987.	Department of Environmental Protection.	Department granted authority to develop plans for the prevention and control of water pollution. Department adopts water quality standards and regulations in compliance with the Federal Water Pollution Control Act; and issues discharge permits. Department empowered to issue corrective orders.	Civil: up to $10,000 fine per day of violation. Criminal: up to $25,000 fine and/or one year in prison per day of violation. False statement or misrepresentation: up to $10,000 fine and/or six months in prison.	The statute's definition of water pollution includes alterations of water resulting in changes in turbidity or temperature which may be harmful to fish or other aquatic life. Statute requires a permit for any discharge; regardless of whether or not the discharge may cause pollution.	River Protection Statute (Conn. Gen. Stat. Ann. T.25 Sec. 102pp to 102vv). Municipalities granted authority to establish river protection corridors and may restrict land use. Some towns along Connecticut River require forest management and sediment control plans for forest operations. Inland Wetlands Statute (T.22a Sec. 361 to 363). Permit required for filling or reclamation of wetlands, road construction and clear-cutting of timber. Stream Obstruction Statute (T.22a Sec. 361 to 363). Permit required for placement of fill or obstruction in coastal, tidal or navigable waters Soil Erosion and Sedimentation Control Act (T.22a Sec. 326 to 329). Municipalities may adopt regulations to control erosion and sedimentation. Coastal Management Act (T.22a Sec. 90 to 112). Municipalities may issue zoning regulations for land use in coastal areas.
Delaware	Environmental Protection Act. Del. Code Ann. T.7 Sec. 6001 to 6060. Enacted 1953; amended 1982, 1983, 1984, 1985, 1986.	Department of Natural Resources and Environmental Control.	Department empowered to develop, administer and enforce pollution control programs. Department adopts rules and regulations and develops statewide water pollution management plan. Department issues permits for discharges and may grant variances to rules and regulations. Department also granted authority to publish a list of activities exempt from permitting procedure. Prior to issuance of permits, proposed activities must be approved by the county or municipality of jurisdiction through zoning procedures. Department may issue cease-and-desist orders for violations.	Civil: from $1,000 to $10,000 fine per day of violation. Criminal: from $50 to $500 fine per day for general violation of rule or regulation or permit condition From $2,500 to $25,000 fine per day for willful or negligent violation. From $500 to $5,000 fine and/or six months imprisonment for false statement or misrepresentation. Department may initiate civil action to recoup cost of damages.	Authority granted Department is sufficiently broad to apply to nonpoint sources. Department list of activities exempt from regulation has not been published, to date. Rock, sand, decayed wood, sawdust, shavings, bark and agricultural wastes are listed as potential pollutants.	Sedimentation and Erosion Control Act (Del. Code Ann. T.7 Sec. 4001 to 4017) requires submission of sedimentation and erosion control plans for land disturbing activities. Most forestry operations are exempt from regulation. Pollution of Streams (T.7 Sec. 1112) prohibits the discharge of any wastes or deleterious substance in sufficient quantities to injure or destroy fish.
Illinois	Ill. Rev. Stat. Ch. 111 1/2 Sec. 1001 to 1052. Enacted 1970; amended 1972 to 1986, 14 times.	Environmental Protection Agency and Pollution Control Board.	Board adopts rules and regulations and establishes water quality standards. Agency recommends regulations for adoption by Board and administers certification and permit systems. Agency responsible for administering National Pollutant Discharge Elimination System program. Agency may take summary enforcement action and issue stop orders for violations.	Civil: up to $10,000 fine per violation and $1,000 per day of violation. Criminal: violations other than hazardous waste disposal: up to $25,000 fine per day of violation, in addition to any other penalties prescribed.	Prohibits placing of any contaminants on land so as to create a water pollution hazard. Potential pollutants include wood residues, sand, silt, rock and agricultural wastes. Water quality standards developed to insure waters are free of floating debris and unnatural turbidity with potential to harm aquatic life.	Fish Protective Regulations (Ill. Rev. Stat. Ch. 111 1/2 Sec. 1001 to 1052) prohibit deposit of wastes in waters or placing of wastes where they may wash into waters, which are harmful to aquatic life. Specifically prohibits deposit of trash, trees, or parts of trees in or along banks of water. Pollution of Streams (Ch. 34 Sec. 3116) grants authority to counties to prevent pollution and issue stop orders for the discharge of pollutants. Local Land Resource Management Planning Act (Ch. 85 Sec. 5803 to 5809) authorizes local government to adopt ordinances to control land use. Purpose of act includes forest land and natural resource conservation. Forest Preserves (Ch. 96 1/2 Sec 6308). Silvicultural activities are permitted in preserves. Prohibits deposit of debris, trees or tree limbs or shrubbery in or along banks of waters within preserves (state or county owned lands). River Conservancy Districts (Ch. 42 Sec. 383 to 410.1) requires the Board of Trustees of river conservancy districts to control pollution through their police powers. Soil and Water Conservation District Law (T. 5 Sec. 106 to 138.2). Directors of districts may adopt land use ordinances for the control of erosion and sedimentation and prevention of water pollution with the approval of three-quarters of district landowners in a referendum. Flood Water Control (Ch. 19 Sec. 65 and 70) requires a permit for placement of woody plant material in or along banks of streams or for construction of stream crossings. Flood plains (Ch. 19 Sec. 65F). Requires a permit for any type of construction in designated floodplains.

Table C.2—Significant features of water quality legislation in the North —Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Indiana	Stream Pollution Control Act. Ind. Stat. Ann T.13 Sec. 1-3-1 to 1-3-18. Enacted 1943; amended 1945, 1949, 1957, 1978, 1985, 1987.	Stream Pollution Control Board and Department of Environmental Management.	Board adopts rules and regulations and establishes standards for the discharge of pollutants. Department issues permits for discharges. Board may issue cease-and-desist orders and bring enforcement actions for violations.	Civil action may be initiated for failure to comply with orders to cease polluting activities within 60 days of issuance. Additional civil penalty of $100 per day of violation past date specified in order or for additional days granted. Criminal: violations are Class B misdemeanor and subject to fine of up to $1,000 and/or 180 days imprisonment.	Act prohibits any discharges which may impair fish life. Broad definition of pollutant includes both organic and inorganic matter which is disposed of in any way into waters, including runoff and seepage.	Stream Obstruction Statutes (Ind. Stat. Ann. T.14 Sec. 2-5-9 and T.13 Sec. 2-4-4) prohibit the obstruction of any navigable waters or other waterway which prohibits the free passage of fish. Scenic and Recreational Rivers Preservation Act (T.13 Sec. 2-26-1 to 2-26-11) requires approval of the Department of Natural Resources Commission prior to harvesting below the high flood mark of designated rivers, which may be up to 200 feet River Commission Act (T 13 Sec 2-27-1 to 2-27-27). Activities which significantly alter the natural and scenic qualities of designated rivers are generally prohibited Individual river commissions have authority to issue permits for activities otherwise prohibited. Exception to permitting authority: activities visible from five feet above water surface Flood Control Act (T. 13 Sec 2-22-1 to 2-22-20) prohibits obstruction of any floodway which could adversely affect fish, wildlife or botanical resources.
Iowa	Water Quality Act. Iowa Code Ann. Sec. 455B. 171 to 455B. 210. Enacted 1965; amended 13 times, 1969 to 1986.	Department of Natural Resources and the Water Pollution Control Commission	Commissioner establishes water quality standards and rules for discharges in accordance with the Federal Water Pollution Control Act Department enforces rules and standards and issues permits. Department authorized to issue cease-and-desist orders.	Civil. up to $5,000 per day of violation Civil penalty provided in Act as alternative to criminal. Criminal:up to $10,000 per day of violation. Repeated offense: up to $20,000 per day of violation. False statement or misrepresentation: up to $10,000 and/or six months in prison.	Definition of water pollution includes any alteration or contamination which is injurious to fish or other aquatic life. Act authorizes local governments to adopt ordinances and regulations for land use in flood plain areas.	Erosion Control Law (Iowa Code Ann Sec. 467A 2 to 467A 75). Erosion control plan not required for timber harvest. However, operations must not exceed soil loss limits established for each district Logging road construction may require erosion control plan if more than 25,000 square feet of soil are disturbed Sec. 109.14 prohibits the obstruction of waters which impede the free passage of fish. Scenic Rivers System Act (Sec 108A 1 to 108A.7) authorizes political subdivisions to zone or otherwise establish land use controls along designated rivers
Maine	Protection and Improvement of Waters Act. Maine Rev. Stat. Ann. T.38 Sec. 361 to 489 Enacted 1954; amended 12 times, 1957 to 1985.	Board of Environmental Protection and municipalities under authority of the Board.	Board charged with the control and prevention of water pollution. Board issues permits and licenses, establishes water quality standards and parameters for the classification of waters Board also establishes criteria for mixing zones required for the dilution of pollutants.	Civil: from $100 to $10,000 fine per day of violation. Criminal: up to $25,000 per day of violation. False statement or misrepresentation: up to $10,000 and/or six months in prison. Court may order restoration of site.	Statute includes sand, dirt, rock and agricultural wastes of any kind as potential pollutants. Prohibited deposits include sawdust, chips, bark and other forest products refuse. Permit may be required for operations conducted below high water mark of ponds over ten acres and in protected river corridors. In wetlands, "normal and customary" forest practices are exempt from permit requirement Log driving is prohibited and the storage of logs in waters requires a permit. Permit required for dredge and fill operations and for construction of permanent structures within or adjacent to streams or rivers when spoil, fill or structure may wash into waters. Under Shoreline Zoning, (Sec. 435 to 447) timber harvesting within 250 feet of normal high water mark of waters, but not associated road construction, is exempt from permit requirements. Timber harvesting is prohibited within shorelands of ponds larger than ten acres in resource protection districts. Creation of clearings within 50 feet of the high water mark of a shoreline is also restricted.	Coastal Management Policies (Maine Rev. Stat. Ann. T.38 Sec. 1801 to 1803) establishes general policies for the protection of coastal resources, with potential application to forestry. Maine Land Use Regulation Law (T.12 Sec. 681 to 689) authorizes Land Use Regulation Commission to issue rules, regulations and standards for land use in unorganized townships. Harvesting and road construction may require permit and/or compliance with standards. Standards limit clearcut size and restrict slash disposal. Regulations require control measures be used to minimize sedimentation and erosion during road and stream crossing construction.

Maryland	Water Pollution Control and Abatement Ann. Code of Md. T.8 Sec. 1401 to 1502. Enacted 1957, amended 13 times, 1973 to 1987.	Department of the Environment.	Department is responsible for development and implementation of pollution control programs. Department adopts rules and regulations, establishes water quality standards, and issues permits. Department may order corrective actions for violations.	Civil: up to $10,000 fine per day Criminal. violation considered misdemeanor. Fine of up to $25,000 per day and/or imprisonment for up to one year Penalty doubled for repeated offenses. Falsification or misrepresentation: fine of up to $10,000 and/or six months in prison.	Statute prohibits the emission of soil or sediment into waters or placement of soil or sediment where it is likely to be washed into waters by runoff of precipitation or by any other flowing waters.	Scenic and Wild Rivers Act (Ann. Code of Md. T.8 Sec. 401 to 411) Harvesting in some river corridors is regulated by local ordinances Sediment Control Act (T.8 Sec. 1101 to 1104). Sediment control plan for harvests disturbing 5,000 square feet or more of soil, or which cross watercourses with drainage area in excess of 400 acres (100 acres for trout streams) Watershed Sediment and Waste Control (T 8 Sec. 1201 to 1210) Permits required for excavating, grading or filling operations in Severn or Patuxent watersheds Chesapeake Bay Critical Area (T.8 Sec. 1801 to 1816) applies to all land within 1,000 feet of mean high tide. Commercial harvests require approval of forest mgmt. & sediment control plans by district forestry board Harvesting prohibited within 50 feet of tidal waters and perennial streams. Clearcutting other than loblolly pine or tulip poplar prohibited within 100 feet of these waters; road construction regulated too.
Massachusetts	Clean Waters Act. Mass. Gen. Laws Ann. Chap. 21, Sec. 26 to 53. Enacted 1966; amended 14 times, 1967 to 1985.	Division of Water Pollution Control within the Department Environmental Quality Engineering.	Division has broad authority to promulgate rules and regulations, establish minimum water quality standards, and issue permits. Division may also issue cease-and-desist orders against violators.	Civil: up to $10,000 fine per day of violation. Criminal: fine of $2,500 to $25,000 and/or one year in jail. Department may order corrective action for violations.	Statute's definition of "pollutant" includes any element of agricultural, industrial or commercial waste, including runoff, whether originating at a point or major non-point source. Regulations exempt silvicultural operations including road construction from which there is natural runoff. Act specifies, however, that some silvicultural operations, such as stream crossings for roads, may require a Section 404 permit	Scenic and Recreational Rivers and Streams (Mass. Gen Laws Ann Chap. 21 Sec. 17B) Counties may regulate, restrict or prohibit activities which could alter or pollute protected rivers and streams. Ordinances could be adopted to restrict silvicultural activities. Protection of Coastal Wetlands (Chap. 130 Sec 105). Activities which involve dredge or fill or otherwise alter, or pollute lands subject to tidal action may be regulated, restricted or prohibited Alteration of Lands Bordering Waters (Chap. 131 Sec. 40) requires written notice of intent to fill, dredge, or alter freshwater or coastal wetlands or any land subject to tidal action and a plan describing activities and their effect on the environment. Pollution of Coastal Waters (Chap. 130 Sec. 23 to 27) prohibits discharge of injurious substances, including sawdust and shavings, which directly or indirectly injure fish in coastal waters Forest Cutting Practices Act (Chap. 132 Sec. 40–46) requires Intent to Cut/Cutting Plan for harvesting Also requires additional wetlands or steep slopes plan, if applicable. Wetlands plan exempts operations from state Wetlands Law (Chap. 131 Sec. 40). Regulations address harvesting systems, skid trail location, stream crossing and road construction Also limit clearcut size and require buffer and filter strips along streams. Additional rules for wetlands and steep slopes
Michigan	Act establishing Michigan Water Resource Commission. Michigan Compiled Laws, Title 3, Sec. 520 to 532. Enacted 1929; amended 1941, 1947, 1949, 1963, 1965, 1968, 1972, 1977.	Michigan Water Resources Commission.	Commission authorized to regulate the storage or discharge of any substance which may affect water quality. Commission establishes water quality standards and issues permits for discharges. Commission has control over alterations of watercourses, floodplains, rivers and streams and may prohibit their obstruction. Act prohibits filling or grading lands located in flood plains or streambeds, except for agricultural purposes, without a permit. Copper or iron mining operations may be exempted from this provision.	Civil: up to $10,000 fine per day of violation. Criminal: from $2,500 to $25,000 fine per day of violation Penalty doubled for repeated offense. Violator liable for restitution of damages to natural resources. Courts may impose probation in addition to fines.	Act prohibits discharge of any substance which is injurious to the value or utility of riparian lands or to fish, aquatic life or plants.	Stream Obstruction Statutes (Mich. Compiled Laws T.9 Sec. 334, T.13 Sec. 1657, T.9 Sec 1175, T.18 Sec. 231) prohibit obstruction of streams or navigable waters with logs, lumber, apparatus or waste materials which prevent the free passage of fish or obstruct navigation. Soil Erosion and Sedimentation Control Act of 1972 (T.13 Sec. 1820(1) to 1820(17)) Counties delegated authority to enforce rules and regulations issued by the Commission and issue or deny permits for activities which may result in erosion or sedimentation. Empowers local governments to adopt more stringent requirements than issued by Commission Act exempts logging from regulation. However, stream crossings constructed to conduct operations may require a permit Shorelands Protection and Management Act (T.13 Sec. 1831 to 1845) empowers Commission and local governments to adopt rules for land use along Great Lakes shorelands. Commission rules may restrict cutting or vegetation, requires buffer

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
						strips be retained and/or management plans in designated areas. Inland Lakes and Streams Act (T.11 Sec. 475 (1) to 475 (15) requires a permit for activities which: (1) dredge or fill bottomland; (2) place a structure in bottomland; or (3) structurally interfere with natural flow of inland lake or stream. Permit required for both temporary and permanent stream crossing. Natural Rivers Act of 1970 (T. 11 Sec. 501 to 516). Counties and townships may require a permit or restrict or prohibit cutting timber along some rivers. Act limits restricted corridor to 100 feet. Gaemaere-Anderson Wetlands Protection Act (T.18 Sec. 595 (51) to 595 (72)) exempts silviculture, lumbering, and harvesting of forest products from permit requirements. Act also exempts minor drainage to improve site for silviculture or lumbering.
Minnesota	Water Pollution Control Act. Minn. Stat. Ann. Sec. 115.01 to 115.83 Enacted 1961, amended 15 times, 1963 to 1987.	Minnesota Pollution Control Agency.	Agency granted broad powers to establish rules and standards and issue permits and orders for pollution control. Enforcement powers include actions to recover civil penalties, injunctions and actions to compel performance.	Criminal: violations considered misdemeanor. Fine from $300 to $40,000 per day and/or one year imprisonment. Second conviction: up to $50,000 per day and/or two years imprisonment. Civil: up to $10,000 fine per day of violation. Exempted from civil liability are acts of God, war, negligence of the state, or sabotage or vandalism.	Definition of "other wastes" includes sawdust, shavings, bark, sand and agricultural wastes. Pollutants include any discharges which are harmful to fish or other aquatic life.	Pollution of Waters Act (Minn. Stat. Ann. Sec. 144.35) and Work in Public Waters Act (Sec 105.42) prohibit the deposit of any sewage or other material which will impair the health of water or placing materials where they may fall or drain into a pond or stream. Sec. 105.42 includes excavation or filling activities. Public Waters and Wetlands Act (Sec. 105.37 to 105.391) empowers state to regulate activities which will change the course, current or cross-section of wetlands or public waters. Prohibits draining wetlands unless replaced with wetlands of equal or greater value. Silviculture not exempted. Any physical change below high water mark would require a permit, including logging road and skid trail construction and associated bridges and culverts. Shoreland Development Act (Sec. 105.485) requires counties and municipalities to adopt an ordinance for use and development of shorelands consistent with state model ordinance and rules. Current rules emphasize destruction of view. Proposed rules for silviculture include (1) maintaining buffer strips adjacent to waters; (2) restrictions for landing and yarding areas and skid and haul roads; (3) prohibition of clearing of vegetation on slopes 30 percent or greater; (4) requiring prompt reforestation; and (5) requiring permit and erosion control plan for forest conversions. Excessive Soil Loss Act (Sec. 40.19 to 40.27) encourages local governments to adopt soil loss ordinances consistent with state model and minimum standards. Forestry included as an "agricultural activity" in rules. A plan may be required for restoring erosion damage after harvest if soil loss is excessive. County Planning and Zoning Act (Sec. 394.21 to 394.26) grants authority to Board of County Commissioners to establish zoning districts for land use, including forestry. Floodplain Management (Sec. 104.01 to 104.07) encourages local governments to adopt ordinances for land use in flood-plains. Ordinances restrict fill, deposit or other use which unduly restrict the capacity of floodplains. Some counties require permit for logging road construction in floodplains. Wild and Scenic Rivers Act (Sec. 104.31 to 104.40). State rules prohibit clearcutting within designated distances of rivers depending on river classification. Trees greater than four inches in diameter may be removed provided continuous tree cover is maintained. County regulations may be adopted which are more restrictive than state.

Missouri	Clean Water Act. Ann. Missouri Stat. T.12 Sec. 644 006 to 644.141. Enacted 1972; amended 1973, 1982, 1983, 1987.	Missouri Clean Water Commission and Department of Natural Resources.	Commission granted broad powers to issue orders and permits. Commission adopt and enforce rules and regulations, and prescribes water quality standards. Department may initiate civil action to force compliance with standards and rules.	Criminal: $2,500 to $25,000 fine and/or one year imprisonment per day of violation. Subsequent convictions: up to $50,000 fine and/or two years imprisonment. False statement or misrepresentation: up to $10,000 fine and/ or six months imprisonment. Civil· up to $10,000 fine per day of violation. Action may be brought to restore damages.	Definition of pollution includes alterations of water turbidity and contamination which is harmful to fish and other aquatic life. Act states that contamination includes both direct and indirect sources including surface runoff. Commission authorized to conduct a planning process to identify silvicultural nonpoint sources of pollution and to develop procedures and methods, including land use requirements, to control sources.	Steam Obstruction Statute (Ann. Missouri Stat., T.16 Sec. 252.200) prohibits obstructing the free passage of fish through any waters of the state. Water Conservancy District Act (T.16, Sec. 257.010 to 257.490) empowers citizens to form river basin conservancy districts through which land use may be regulated.
New Hampshire	Water Pollution and Disposal of Wastes Act. N.H.R.S. Ann. Sec. 149:1 to 149:26. Enacted 1947; amended 11 times, 1955 to 1986.	New Hampshire Water Supply and Pollution Control Commission.	Commission has broad authority for the discharge of pollutants in waters and alterations near waters. Commission issues permits, promulgates rules and regulations, and classifies waters into one of four quality types Commission may issue cease-and-desist orders.	Civil: up to $10,000 fine per day of violation. Criminal: up to $25,000 fine per day and/or six months in prison.	Act includes decayed wood, sawdust, bark, shavings and other substances harmful to human, animal, fish or aquatic life as potential pollutants. Prohibits placing trees or parts thereof in waters. Detailed plans must be submitted for forest operations in lands bordering water. Upon approval of the Commission, a permit will be issued. Requirement can be circumvented by signing of an agreement to implement appropriate BMP's to protect water quality. If operator fails to comply with BMP's, he is subject to penalties under the law and will be required to submit detailed plans for future operations.	Fill and Dredge in Wetlands (N.H.R.S. Ann. Sec. 483-A:1 to 483-A:7) requires permit for some activities in wetlands such as construction of stream crossings. Slash and Mill Waste (Sec. 224:44-b) prohibits disposal of slash in waters or within 25 feet of streams or rivers capable of float-ing a canoe or within 50 feet of navigable rivers or ponds greater than 10 acres. Limits slash dispos-al to 4 feet above ground between 50 and 150 feet of ponds greater than 10 acres or navigable streams or rivers. Cutting of Timber near Public Waters and Highways (Sec. 224: 44-a) limits cutting of trees to 50 percent of basal area within 150 feet of ponds greater than ten acres and navigable streams and rivers or within 50 feet of any other continuously flowing stream or river.
New Jersey	Water Pollution Control Act N J. Stat. Ann. T.58 Sec. 10A-1 to 10A-37 Enacted 1977; amended 1981, 1984, 1986.	Department of Environmental Protection.	Commissioner of Department of Environmental Protection empowered to adopt rules and regulations, classify bodies of water and establish water quality standards for each class, and issue permits. Commissioner may, by regulation, exempt certain discharges from permit requirements. Possible exemptions include: (1) Uncontrolled nonpoint source discharges composed entirely of stormwater runoff; (2) nonpoint discharges in general; and (3) discharges of dredge and fill material.	Civil: up to $50,000 fine per day of violation. Criminal: fine of $5,000 to $50,000 and/or six months imprisonment per day of violation Penalty doubled for repeated offense. False statement or misrepresentation: up to $20,000 fine and/or up to six months imprisonment. Assessment of civil liability for damages.	Act defines pollutants to include dredged spoil, rock, sand, agricultural waste or other residue. Silvicultural nonpoint source pollution could be exempted at the discretion of the Commissioner through regulations.	Flood Hazard Area Control Act (N.J. Stat. Ann. T.58 Sec. 16A-50 to 16A-66) requires permits for land disturbing activities affecting more than 5,000 square feet in flood hazard areas. Logging road construction may require a permit for extensive operations. Stormwater Management Plan (T.40 Sec. 55D-93 to 99). Municipalities required to adopt ordinances to minimize stormwater runoff and control nonpoint source pollution. "Nonpoint pollutants" include silvicultural sources. To date, ordinances have not been adopted. Soil Erosion and Sediment Control Act (T.4 Sec. 24-39 to 24-55). Soil Conservation Committee establishes standards and may require plans for the control of sedimentation and erosion from land disturbing activities involving 5,000 square feet or more of soil. To date, plans have not been required for silvicultural operations. Could be applied when large areas are disturbed during logging road construction. Wild and Scenic Rivers Act (T.13 Sec. 8-45 to 8-54). Department of Environmental Protection establishes minimum standards for land use in river corridors. Municipalities may adopt rules and regulations more stringent than Department. To date, no regulations or standards have been adopted. Pinelands Protection Act (T.13 Sec. 18A-1 to 18A-49) applies to approximately one million acres. Pinelands Commission requires harvesting plan be approved by the Bureau of Forestry prior to issuance of a permit by the Commission. Act prohibiting the draining of deleterious substances into waters (T.23 Sec. 5-28 to 5-29.1) exempts application of chemicals on forest crops. Freshwater Wetlands Act(T.13 Sec. 9B-1 to 30) regulates dredging, draining, filling, and other alterations of freshwater wetlands, including cutting of trees. Exempt from permitting process are "normal" silvicultural operations; includes harvesting and road construction in compliance with BMP's and a management plan approved by State Forester. Conversion of wetlands to manipulate tree species composition not exempt.

Table C.2—Significant features of water quality legislation in the North—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
New York	Water Pollution Control Act. Cons. Laws of N.Y. Art. 17 Sec. 0101 to 1907. Enacted 1972; amended 12 times, 1973 to 1987.	Department of Environmental Conservation	Department determines classifications of waters and adopts standards of quality and purity for each class. Department adopts rules and regulations to prevent pollution and issues permits. Department authorized to issue cease-and-desist orders for violations.	Civil: up to $1,000 fine per violation Criminal: fine from $2,500 to $25,000 per day of violation and/or one year imprisonment. Penalty double for repeated offenses.	Potential pollutants include substances which may be harmful to aquatic life. Prohibited "industrial wastes" include substances resulting from the development or recovery of any natural resource, which may be a potential pollutant. Prohibited "other wastes" include sawdust, decayed wood, shavings and bark. Act prohibits the discharge of both organic and inorganic matter which is not in compliance with Department standards.	Wild, Scenic and Recreational Rivers (Cons. Laws of N Y Art 15 Sec 2701 to 2723). Regulations require a permit for clearcuts in excess of 25 acres and include numerous rules for road and stream crossing construction, felling and skidding trees, debris removal, and buffer strips in river corridors. Fish and Wildlife Law (Art. 11 Sec. 0501 to 0536) Act prohibits the deposit of sawdust, shavings, or bark in waters in amounts which would harm fish or wildlife. Prohibits obstruction of waters which hinder the passage of fish. Prohibits the deposit of soil in streams or on banks of streams inhabited by trout. Freshwater Wetlands Regulations (Art. 24 Sec. 0701 to 0705). Act regulates draining, dredging or filling of freshwater wetlands. Permits required for clearcuts within wetlands, but are usually not granted. Selective cutting is exempt from regulation. Clearcuts in areas adjacent to wetlands require permit, and are usually granted. Stream Protection Law (Art. 15 Sec. 0501 to 0503). Act requires a permit for changing, modifying, or disturbing streams or banks of streams within designated water classifications. Excavation or fill in navigable waters (Art. 15 Sec. 0505) requires permit for excavation or fill below the high water mark of navigable waters and in adjacent wetlands or marshes.
Ohio	Water Pollution Control Act. Ohio Rev. Code Ann. Sec. 6111.01 to 6111.99) Enacted 1953, amended 14 times, 1955 to 1984.	Department of Environmental Management	Department promulgates rules and regulations and establishes water quality standards. Department issues permits and orders for pollution control. Act prohibits placing any waste in a location where water pollution could result without a permit. Exception. application or runoff of materials used for agricultural purposes. Department may seek injunction against violators.	Criminal: up to $25,000 fine and/or one year imprisonment.	Definition of pollutant includes decayed wood, sawdust, bark shavings, other wood debris and silt.	Pollution Control Program (Ohio Rev. Code Ann. Sec. 1501.20) requires Soil and Water Conservation Commission to develop program for agricultural pollution abatement to meet state water quality standards. Commission currently has no enforcement power. Department of Natural Resources is seeking amendment for $100 fine per day for pollution resulting from agricultural (including silvicultural) sedimentation. Watershed District Law (Sec. 6105.01 to 6105.99) prohibits obstruction of restricted floodway without consent of Board of Directors of watershed districts.
Pennsylvania	Clean Streams Act. Penna. Stat. Ann. T.35 Sec. 691.1 to 691.1001. Enacted 1937; amended 1945, 1956, 1965, 1970, 1976, 1978, 1980.	Department of Environmental Resources and Environmental Quality Board	Department has broad authority to adopt rules and regulations and establish standards to control pollution. Department issues permits for discharges and may seek injunctions and issue orders for abatement of polluting activities.	Civil: up to $10,000 fine per day of violation. Criminal: from $100 to $10,000 fine for violation. Default of payment. 90 days imprisonment. Willful or negligent violations: from $2,500 to $25,000 fine and/or one year imprisonment. Additional offense within two years of first offense: from $2,500 to $50,000 fine and/or two year imprisonment	Act defines pollution to include contamination which is injurious to fish or other aquatic life and alterations resulting in changes in water temperature. Exempt from penalties is pollution in the form of sediment resulting from an act of God on land for which an approved conservation plan has been implemented. By inference, other causes of sedimentation, including that resulting from forest operations, would be subject to regulation. Under regulations issued under the Act, detailed, site specific plans are required for erosion and sedimentation control for silvicultural operations where earth disturbing activities exceed 25 acres.	Flood Plain Management Act (Penna. Stat. Ann. T.32 Sec. 679.101 to 679.601). Plans to control obstruction of flood waters implemented by local governments. Some may regulate forest operations. Storm Water Management Act (T.32 Sec. 680.1 to 680.17). Local governments may enact ordinances for the control of runoff and sedimentation and erosion. Some may regulate forest operations. Dam Safety and Encroachment Act (T 32 Sec. 693.1 to 693.27). Permit required for both permanent and temporary water crossings constructed during harvesting operations. Scenic Rivers Act (T.32 Sec 820.21 to 820.29). Recommended guidelines for silvicultural operations have been issued Protection of Property and Water Act (T.30 Sec. 2501 to 2506). Permits required for activities which alter streams, water or watersheds in any way which may damage fish.

Rhode Island	Water Pollution Control Act. Gen. Laws of R.I. T.46 Sec. 12-1 to 12-37. Enacted 1920; amended 24 times, 1921 to 1986.	Department of Environmental Management	Department empowered to adopt standards and issue rules and regulations for the control of water pollution. Department classifies waters and issues permits for the discharge of pollutants. Department has authority to issue stop orders for violations.	Civil. up to $5,000 fine per day of violation. Criminal: up to $10,000 fine and/or 30 days imprisonment per day of violation. False statement or misrepresentation: up to $5,000 and/or 30 days imprisonment.	Act defines pollutant to include agricultural wastes. Legislation is sufficiently broad to cover nonpoint sources of pollution. Act prohibits placing any pollutant where it is likely to enter waters or to place any solid waste materials, junk or debris whether organic or inorganic in waters.	Soil Erosion and Sediment Control Act (Gen. Laws of R.I. T 45 Sec 46-1 to Sec. 46-6) Cities and towns may require permits for earth disturbing activities Act exempts harvest activities on property utilized for silvicultural purposes. Road construction may require a permit and erosion control plan if extensive or if involving slopes greater than ten percent. Freshwater Wetland Act (T.2 Sec. 1-18 to 1-27) prohibits excavation, draining or filling of wetlands. Also prohibits placing garbage, earth, rock, sand or other materials in waters. Harvesting operations may require a management plan, depending on extent of operations.
Vermont	Water Pollution Control Act. V.S.A. T.10 Sec. 1250 to 1384. Enacted 1947; amended 15 times, 1949 to 1987.	Vermont Resources Board and Department of Water Resources and Environmental Engineering within the Agency of Environmental Conservation.	Act establishes classification parameters for waters. Board adopts standards of water quality for various classes. Agency establishes rules and regulations for pollution control and has authority to issue permits. Act addresses stormwater runoff and alteration of wetlands. Agency authorized to bring suit to force compliance with Act and may order corrective action for violations.	Civil: up to $10,000 fine per day of violation. Criminal: up to $25,000 fine and/or six months imprisonment per day of violation. Falsification or misrepresentation: up to $10,000 fine and/or six months imprisonment. Sawmill Waste: $100.00 fine per offense.	Act prohibits deposit of sawdust, shavings, edgings, slabs or other sawmill refuse into waters or placing wastes in such a manner as to wash into waters Forest operations must comply with acceptable management practices (AMP's) to be exempt from permitting requirements under Act. Department of Forests, Parks and Recreation issues AMP's.	Protection of Navigable Waters and Shorelands Act (V.S.A. Sec. 1421 to 1426). Municipalities authorized to adopt shoreland zoning bylaws to control pollution and protect fish and aquatic life. Some forest operations may be restricted. Water Resources Management Act (Sec. 901 to 923) grants broad authority to Water Resources Board for protection of wetlands. Board may not adopt rules which restrain silvicultural activities without consent of the Department of Forests, Parks and Recreation. An Act Relating to Regulation of Wetlands (Senate Bill 95 No. 188). Sections related to forestry duplicate Water Resource Management Act Rules and regulations currently being developed will restrict some forest operations such as draining wetlands to harvest and road and stream crossing construction in wetlands
West Virginia	Water Pollution Control Act. W. Va. Code, Chap. 20, Art. 5A-1 to 5A-21 Enacted 1969; amended 1976, 1978, 1983.	Division of Water Resources (within Department of Natural Resources) under authority of Water Resources Board.	Division of Water Resources is authorized to carry out requirements of Federal Water Pollution Control Act; has permit issuing authority and may issue stop orders. Exception: law does not apply to farm ponds, industrial settling ponds and water treatment facilities.	Civil: fine not to exceed $10,000 per day of violation. Fine can be imposed only by civil action initiated in circuit court of county where violation occurs. Criminal: violation considered misdemeanor; punishable by fine of $100 to $25,000 per day of violation and/or up to one year in jail Department of Natural Resources can initiate court action to recover costs of damage.	Law is sufficiently broad to include nonpoint pollutants under its provisions. Decayed wood, sawdust, shavings, and other wood residues are specifically listed as potential pollutants. Stringent water turbidity standards have been established. Exceptions for logging have been made where a site specific BMP plan is in effect.	Stream Obstruction Law (W. Va. Code Chap. 61. Art. 3-47) prohibits any felling of timber that would obstruct a navigable or floatable stream. Natural Stream Preservation Act (Chap. 20, Art. 5B-1 to 17) prohibits activities which obstruct the free-flowing characteristics of designated streams without a permit. Act has not been applied to forest operations to date.

Table C.2—Significant features of water quality legislation in the North—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Wisconsin	Water and Sewage Act. Wis Stat. Ann. Sec 144.01 to 144.27. Enacted 1913; amended 15 times, 1919 to 1986.	Department of Natural Resources.	Department has broad authority for supervision and control over state waters. Department develops regional plans, establishes water quality standards, adopts rules and regulations, and issues permits for discharges. Department may issue temporary emergency orders to protect public health and stop orders for abatement of pollution. Department required to prepare comprehensive plan for application of municipal ordinances regulating navigable waters and shorelands. Act authorizes municipal construction site erosion control and storm water management zoning ordinances. Department required to develop standards for ordinances.	$200 to $5,000 fine per day of violation.	Prohibits the disposal of garbage or refuse where it is likely to be washed into water. Prohibited are discharges which are deleterious to fish and unnecessary siltation resulting from gross neglect of land erosion. Act establishes a nonpoint source pollution program providing technical and financial assistance. Department promulgates rules and standards concerning BMP's which must be met for cost sharing grants.	Wetlands Zoning Act (Wis. Stat. Ann. Sec. 61.351) requires villages to enact ordinances consistent with Department of Natural resources (DNR) minimum standards to protect shorelands. Access roads and stream crossings for logging operations may require permit and/or be subject to DNR standards. Shoreland Zoning on Navigable Waters Act (Sec. 59.971) requires counties to enact zoning ordinances to protect shorelands within 1,000 feet of lakes and ponds and 300 feet from rivers and streams. Clearcuts are limited to 30 feet for each 100 feet along shorelands within a 35 foot corridor. Slash Disposal Act (Sec. 26.12) requires timber owners or operators to remove logging slash from lakes and streams. Environmental Impact Statement (EIS) Act (Sec. 23.40). DNR determines whether EIS required based on information submitted when applying for permit. Permit required for stream crossing, therefore would be subject to review. Soil and Water Conservation Law (Sec. 92.02 to 92.16) requires Department of Agriculture to develop model ordinances for land use for adoption by counties and municipalities. Local ordinances may restrict land management practices which cause excessive erosion, sedimentation, nonpoint source pollution, or stormwater runoff. Ordinances must be approved in referendum. Wild Rivers Act (Sec. 30.26) designates Pike, Pine and Popple rivers for preservation. Requires DNR to work with counties and towns to establish program for river protection. Requires DNR to cooperate with USFS, timber companies, and private landowners in implementing land use practices. Some ordinances restrictive to forest practices have been adopted. Lower St. Croix River Preservation Act (Sec. 30.27) requires local governments within designated protected areas to enact zoning ordinances in compliance with DNR guidelines and standards. Some ordinances have been restrictive to forest operations. Obstruction of Navigable Waters (Sec. 30.15) prohibits placing any obstruction in navigable water or tributaries which impedes navigation. Enlargement and Protection of Waterways Act (Sec. 30.19). Prohibits grading or otherwise removing top soil from banks of navigable waters which expose more than 10,000 square feet. Exempts agricultural land use. Changing of Streamcourse Act (Sec. 30.195) prohibits changing of course or straightening of navigable streams without permit. Under authority of Sec. 30.15, 30.19, and 30.195, both temporary and permanent stream crossings associated with logging require a permit.

Table C.3—Significant features of water quality legislation in the Rocky Mountain Region

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Arizona	Ariz. Rev. Stat. Ann. Sec. 49-201 to 321 resulting from additions, transfers and renumbering from Title 36 (enacted in 1956 with subsequent amendments). Enacted in 1986, effective 1987	Department of Environmental Quality.	Department to promulgate water quality standards for all navigable waters, and develop a program for control of nonpoint source pollution into such waters. As part of this program, Department may establish BMP's for silvicultural activities. Forestry operations may require either individual or general permit at Department's option. Department may issue order requiring initiate compliance with statutory provisions, order will become final and enforceable within 30 days unless administrative hearing is requested. Department may request a temporary restraining order, preliminary or permanent injunction, or any other relief necessary to protect public health.	Civil penalties up to $25,000 per day per violation plus costs of litigation. Monetary damages to be paid to water quality assurance revolving fund. Criminal penalties range from felony to misdemeanor depending upon whether the violator was fully knowledgeable, negligent, or reckless. Violators may also be responsible for remedial action costs.	Sections R9-21-202 to 205 of Administrative Rules and Regulations of Arizona 1986 prohibit water quality degradation. Otherwise, Department has no non-point source program beyond water quality standards. No forestry BMP's have been developed and none are expected. Only standards likely to affect forestry practices are turbidity and temperature. Regulations governing use of agricultural pesticides currently under development for protection of groundwater.	Ariz. Rev. Stat. Ann. Sec. 17-231, 237; requires cooperation between Department of Environmental Quality and Game and Fish Commission in abatement of water pollution injurious to wildlife. Commission may also bring suit in such matters. Ariz. Rev. Stat. Ann. Sec. 45-573 requires cooperation between Department of Environmental Quality and Department of Health Services on development of water quality management plans.
Colorado	Colorado Water Quality Control Act. Colo. Rev. Stat. Sec. 25-8-101 to 703. Enacted 1973, supplemented 1986.	Department of Health through Water Quality Control Commission.	Policy objectives of legislation are two-fold. (1) protect quality of water resources, and (2) maximize the beneficial use of water resources consistent with the welfare of the state. Act does not supersede or materially diminish prior established water rights. Water Quality Commission within Department has authority to classify waters and promulgate water quality standards to control pollution. In developing standards, Commission is directed to consider whether pollution is from a natural source. Commission may promulgate regulations for the keeping of logs in water. Commission may not adopt standards for agricultural nonpoint sources of discharge which materially injure existing water rights. Department is to administer standards and programs developed by Commission. Department required to establish permit system for regulation of point sources of pollution; there are no particular provisions governing nonpoint sources. Department may issue "cease and desist" and "clean-up" orders. Failure to comply with such orders may result in temporary restraining order or injunction.	Civil: up to $10,000 per day of violation. Civil penalty credited to water quality control fund. Criminal: up to $12,500 if violator is negligent or reckless, up to $25,000 if violator is fully knowledgeable of the offense.	Standards that may be promulgated under the Act's authority which could impact forest management include those for turbidity, temperature, and suspended solids. At present, however, there are no standards for turbidity and suspended solids, and there is no program for regulation of nonpoint pollution sources. No forestry BMP's have been developed. An assessment and management plan for nonpoint sources of pollution is currently under development. No reference exists for excluding forest management operations from the point source pollution permit requirement as there is for irrigation return flow.	Colorado Soil Conservation Act (35-70-101 to 121) established State Soil Conservation Board to conserve and protect water resources, including: (1) the initiation of watershed planning to prevent flooding, and (2) the construction of structures to maintain soil stability and control erosion. Colo. Rev. Stat. 33-5-101 to 106 provides that no state agency may modify a watercourse without notification and a permit to insure protection of fishing streams. Law does not operate to diminish existing water rights and does not apply to irrigation projects. State Board of Agriculture has authority under Colo. Rev. Stat. 23-30-202 to "foster and promote" control of soil erosion on forest lands. Pesticide Applicators' Act (Colo. Rev. Stat. 35-10-101 to 125) provides that regulation of distribution, use, and application of pesticides is to involve balance of social utility and cost. Colo. Rev. Stat. 36-8-101 to 110. Regulates use of streams for floating logs to be used for any purpose; such use requires a permit from state engineer. Colo. Rev. Stat. 20-30-202 authorizes State Board of Forestry to "foster and promote" the control of soil erosion on forest lands. Colo. Rev. Stat. 23-30-301 states that policy objective of Colorado State Forest Service is to: "conserve forest cover on watersheds".

Table C.3—Significant features of water quality legislation in the Rocky Mountain Region—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Idaho	Environmental Protection and Health Act of 1972. Idaho Code, Sec 39-101 to 118. Enacted 1947, amended 1973, 1979, 1980, supplemented 1987.	Department of Health and Welfare, Environmental Protection Division.	Department to promulgate and enforce regulations to enhance and preserve water quality. Department authorized to recommend rules to Board of Health and Welfare regarding water pollution, and issue permits as prescribed by law. Department also authorized to conduct investigations of violations of water quality standards. Department may use compliance schedule to assure timely compliance with regulations. Department authorized to implement water quality standards adopted by legislature	Civil penalty of $1,000 per day of violation or $10,000, whichever is greater, plus reimbursement of remedial costs incurred by the state. Criminal. willful or negligent violation is misdemeanor offense punishable by fine of up to $300 for each violation. Each day a violation occurs is separate offense.	Water quality standards acknowledge economic necessity of nonpoint pollution activities. Management of nonpoint pollution designed to only reduce such pollution; state's position is that it cannot be eliminated without severe economic impact Generally, standards prohibit sediment in quantities which impair beneficial use of water. Nonpoint sources of pollution specifically include silt, sand and rock resulting from silvicultural activities, or from log storage in water Silvicultural BMP's designed to protect water quality established in rules promulgated under Forest Practices Act (Idaho Code Sec. 38-1301 to 1312) These rules certified as approved water quality BMP's by Section 16.01 2300.05 of water quality standards issued by Department BMP's are mandatory for all forestry operations. Department responsible for evaluation and modification of BMP's to insure protection of beneficial use of water. Failure to meet water quality standards is *not* violation of law, but rather occasion for evaluating effectiveness of BMP's in protecting water quality. Operators failing to follow BMP's are subject to compliance schedule and fine. Injunctive and judicial relief are also available. Where BMP's have not been developed, activity must be conducted to minimize detrimental impact to water	The Idaho Forest Practices Act (Idaho Code Sec. 38-1301 to 1312) authorizes promulgation of rules to establish BMP's to protect water quality during all phases of forest management. Drainage systems must control runoff waters from exposed surfaces. Slash and waste materials must not enter streams. Streams to be protected by avoiding skidding and cable yarding in or through them, and by retaining vegetation to shade water and stabilize soil. Chemical, road construction, and reforestation BMP's are also designed to protect water quality. BMP's last evaluated for effectiveness in protecting water quality in 1985. Results indicated that revision of Forest Practices Act rules was necessary. Rules revised in 1986 and incorporated into 1987 draft of Forest Practices Water Quality Plan Feedback cycle for continuous proposal, implementation, and evaluation of BMPs also included. Violation of BMPs is misdemeanor. Stream Channel Protection Act (Idaho Code 42-3801 to 3812) protects against deleterious alteration of stream channels. Alterations impacting wildlife, aquatic life, recreation, or other facets of water quality require a permit from Department of Water Resources. Act does not diminish existing water rights. Failure to obtain permit (misdemeanor) may result in fine of $150 to $500, plus additional fine of up to $150 per day that violation continues. Department has issued regulations governing stream channel alterations, these are certified as approved BMP's which are mandatory for forestry operations Idaho Code Section 52-101 provides that unlawful obstruction of free passage or use, in customary manner, of any navigable lake, or river, stream, canal or basin is considered public nuisance. Idaho Code Sections 42-3601 to 3604 provide that Department of Lands is to cooperate with federal agencies in planning "works of improvement" (as per Watershed Protection and Flood Prevention Act of 1954, 16 USC Sec. 1001-1009) to prevent erosion, floodwater, and sediment damage. Idaho Code Sections 58-101, 140 to 147 provides that encroachments into lakes regulated by Board of Land Commissioners. Violators subject to fine ranging from $150 to $2500 Idaho Code Sections 58-401-405 provide that trees on state lands needed for conservation of irrigation water cannot be felled. Nonmerchantable dead and down timber on state land not required for water conservation (soil stabilization) may be informally sold by Department of Lands as firewood. Department of Water Resources must be given notice and opportunity to interpose objections prior to any timber sale.
Kansas	Water Supply and Sewage Act. Kansas Stat. Ann. Ch. 65 Art 16 Sec. 1 to 71W. Enacted 1897; amended 1909, 1923, 1927, 1967, 1974, 1977.	Department of Health and Environment	Department establishes water quality standards and issues permits for the discharge of sewage. Department adopts rules and regulations for petroleum products storage, salt solution mining and laboratory certification where water sample analysis conducted. Department may issue stop orders for violations.	Criminal: $2,500 to $25,000 fine per day of violation. False statement: up to $10,000 fine per day. Civil: up to $10,000 per day of violation. Violators also liable for costs of restoration of damages.	Definition of pollutant includes alterations which are harmful to plant, animal or aquatic life.	Stream Obstruction Statutes (Kansas Stat. Ann. Ch 32 Art 1 Sec 2, Ch 82A Art. 3 Sec 01 and Ch. 24 Art 2 Sec. 06) prohibit: (1) obstructing the free passage of fish, (2) willful obstruction or filling of any drain, ditch or watercourse, and (3) obstructions which change or diminish the course, current or cross-section of waters Floodplain Regulation Act (Ch. 12 Art. 2 Sec. 06) grants local governments the authority to establish floodplain zones and restrict land use through ordinances and regulations. Must be approved by Chief Engineer of Water Resources.

Montana	Montana Water Quality Act. Mont. Code Ann. Sec. 75-5-101 to 75-5-641. Enacted 1967; amended 1971, 1973, 1974, 1975, 1977; supplemented 1985.	Department of Health and Environmental Sciences.	Purpose of Act is to protect both quality and quantity of water. Board of Health and Environmental Sciences authorized to adopt rules to achieve this objective, including classification of all waters and development of water quality standards. Standards and classes not to allow water to be degraded below its existing state, unless justified by economic or social development. Water quality standards need not exceed "natural" level of quality, where "natural" is defined as conditions or material present from water runoff over which man has no control or from developed land where all reasonable land, soil, and water conservation practices (BMP's) have been applied. New sources of pollution require permit, existing quality level must be maintained	Civil: violators subject to fine of up to $10,000. Each day of violation constitutes separate offense Criminal: willful or negligent violators subject to fine of up to $25,000 per day of violation and up to one year in prison. Subsequent convictions subject violators to $25,000 (maximum) fine and two years imprisonment.	Water quality standards focus on "natural" quality of water. Standards classify water by beneficial use, e.g. with respect to water classified for lower beneficial uses, greater deviation is allowed from level of pollutants naturally occurring in the stream. However, land management activities must not generate pollutants in excess of natural levels, regardless of stream class Forestry BMP's developed by Department of State Lands include guidelines on road construction, harvesting, reforestation, and fire suppression. Under Memorandum of Understanding, both private and public forest managers have agreed to abide by established BMP's. Runoff and sedimentation acceptable if reasonable conservation practices (BMP's) are applied and beneficial uses of water are maintained. Exceptions to nondegradation rules allowed based on need for social and economic development.	Mont. Code. Sec. 76-13-101 to 601 provide for protection and conservation of forest, water, and range resources including regulation of streamflow and prevention of soil erosion. Mont. Code Sec. 75-6-101 to 13 provide for the protection of public water supplies Prohibit building logging camps or roads near public water supplies, and industrial waste discharge from development of natural resources into such waters. The Natural Streambed and Land Preservation Act of 1975 (Mont. Code Sec. 75-7-101 to 124) prohibits unauthorized alteration of streambeds. Board of Natural Resources and Conservation authorized to issue regulations governing streambed alterations. Existing water rights are preserved. Failure to obtain permit may subject violator to fine of $25 to $500 per day plus remedial costs Mont Code Section 27-30-101 declares any obstruction or injury of navigable lake, river, bay, stream, or canal to be a nuisance Mont. Code Sec. 75-7-201 to 217. Permit required for alteration of lakeshores
Nebraska	Environmental Protection Act. Rev. Stat. Neb. T.81 Sec. 1501 to 15,127. Enacted 1971; amended 12 times, 1972 to 1987	Department of Environmental Control and Environmental Control Council.	Council adopts rules and regulations and sets standards for land, air and water quality. Department enforces provisions of the Act and Council rules and regulations. Department issues permits and may order violator to take corrective action Department may grant variances Act addresses litter control and disposal.	Criminal: up to $5,000 fine per day of violation and/or six months imprisonment. Civil: up to $5,000 per day of violation Violators responsible for pollution resulting in the death of fish or wildlife are liable for compensation to state for restocking fish or replenishing wildlife. Prosecutions civil in nature except where clear criminal intent or knowing violation takes place.	Legislative authority sufficiently broad to include nonpoint sources of pollution. Purpose of Act includes the protection of fish and other aquatic life.	Floodplain Management Act (Rev Stat Neb. Sec 31-1001 to 31-1031) requires a permit prior to obstruction of any watercourse or floodplain. Nebraska Natural Resource Commission develops and adopts minimum standards for incorporation into local governmental regulations. If not adopted by local governments, state regulations are automatically effective. Littering of Waters Act (Sec. 37-516) prohibits placing litter, trash, lumber or any material injurious to aquatic life in or near waters. Fishway Through Dams Act (Sec. 37-406) requires owner of dam or other obstructions across watercourse to insure flow of water sufficient for support of aquatic life Stream Obstruction Statute (Sec 455.160) prohibits and deems a nuisance any obstruction, diversion, filling up, ditching or draining any watercourse which has been prohibited by a resolution of the drainage district. Erosion and Sediment Control Law (Sec. 2-4601 to 2-4613) requires natural resource districts to adopt a program for implementation of state's erosion and sediment control plan, including soil loss limits Regulations must be at least as stringent as state's. Silvicultural activities are regulated under the law.
Nevada	Nevada Water Pollution Control Law. Nev. Rev. Stat Sec. 445.131 to 445.354. Enacted 1973; amended 1977, 1979, 1981, 1985.	Division of Environmental Protection within Department of Conservation and Natural Resources	Purpose of Act is to maintain quality of water consistent with beneficial uses and encourage use of pollution control methods State Environmental Commission authorized to adopt water quality standards and regulations to control nonpoint source pollution Standards must protect designated beneficial use of each stream segment Standards proposed may vary from those based on recognized criteria if circumstances justify. If existing water quality exceeds applicable standard, water quality must be maintained at the higher existing level.	Director may issue corrective order to remedy diffuse source of pollution, but no civil or criminal penalty other than injunctive relief or temporary restraining order may be imposed. Diffuse source violators are excepted from monetary penalties.	Commission authorized to regulate diffuse (non-point) sources of pollution, including those emanating from silvicultural operations, in order to enforce non-degradation policy of water quality standards. Diffuse source discharges must be controlled by reasonable methods, based on particular location and economic capability of project or development. Silvicultural activities exempt from discharge permits unless certified as significant contributor to pollution. Municipalities charged with administering pollution control regulations promulgated by Commission.	Nev Rev Stat Sec. 472.043 provides for the maintenance of vegetative cover on forest and watershed land in order to conserve water and soil. State Forester Firewarden is authorized to enter into contracts and take other measures designed to meet this objective. Nevada Forest Practices Act of 1955 (Nev. Rev Stat Sec 528.010 to 528 120) requires issuance of a permit prior to any logging or cutting operation. Permit mandates submission of a logging plan, including proposed road construction specifications and erosion control measures. Tractor logging on slopes in excess of 30 percent gradient requires a variance from State Forester Firewarden Erodibility of soil must be considered in variance application. Variance is also required to harvest trees.

Table C.3—Significant features of water quality legislation in the Rocky Mountain Region—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
					Forestry operations must utilize BMP's developed by State Board of Forestry under state Forest Practice Act, for non-point pollution control. Accepted forestry BMP's focus on five planning criteria for control of runoff and sedimentation resulting from forest management activities: silvicultural treatments, logging methods, erosion control and road-building, hazard reduction, and forest protection.	operate equipment or construct logging roads within 200 feet of a body of water. Erosion control is primary objective. Nevada Forest Practices Act of 1955 is also reflected in numerous management specifications to prevent runoff and sedimentation. State Forester Firewarden authorized to adopt BMP's under the Act. As discussed above, regulations under Water Pollution Control Law require that selected BMP's, depending on particular situation, be utilized in conjunction with forestry operations in order to control non-point water pollution. Nev. Rev. Stat. Sec. 503.430 Forest products processing waste such as sawdust, shavings, etc. introduced into water at any time in a manner deleterious to fish is a misdemeanor offense. Nev. Rev. Stat. Sec. 445.080 to 120 concern the protection of Lake Tahoe. Permit required for alteration of shoreline. Nev. Rev. Stat. Sec. 445.100 authorizes State Environmental Commission to adopt regulations concerning Lake Tahoe watershed. Any timber operations within Tahoe Basin must have approval of Tahoe Regional Planning Commission. Nev. Rev. Stat. Sec. 244.365. Boards of County Commissioners authorized to bring suit against any violator who deposits sawdust in any river or stream. Nev. Rev. Stat. Sec. 535.100. Lumber mills prohibited from obstructing natural stream flow
New Mexico	Water Quality Act N.M. Stat. Ann. Sec. 74-6-1 to 13 Enacted 1978: amended 1985, supplemented 1986.	Water Quality Control Commission (composed of officials from relevant state resource management agencies). Lead agency is Department of Health and Environment.	Commission authorized to adopt comprehensive water quality standards, regulations, and classifications. Fixed-term, individual variances can be granted if compliance with regulations is unduly burdensome. Commission may require permit, issued by constituent agencies charged with administration of standards and regulations. No regulation or water quality standard is adopted until after public hearing. Persons affected by regulations may petition court for relief. Court may strike regulations which are illegal, arbitrary, or not supported by evidence as to their purpose. Commission may seek injunctive relief. Commission *not* authorized to regulate pollution confined entirely within property on which it occurs.	Civil: penalties not to exceed $1,000 for each violation. Each day violation occurs is separate offense. Violators also liable for reasonable remedial costs. Violation of permit regulations is misdemeanor punishable by fine of $300 to $10,000 per day and one year imprisonment. Civil penalty for permit violation may not exceed $5,000 per day.	Water quality standards as such are unenforceable, but are primarily used as guidelines in evaluating discharge permits. The standards primarily affecting forest management activities are those protecting high quality cold water fisheries and domestic water supplies. These standards are very stringent. Water quality regulations prohibit disposal of refuse in a natural watercourse. Voluntary guidelines (BMP's) concerning most aspects of forest management have been certified by Water Quality Control Commission. State water quality management plan requires evaluation of effectiveness of voluntary BMP's in protecting water quality. Evaluation was due at end of 1987, after three year trial period.	Forest Conservation Act (N.M. Stat. Ann. Sec. 68-2-1 to 25) authorizes Forestry Division of Natural Resources Department to enforce all laws and regulations concerning logging and forest land conservation in order to maintain water quality. N.M. Stat. Ann. Sec. 30-8-2. Water pollution defined and declared a public nuisance, punishable as a misdemeanor. N.M. Stat. Ann. Sec. 17-4-29 requires persons floating logs, timber, or other forest products to deposit 1000 trout fingerlings annually into fisheries specified by Department of Game and Fish. Violation of statute is a misdemeanor, but statute is rarely if ever enforced. N.M. Stat. Ann. Sec. 72-10-2 authorizes commissioners elected from community to bring suit against any person who obstructs community spring, dam, or breakwater.

North Dakota	Water Pollution Control Law. N. Dak. Century Code, Sec. 61-28-01 to 61-28-06. Enacted 1967; amended 1969, 1971, 1973, 1975, 1983.	Department of Health and Water Pollution Control Board	Department authorized to adopt rules and regulations for pollution control and establish water quality standards. Department issues permits and orders. Department may seek injunction to stop violations.	Criminal: up to $25,000 fine per day of violation and/or one year imprisonment. Penalty is doubled for second offense. Civil: up to $10,000 fine per day of violation.	Definition of pollution sufficiently broad to include nonpoint sources. Rock, sand and agricultural wastes are potential pollutants.	Soil Conservation District Law (N. Dak. Century Code, Sec 4-22-01 to 4-22-51). Land use regulations, including those for forestation and reforestation, may be adopted upon approval of two-thirds of the voters in the district through referendum. Obstruction of Watercourse Statute (Sec. 61-01-07) prohibits obstruction of or diversion of water from any ditch, drain or watercourse. Water Resource District Law (Sec. 61-16.1-09 to 61-16.1-52). District boards are authorized to adopt rules and regulations to prevent pollution or other misuse of water resources, streams or bodies of water. Permit required for draining ponds, sloughs, or lakes over 80 acres in size. State engineer empowered to take action to rehabilitate damages. Floodplain Management Act (Sec. 61-16.2-01 to 61-16.2-13) requires communities to adopt ordinances in compliance with national flood insurance program. Encourages communities to adopt and enforce floodplain management ordinances. Activities which increase base flood level prohibited. Little Missouri Scenic River Act (Sec. 61-29-01 to 61-29-06). Little Missouri River Commission empowered to promulgate management policies. Prohibits diversion of water for purposes other than agriculture, recreation, or dredging on Missouri River or tributaries of river.
South Dakota	Water Pollution Control Act, S. Dak. Code Laws Ch 34A-2 Sec. 1 to 99. Enacted 1935, amended 15 times, 1939 to 1987	Department of Water and Natural Resources under authority of Water Management Board.	Water Management Board authorized to issue water quality and effluent standards, classify waters as to beneficial uses, and establish rules for issuance of permits. Department issues permits and enforces permit conditions, and may issue orders for prevention, abatement, or control of pollution Board may initiate court action against continuation of a violation or failure to comply with an emergency order.	Violations Class 1 misdemeanor. Criminal: up to $10,000 fine per day of violation and up to one years imprisonment. Civil: up to $10,000 per day of violation.	Definition of pollution includes alterations which exceed water quality standards for temperature or turbidity or which are likely to be harmful to birds, fish or other aquatic life. Potential pollutants include agricultural wastes, rock, sand and dredged spoil. Act infers it is applicable to non-point source discharges (Sec. 34A-2-39.1).	Restriction on Riparian Use Act (S. Dak. Code Laws Ch. 46 Sec. 5-1) prohibits polluting of natural springs or streams and activities which will alter their natural flow. Ch.46 Sec. 5-1.1 prohibits obstruction of navigable waters. Scenic Rivers Act (Ch. 46A-1-15 to 16) authorizes the Board of Water and Natural Resources to designate certain rivers or sections of rivers as wild, scenic, or recreational. After designation, no development shall occur which alters natural and scenic beauty. Act establishing Watershed Districts (Ch. 46A-14 Sec. 1 to 92). Watershed districts may be established to regulate the flow of streams, diversion of watercourses, and for imposition of preventative or remedial measures for control of soil erosion and siltation of watercourses. Soil Erosion and Sediment Damage Law (Ch.38-8A Sec. 1 to 28). Conservation district supervisors required to develop standards for control of erosion and sediment resulting from land disturbing activities. Political subdivisions responsible for granting permits. Process must insure activities are in compliance with standards. Some activities require submission of a plan. Agricultural activities, including forestry, are exempt provided standards are met. Protection of Fishing Waters Act (Sec. 41-13-1 to 41-13-11) prohibits the placement of sawdust, refuse or sedimentary materials into waters supporting game fish or to deposit it in such a way as to be carried into waters by natural causes.

Table C.3—Significant features of water quality legislation in the Rocky Mountain Region—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Utah	Utah Water Pollution Control Act. Utah Code Ann. Sec. 26-11-1 to 20. Enacted 1953; amended 1981, 1982, 1987, supplemented 1987.	Water Pollution Control Committee (composed of Director of Department of Health and eight members appointed by governor), under Department of Health.	Committee to develop programs to prevent, control, and abate new and existing water pollution. Committee may promulgate water quality and effluent standards, and classifications based on "reasonable uses". Discharge of any pollutant into water which menaces public health or impairs beneficial uses of waters is public nuisance. Governor may identify areas with water quality problems. Committee authorized to classify waters according to reasonable present and future use, and to issue water quality standards for each classification. Public hearing required prior to promulgation of water quality standards or classes. Committee may seek injunctive relief, or compliance order.	Civil: up to $10,000 per day, or up to $25,000 per day for willful or grossly negligent violation of Secs. 26-11-8(2) and 26-11-14 Subsequent violations: maximum penalty of $50,000 per day.	Forest lands generally fall into "Class 1 and 2" lands for the protection of domestic, recreational and other beneficial water uses. Turbidity and temperature standards are the ones most relevant to forest management. Discharges which do not meet use classification standards are prohibited. Water quality standards require existing quality not be degraded, unless reduction justified by economic or social development. Water for human consumption protected by higher standards. Diffuse sources of pollution (non-point) into such waters must be controlled by either BMP's or regulatory programs. No statewide system of forestry BMP's exists, but certain local BMP's are certified under state 208 water quality plan. Voluntary inclusion of BMP's in timber sale contracts has been effective in meeting water quality standards. State-wide certification of forestry BMP's is underway.	Utah Code Ann. Sec. 23-15-6 prohibits pollution of water crucial to wildlife, including aquatic life. Utah Code Ann. Sec. 76-10-203 prohibits obstruction of irrigation watergates by floating logs or timber (antiquated). Utah Code Ann. Sec. 17-8-5.5 Counties may issue ordinances for protection of flood plains and channels. Utah Code Ann. Sec. 65-1-75 authorizes State Land Board to take necessary measures to prevent damaging floods and conserve state's natural resources. Statute recognizes role of improper timber management in flooding and authorizes Board to take steps to prevent flooding resulting from poor timber management. Utah Code Ann. Sec. 63-11-17.5 authorizes Division of Parks and Recreation to regulate development on lands within their jurisdiction. Division may impose regulations which are stricter than municipal ordinances.
Wyoming	Wyoming Environmental Quality Act (Wyo. Stat. Sec. 35-11-101 to 1104. Enacted 1973; amended 1977, supplemented 1987.	Environmental Quality Department.	Discharge of any pollutant into water or alteration of physical, chemical, or biological properties of water is prohibited, except by permit. Division of Water Quality may develop regulations and water quality standards, including effluent limitations, and classify surface waters.	None specified.	Water quality standards serve as indicator as to whether BMP's should be developed. Violation of water quality standards by a nonpoint source is sufficient justification for development of BMP's. Water quality indicators relevant to forestry include water temperature and turbidity. To date, only turbidity has been used to limit forestry activities. Currently, no BMP's established for harvesting activities. Forest Management activities considered to have only minor impact on water quality in state. However, voluntary silvicultural BMP's are currently under development.	Wyo. Stat. Sec. 11-16-101 to 132 establish soil conservation districts to promote soil conserving practices Wyo. Stat Sec. 35-4-202. Sawmill owners who dump sawdust or chemical wastes into *natural* stream or lake thereby killing fish or rendering water impure are guilty of misdemeanor. Violation punishable by fine of $50 to $100 or imprisonment from one to six months. Each day of violation is separate offense. Wyo. Stat. Sec. 41-5-108 requires permit for floating logs in streams or rivers (antiquated). Wyo Stat. Sec. 41-8-101 to 126 create watershed improvement districts as subdistricts of soil conservation districts. Each improvement district must lie within a watershed. Improvement districts authorized to develop local watershed protection programs and ordinances, which could impact silvicultural activities.

Table C.4—Significant features of water quality legislation in the Pacific Coast Region

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Alaska	Alaska Stat. Sec. 46.03.050 to 130, 320 to 800, 850. Enacted 1969, amended 1977, 1978, 1980, 1981, 1982, supplemented 1986.	Department of Environmental Conservation.	Law provides general prohibition of water, land and air pollution which has withstood constitutional challenge. Department may propose water quality standards and determine qualities and properties of water which indicate a polluted condition. After public hearings, Department authorized to develop water quality standards, classify waters as to minimum quality, or both. A short term variance from standards is available if economic or social development justify water quality reduction. Department also authorized to regulate use of pesticides. Activities impairing domestic water quality are prohibited as a nuisance. Department may issue compliance order for violation of water quality standards.	Civil penalty for initial violation ranges from $500 to $100,000 and up to $5,000 for each day violation continues. Penalty determined by degree of environmental damage, investigation and litigation costs, and economic savings realized by the violator. Violator is also liable for cost of restoring environment to original condition. Court may grant temporary or preliminary equitable relief. Violations punishable as misdemeanors. Each day a violation occurs is a separate offense.	Department has created water quality "use classes" which specify the degree of degradation not to be exceeded by human activity. Forest management is impacted by turbidity and sedimentation water quality parameters and pesticide regulation. Water quality standards consider social and economic factors as well as scientific criteria for protection of environment. Voluntary BMP's (in conjunction with Alaska Stat. 41.17.010) regulate forest management activities to meet requirements of water quality "use classes". Since BMP's are voluntary, standards may be enforced whether or not BMP's are being used.	Alaska Stat. Sec. 41.17.010 to 950 established Division of Forestry within Department of Natural Resources to execute forest management standards, policies, and guidelines. Department of Natural Resources may develop regulations for control of nonpoint sources of pollution, in cooperation with Department of Environmental Conservation. Scope of regulations includes all aspects of forest management with recognition of environmentally sensitive areas (e.g. stream buffer zone for eagle habitat) and BMP's. As voluntary guidelines, BMP's are not site-specific, but must be adapted to protect the water resources of the area. Department of Natural Resources is charged with review of proposed forest management plans and subsequent inspections to ensure compliance with water pollution regulations. Departments cooperate to evaluate plans to use broadcast chemicals. Violators are liable for civil fine up to $10,000, depending upon the amount of environmental damage, economic savings reaped by the violator, degree of intent or negligence, and past violations. Department of Natural Resources may issue a temporary stop order if violation is likely to result in irreversible harm. Department of Natural Resources may not usurp the statutory authority of other state agencies, unless authorized by Alaska Coastal Management Act or by the Department of Environmental Conservation. Alaska Stat. Sec. 16.05.870 to 900 provides that Department of Fish and Game shall identify specific water bodies important to spawning, rearing and migration of anadromous fish and review plans to use such waters (e.g. log dragging). Use of these waters without Departmental review and approval is a misdemeanor punishable by a $1,000 (maximum) fine. Violator is liable for restoration costs and other penalties imposed by the court. Alaska Stat. Sec. 16.10.010 prohibits the dumping of waste such as tree limbs or foliage, stumps, sawdust, planar shavings, earth or other debris into salmon spawning streams in support of the policies underlying Sec. 16.05.870. Permit for obstruction of such waters required by Department of Environmental Conservation. Violation of Sec. 16.10.010 is a misdemeanor punishable by a fine of $100 to $500. Alaska Stat. Sec. 16.20.185, 16.20.240 to 260 requires Department of Fish and Game to protect habitat of endangered species. Board of Fisheries and the Board of Game authorized to adopt regulations governing the taking of fish and game from critical habitat areas. Before land in these areas may be developed, leased or otherwise disposed" of, the Department of Fish and Game must be notified. Written approval of the plans for disposal of the land from the Department may be required. 5 AAC 95.010 to 990, regulations for management activities on game refuges and critical habitat areas, require a permit for such activities and mitigation of adverse environmental impacts. 6 AAC 80.100 incorporates Alaska Stat. 41.17 into Alaska Coastal Management Program. Attorney General's opinion (J-66-224-79) indicates that the Department of Natural Resources's regulation of forest management practices preempts only the forest management standards of Alaska Stat. 46.40 (Coastal Zone Management Act), and not the entire act.

Table C.4—Significant features of water quality legislation in the Pacific Coast Region—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
California	Porter-Cologne Water Quality Control Act, California Water Code. California Stat. Sec. 13000 to 13361. Enacted 1969; effective 1970. Amended 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1982, 1984, 1985, 1986.	Water Resources Control Board.	Authorizes Board to formulate water quality policy and to promulgate regulations for protecting water quality. Cities and counties may also adopt regulations, which must be consistent with those issued by Board. Identifies nine water quality regions and authorizes regional board for each. Provides for State Water Quality Control Plan, which is to include "basin" plans formulated by each regional board. Requires regional boards to establish water quality standards to protect beneficial uses. Authorizes regional boards to prescribe requirements for any discharge (essentially a permit program). If requirements have been prescribed, a waste discharge report must be filed with the Board.	Civil penalty for failure to file waste discharge reports and/or for deviations from discharge requirements ranges from $1,000 to $5,000 fine per day of violation, depending upon whether imposed administratively or judicially. Regional boards may issue cease and desist, and clean-up and abatement orders. Civil penalty for failure to adhere to cease and desist orders up to $6,000 per day of violation. If clean-up and abatement orders are ignored, state may take remedial action and the cost is imposed upon the violator.	Implications for forestry begin at the state level with the Water Resources Control Board. The Board has adopted a nondegradation policy which states that whenever existing water quality is better than that established by policy, such existing high quality will be maintained unless it can be demonstrated that any change will be consistent with maximum benefit to the people of the state, will not unreasonably affect present and anticipated beneficial use of such water, and will not result in water quality less than that prescribed by policy. Board has also required that each regional plan contain prohibitions against discharge of soil, silt, bark, slash, sawdust, or other organic or earthen material from logging operations into any stream or watercourse in quantities deleterious to fish, wildlife, or other beneficial uses, or against the placing of such materials at locations where they could pass into any stream or watercourse. The nondegradation policy and these two non-point pollution prohibitions summarize the Board's general position regarding protection of beneficial water uses from the adverse effects of timber harvesting and associated activities. Within this general framework, the nine regional boards carry the primary responsibility for on-the-ground regulation of water quality in accordance with their individual "basin" plans. With respect to forestry operations, these plans address the sources of pollution in each basin from timber operations, the types of impacts that such pollution may have on beneficial uses, and the water quality standards and objectives needed to protect water quality and beneficial uses. Regulation is effected through the water quality related rules promulgated under the state's forest practice act (Z'berg-Nejedly Forest Practice Act of 1973, Calif.Stat. Sec. 4511–4621). These rules are minimum-protection standards applicable to all commercial timber operations on non-federal timberlands. The current rules interact with the State Water Code by defining the beneficial uses of water to include those uses listed in the Water Code. With respect to non-point pollution, the rules cover silvicultural methods, harvesting practices and erosion control, water-	Section 30417 of the 1976 California Coastal Act authorizes the Coastal Commission to identify special treatment areas within the coastal zone and to recommend forestry operation rules to the Board of Forestry which are adequate to protect the natural and scenic qualities of these areas. These rules impose higher than average standards for forestry activities within these areas. California Fish and Game Code (California Stat Sec. 1603, 1606) provides that any person who obstructs or diverts any water body of those designated by the Department of Fish and Game must first notify the Department and follow procedures recommended by it; submitting a timber harvesting plan as required by the Forest Practice Act will constitute sufficient notice. California Statutes Section 5650 prohibits deposit of any slabs, sawdust, shaving, etc. into any waters of the state, with violation constituting a misdemeanor. California Statutes Section 5093.68 essentially imposes the same requirements as do the forest practice rules on "special treatment areas" designated under the state Wild and Scenic River Act.

					course and lake protection, and construction of logging roads and landings. The Forest Practice Act provides that timber operations will be exempt from the Water Code's waste discharge requirements if the forest practice rules promulgated under the Act are certified by the federal Environmental Protection Agency (EPA) as constituting best management practices (BMP's) for silviculture pursuant to Section 208 of the Federal Water Pollution Control Act. Such certification is presently pending. Until it is effective, the regional boards can impose specific waste discharge requirements on timber operations. As a practical matter, however, they seldom do.	
Hawaii	Basic Water Pollution Statute. Hawaii Rev. Stat. Ch. 342-1 to 20, 31-35 Enacted 1972, amended 1973, 1980, 1982, 1984, 1985. State Water Code. Hawaii Rev. Stat. Ch. 175C-1 to 101. Enacted 1987.	Department of Health.	*Water Pollution Statute*: Department charged with prevention, control and abatement of water pollution. Department may establish water quality and effluent standards, and promulgate regulations to control pollution according to local conditions. Pollution discharge into state waters controlled by permit. Department may also approve variances, issue "cease and desist" orders, and initiate court action for injunctive relief. *State Water Code*: authorizes Commission on Water Resource Management to develop statewide water management areas and instream waterflow standards. Commission authorized to promulgate instream flow standards on stream-by-stream basis. Water management areas control water use in areas where resource is threatened. Instream flow standards describe waterflow necessary to protect variable interests in streams, including recreational, wildlife, and fishery interests. Commission must hold public hearing for discussion of proposed standards. Permit required to alter stream channels. Administrative rules implementing State Water Code currently under development.	Civil: Department may initiate civil action to recover penalty. Criminal: for willful violation of any rule or regulation violator may be fined from $2,500 to $25,000 per day and may be imprisoned for up to one year.	Specifically designated pollutants include sediment, soil, and sand. Agricultural wastes also designated as potential pollutants. Established Water quality criteria relevant to forest management include those related to detrimental alteration of water turbidity or temperature.	Hawaii Pesticides Law (Hawaii Rev. Stat. Ch. 149A-31 to 33) regulates the application of pesticides and provides for the suspension or cancellation of pesticide use if chemical residues are detected in drinking water, or under other conditions of "unreasonable adverse [environmental] effects". Hawaii Rev. Stat. Ch. 180C-2. County governments may enact ordinances for erosion and sediment control, primarily from urban sources. Hawaii Rev Stat. Ch. 183-1 to 45. Department of Natural Resources responsible for protecting, extending, and increasing forest reserves for watershed management. Forest and water zones established in each county. Zones encourage highest economic use of resource consonant with water conservation. In subzones within reserve zones, Department may specify land use—including commercial timber growing. Regulations may prohibit unlimited cutting of forest growth or forestry practices detrimental to water conservation. Hawaii Rev. Stat. Ch. 205A. Controls on development of coastal areas do not restrict planting, cultivation, and harvesting of trees or other forest products, unless such activities have a cumulative negative impact on water resources. Under such conditions forest management is "development" and subject to permit requirement. In issuing permits, County Planning Commission must seek to minimize impact on water quality. Hawaii Rev. Stat. Ch. 181 prohibits discharge of poisonous or noxious effluent into streams or shorewaters. Specifies guidelines for reclamation. Hawaii Rev. Stat. Ch. 339 prohibits dumping of litter into water. Definition of "litter" does not include nonpoint pollutants.

Table C.4—Significant features of water quality legislation in the Pacific Coast Region—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Oregon	Ore. Rev. Stat. Sec. 468.700 to 468.778. Enacted 1953, amended numerous times.	Department of Environmental Quality.	It is public policy to protect and improve water quality, and to prevent or abate pollution. Polluting water is not a reasonable or natural use of such waters and is prohibited, as is discharge of wastes which reduces quality. Environmental Quality Commission authorized to develop water quality standards based upon specifically enumerated quality criteria which are specified in statute. Persons who injure or destroy fish and wildlife or habitat are strictly liable for restoration costs.	Civil penalty of up to $500 per day of violation. Penalties for specified violations such as discharge permit violation up to $10,000 per day of violation.	Department of Environmental Quality has issued comprehensive water quality regulations. These include general guidelines and specific standards which apply to each individual drainage basin. Guidelines applicable to forestry address antidegradation, restrictions on log handling in public waters, and forest management activities. The latter are directed to be conducted in accordance with the Oregon Forest Practices Act (OFPA). Specific standards include water quality characteristics such as turbidity and temperature. Primary protection of water quality relative to forest management is thus derived from rules (BMP's) promulgated under the Forest Practices Act. These control impact of forest practices on water quality for three regions within state. Rules establish minimum standards for chemical use, slash disposal, reforestation, road construction, and harvesting. The rules have been certified by the federal Environmental Protection Agency (EPA) as acceptable BMP's for purposes of the Federal Water Pollution Control Act.	Oregon Forest Practices Act (Ore. Rev. Stat. Sec. 527.610 to 527.730) authorizes promulgation of rules (BMP's) regarding forest management activities and protection of water quality. Rules are designed to assure sustained yields of timber while protecting water, air, and soil quality. State Board of Forestry authorized to adopt rules as minimum standards for forestry practices. Rules must maintain water, air and soil quality, and provide for protection of fisheries, wildlife habitat and sensitive ecological sites. Board must resolve any conflicts between rules and special management requirements of sensitive areas. Forest practice activities must conform to water quality standards. Rules recently changed to require a written management plan if harvesting is to occur within 100 feet of a Class I stream or within 300 feet of a site inventoried for threatened and endangered species. Evaluation of OFPA indicates that forestry rules have been "moderately effective mechanism for improving water quality in forest streams". Violation of OFPA is a misdemeanor. Each day of violation is a separate offense. Forest Practice Rules (Ore. Admin. Rules 629-24-101 to 646) include general rules and specific standards for each of 3 regions. General rules require notification of the State Forestry Division prior to conducting forest management activities and prior approval of stream channel alterations. General rules also provide for stream classification system, criteria for riparian area boundaries, limits on use of chemicals, and slash disposal guidelines. Regional rules cover all aspects of forest management. A provision for the protection of waters requires landowners to maintain riparian areas along the boundaries of Class I water. Ore. Rev. Stat. Sec. 390.805 to 390.925 establish Oregon Scenic Waterways System in which recreation, fish, and wildlife interests are of paramount importance. Department of Transportation authorized to adopt rules regarding management of lands adjacent to scenic waterways. Rules restrict road construction and require timber harvests be conducted to maintain aesthetic value of water. Department must be given notice prior to timber harvest for evaluation of impact on scenic water. Department may attempt to alter timber harvest plan or acquire land by purchase, gift, or scenic easement. Ore. Admin. Rules 736-40-005 to 095 require timber harvests to conform to preservation of scenic beauty of waterway. Department of Transportation management of "adjacent lands" includes all land within 1/4 mile of streambank, excluding lands which do not affect the view from scenic waterway. Management prescribed by Department is determined by subjective evaluation. Ore. Rev. Stat. Sec. 541.605 to 695 require permit for removal of any material from streambank, with exceptions for forestry activities in compliance with Forest Practice Rules. Ore. Rev. Stat. Sec. 549.400 prohibits obstruction or pollution of any waterway or drainage improvement.

Washington	Washington Water Pollution Control Act. Wash. Rev. Code Ann. Sec. 90.48.010 to 90.48.910. Enacted 1971; amended 1973, 1975, 1983, 1985.	Department of Ecology	It is state policy to insure water purity for all beneficial uses. Act creates Water Pollution Control Commission which is authorized to develop regulations and water quality standards. Any discharge which pollutes waters is prohibited. State may bring action against violators for costs of restoring environment. Department has sole responsibility for and authority over water quality standards and regulation of nonpoint sources of pollution in state. Regulations promulgated under state's Forest Practices Law must meet water quality standards and satisfy water pollution control laws. Department required to monitor water quality and has final authority to modify forest practice regulations as they pertain to water quality. Permit requirements and penalties imposed by Act do *not* apply to forestry activities that are in compliance with Forest Practices Act. Forest Practices Act and corresponding regulations must also satisfy requirements of Federal Water Pollution Control Act (33 USCA Sec. 1288, 1289, 1315).	Criminal: violations punishable by fine of up to $10,000 plus litigation costs. Violator may be imprisoned for up to a year. Each day of violation is separate offense. Civil penalty of up to $10,000 per day of violation.	Department of Ecology has developed separate set of standards pertaining specifically to forestry operations. However, there is no criminal or civil penalty for degradation of water quality by practices which are in compliance with regulations issued under Forest Practices Act. Department of Ecology has not developed a forestry non-point pollution control program of its own. However, BMP's and regulations issued under Forest Practices Act are subject to modification by Department if they fail to meet water quality standards. Water quality characteristics relevant to forestry include those for temperature and turbidity. Forest Practices Act regulations have been certified as meeting requirements of Section 208 of Federal Water Pollution Control Act.	Forest Practices Act (Wash. Rev. Code Ann. Sec. 76.09.010 to 76.09.950) authorizes forest practices regulations which comply with Section 208 of Federal Clean Water Act concerning nonpoint pollution control. Department of Ecology may propose forest practices regulation relating to water quality in cooperation with Forest Practices Board; Department has final authority. Recent legislative changes authorize Department of Natural Resources to prepare hazard reduction plan for sites where soil erosion poses significant danger to public resources. Riparian zones protected by requiring some trees be left standing. Department of Natural Resources may issue "stop work" order, or a "notice to comply" to violators. Department of Ecology may enforce compliance with Act 6 if Department of Natural Resources fails to do so. Violators may be subject to a fine of $500 per day of violation plus an additional penalty of $100 to $1,000 and up to one year imprisonment. Statutory restrictions on authority of local governments to promulgate their own forest practice rules (Sec. 76.09.240(4)) held invalid in *Weyerhauser v. King County (91 Wash 2d. 721, 1979)*. Forest Practices Rules and Regulations (Wash. Admin. Code Ch. 173-202-010 to 020). Regulations pertaining to water quality protection are individually adopted by Forest Practices Board and Department of Ecology after the agencies have reached agreement. Water quality provisions are found in forest practices regulations concerning timber harvesting, reforestation, road construction and chemical application. Evaluation of regulations in 1980 indicated that impact of forestry on water quality is relatively low overall, but impact from individual operations was severe in some cases. Recently proposed amendments are the product of broad consensus among government agencies, public interest groups, and forest products industry. Primary goal is to maintain viable forest industry and protect quality of natural resources. Amendments accepted "in concept" by Forest Practices Board include (1) creation of riparian management zones, (2) limitations on road construction and timber harvests in riparian zones, and (3) further restrictions on application of silvicultural chemicals to protect water quality. Wash. Rev. Code Ann. Sec. 7.48.010. Obstruction of stream channels used for rafting logs, timber, or lumber is a nuisance. Wash. Rev. Code Ann. Sec. 9.66.010. Unlawfully befouling, obstructing or interfering with a lake, navigable river, bay, stream, canal or basin is a public nuisance. Wash. Rev.

Table C.4—Significant features of water quality legislation in the Pacific Coast Region—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
						Code Ann. Sec. 75.20.050 to 140 concern protection of streambeds from impacts by hydraulic projects. Department of Fisheries authorized to evaluate projects and deny approval or require modification to protect fisheries. Violation of Act is a gross misdemeanor and a public nuisance. Civil penalty of up to $100 per day of violation may be imposed. Recently proposed amendments suggest giving Department of Fisheries or Department of Game discretion on penalty imposed: either fine, or gross misdemeanor charge punishable by fine and imprisonment. Wash. Rev. Code Ann. Sec. 76 32.040. This 19th century statute authorizes timber companies to channelize streams, remove obstacles, etc. Such improvement projects may not impede or obstruct stream outlets or interfere with use of such streams. Wash Rev. Code Ann. Sec. 76.42.030 to 070 authorize Department of Natural Resources to remove wood debris from navigable waters. Disposal of wood debris into such waters is prohibited Wash. Rev. Code Ann. Sec. 79.01.128. Department of Natural Resources may modify management practices on public lands within municipal watersheds so that water quality exceeds state standards. Municipality must reimburse Department for additional management costs incurred. *Fransen v. State Board of Natural Resources* (66 Wash. 2d 672, 1965) held that state may not *sell* its forest lands to achieve statutory objective. Wash. Rev. Code Ann. Sec. 79.72.010 to 900 authorize Department of Parks and Recreation to take measures to protect scenic rivers. To date Department has relied upon existing regulations to protect scenic rivers' water quality. However, conservation plan with possible regulatory standards is under development. Wash. Rev Code Ann. 88 28.050 imposes a fine of up to $200 per day upon persons who obstruct navigable streams, channels, or rivers, excluding booms to secure floating logs. Wash. Rev. Code Ann. Sec. 90.28.150 provides for stream improvements (clearing debris or straightening of channel) when necessary for logging. "Shoreline Management Act of 1971 (Wash. Rev Code Ann. Sec. 90.58.010 to 930) is designed to protect natural character, ecology, and public access to shorelines, including banks of streams and lakes. Act requires permit for development along shorelines, including logging road construction. Harvesting within 200 feet of identified shorelines is limited to selective cuts of no more than 30 percent of merchantable volume. Other" harvesting methods may be used if selective cut is ecologically detrimental, or for approved land development. Challenge to statutory limitation on road construction defeated (*Weyerhauser Co. v. King* 91 Wash. 2d 721, 1979).