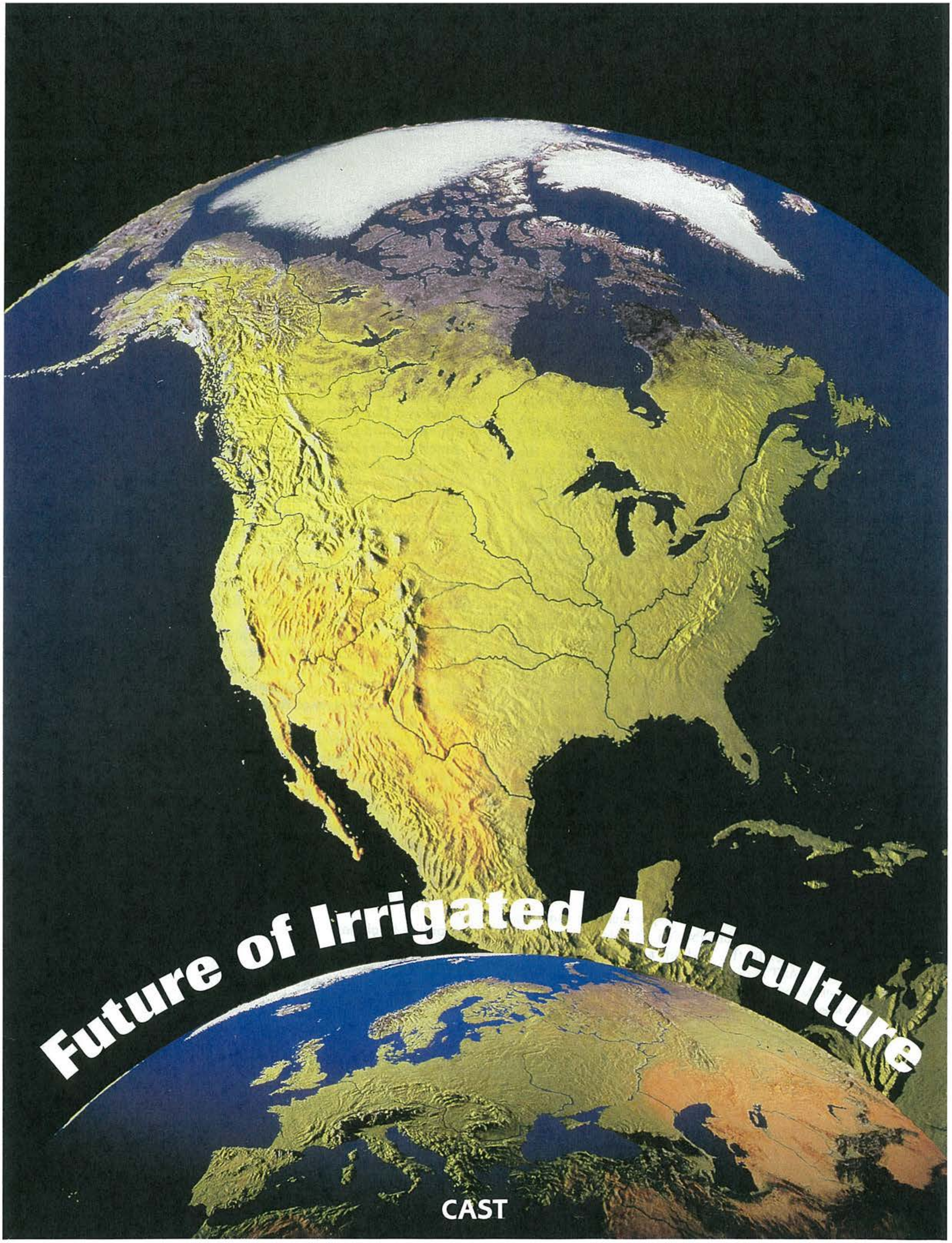

Future of Irrigated Agriculture

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CAST

The Science Source for Food,
Agricultural, and Environmental Issues

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Task Force Report

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Council for Agricultural Science and Technology

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Foreword

Following a recommendation by the CAST National Concerns Committee, the CAST Board of Directors authorized preparation of a report on the future of irrigated agriculture.

Dr. Henry J. Vaux, Jr., Associate Vice President, Division of Agriculture and Natural Resources, University of California, served as the chair for the report. A highly qualified group of scientists served as task force members and participated in the writing and review of the document. They include individuals with expertise in agricultural economics and sociology, and water and other natural resource economics.

The task force met to discuss and agree on an outline and writing assignments. They then prepared an initial draft of the report. They revised all subsequent drafts of the report and reviewed the proofs. The CAST Executive and Editorial Review committees reviewed the final draft. The CAST staff provided editorial and structural suggestions and published the report. The authors are responsible for the report's scientific content.

On behalf of CAST, we thank the authors who gave of their time and expertise to prepare this report as a contribution by the scientific community to public understanding of the issue. We also thank the employers of the authors, who made the time of these individuals available at no cost to CAST. The members of CAST deserve special recognition because the unrestricted contributions that they have made in support of CAST have financed the preparation and publication of this report.

This report is being distributed to members of Congress, the White House, the Department of Agriculture and its related agencies, the Food Safety Inspection Service, the Congressional Research Service, the Food and Drug Administration, the Environmental Protection Agency, the Agency for International Development, and the Office of Management and Budget, and to media personnel and institutional members of CAST. Individual members of CAST may receive a complimentary copy upon request for a $3.00 postage and handling fee. The report may be republished or reproduced in its entirety without permission. If copied in any manner, credit to the authors and to CAST would be appreciated.

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Henry J. Vaux, Jr.
Chair

Interpretive Summary

Irrigated agriculture in the western United States is faced with a confluence of change. Competition for increasingly scarce water supplies to serve growing urban and environmental needs means that water will become less generously available for irrigation. Ground water overdraft, which occurs in many locales throughout the West, cannot be sustained indefinitely, and some irrigated acreage ultimately will disappear as a result. Historically, federal water and agricultural policies have been very supportive of irrigated agriculture. Future policies will be less favorable as the federal government continues to transfer responsibility for water management to the states and as agricultural commodity programs and other agricultural support programs are curtailed or phased out. Environmental policies undoubtedly will require irrigated agriculture to economize on the use of natural resources and to minimize its contribution to environmental degradation. Simultaneously, the economic circumstances of western agriculture will become more demanding as markets for food and fiber become increasingly globalized.

Change will not affect all regions of the West equally. Ground water overdraft is most severe on the southern Great Plains but also is significant in Arizona and California. Rapidly growing urban areas will compete with irrigated agriculture for relatively fixed supplies in California and Arizona. Competition from environmental and instream uses will be pervasive but most intense in the Pacific Northwest where additional instream flows may be required to support anadromous fish, hydroelectric power generation, and navigation. Native American claims on western water supplies are potentially very large, particularly in central and southern Arizona. While it is unlikely that many of these claims will be settled, settlements favoring Native Americans would likely result in the shifting of some irrigated agriculture in Arizona to reservation lands. Settlements requiring additional instream flows could affect agricultural water supplies adversely in the Pacific Northwest and in specific locales elsewhere.

Historically, western growers generally have been both adaptive and innovative and thus have been able to adjust to change successfully. Many strategies are available to growers attempting to adapt to the future. These strategies include altering the crop mix to emphasize high-value fruits and vegetables; employing sophisticated technology and management schemes in managing water at the field level; and investing in research to develop improved crops, cultivation methods, and irrigation-water management techniques. New and emerging means of adaptation will continue to evolve. Technologies permitting automation of irrigation systems and allowing water to be managed more precisely are developing. The advent of biotechnology adds greatly to the possibilities of developing new varieties of crops that are cheaper to produce because they require less water and other inputs but also yield products of superior quality. Innovations in the management of farming operations also should allow growers to adapt to changing and less favorable circumstances.

Most of the laws and institutions governing and guiding irrigated agriculture were developed in another era and are ill suited to one in which premiums will be placed on efficient water use, flexibility, and adaptability. These include antiquated systems of state and federal water laws, enforcement systems that create uncertainty about who is entitled to use how much, legal systems that fail to provide incentives to manage water efficiently, barriers to market-like exchange of water rights, and water management jurisdictions that do not properly account for the various interdependencies in water use. In addition, existing rates of investment in agricultural research and development in the United States are below those in other developed countries despite the fact that research and development will be critical if U.S. growers are to adapt and to compete effectively in global markets.

The ability of western growers to adapt successfully to future circumstances will depend, in part, on the development of new institutions and policies better suited to an era of water scarcity. Among the measures that would help western growers adapt are the following:

1. Policies creating consistency and certainty in the regulatory environment in which irrigated agriculture operates.
2. Policies establishing marketlike forces and incentives. These policies would signal growers in the same way that markets do and would allow each grower to adjust and to adapt in ways best suited to local circumstances. Such policies can harness the entrepreneurial abilities of individual growers while mandating compliance with environmental, safety, and other regulations.
3. Policies facilitating the establishment of well-functioning water markets but providing appropriate protection for third parties. Markets provide the opportunity to reallocate water voluntarily, with benefits, to both buyer and seller. Coercive means of reallocation do not always provide benefits to all participating parties.
4. Policies providing for and underwriting public investment in basic research and in research yielding benefits that cannot be appropriated exclusively by individual growers. Research and development contributed significantly to the emergence of the U.S. agricultural economy as the strongest and most productive in the world. Investment in research and development will be crucial in helping the nation maintain this position in an increasingly competitively global environment.

Executive Summary

Over the last century, irrigated agriculture in the western United States has grown and prospered in an environment characterized by plentiful water supplies, generous and supportive government policies, and reasonably favorable economic circumstances. This environment is undergoing profound change. Ground water overdraft and intensifying competition for scarce water supplies will decrease the amount of water available for irrigation in the West. Federal water and agricultural policies are likely to become less favorable to irrigated agriculture. The economic circumstances of western agriculture will be more demanding as markets for food and fiber become increasingly globalized. These changes will require western growers to adapt if irrigated agriculture is to remain productive and profitable.

The history of irrigated agriculture in the West illustrates how growers generally have adapted and remained competitive in the face of changes such as the unanticipated escalation of energy costs during the 1970s. Successful adaptive strategies include altering the mix of crops to emphasize high-value fruit and vegetable crops; employing sophisticated technology and management schemes in managing water at the field level; and investing in research to develop improved crops, cultivation methods, and irrigation-water management techniques. New technologies and practices are evolving. Technologies permitting automation of irrigation systems and allowing water to be managed more precisely are becoming available. The biological revolution and the advent of biotechnology hold promise for the development of new crops that can be grown more cheaply or can yield produce of superior quality. Innovations in the management of farming operations also should allow growers to adapt to changing and less favorable circumstances.

Change will not affect all regions of the West equally. Ground water overdraft occurs to some extent throughout the West except in the Imperial Valley and the Upper Colorado/Great Basin regions. The effects of overdraft are likely to be most severe in the southern Great Plains, where significant irrigated acreage may be removed from production during the next 20 years. The Central Valley of California and central and southern Arizona also will be affected by lowered water tables, and some acreage will be lost to production in these regions. Rapidly growing urban areas will compete with irrigated agriculture for relatively fixed supplies of water in California and Arizona. Competition from environmental and in-stream uses will be pervasive but likely will be most intense in the Pacific Northwest, where in-stream flows require augmentation during times of low-flow to support anadromous fish, hydroelectric power generation, and navigation. Competition from environmental uses is likely to have less of an impact in Arizona and on the western Great Plains than elsewhere in the West.

Native American claims on western water supplies are potentially very large. Although it is unlikely that many would be settled in the next two decades, these claims cast considerable uncertainty on the future of prevailing patterns of water rights. In central and southern Arizona, where potential Native American claims are especially large and would be based on the need for irrigation water, legal settlements favoring Native Americans might result in a shifting of the locus of irrigated agriculture to reservation lands. Settlements requiring enhanced in-stream flows could affect agricultural water supplies adversely in specific locales, especially in the Pacific Northwest.

Federal water and agricultural policies will become less generous and supportive of irrigated agriculture in the future. The federal government continues to devolve on the states the responsibility for development and management of water resources. State policies are likely to emphasize improved management practices rather than investment in the development of additional water supplies. In addition, western growers who have benefited from subsidized water and power rates are likely to face increases in these rates to levels closer to prevailing market prices. Simultaneously, federal agricultural policies will become less generous. Commodity payment policies, which have insulated growers from low commodity-prices, are being phased out.

New policies will focus increasingly on the regulation and control of agricultural practices having adverse effects on the environment. Growers in all regions of the West will be under increasing pressure to minimize air and water pollution and erosion and to help protect endangered species. Frequently, these policies will increase production costs in irrigated agriculture, and growers will need to innovate in developing and adopting technology and management schemes to offset these cost increases. Although future federal water and agricultural policies will not treat irrigated agriculture punitively, irrigated agriculture likely will cease to receive favored treatment. Simultaneously, western growers will be subject to intensifying competition as the agricultural economy globalizes.

The North American Free Trade Agreement (NAFTA) and the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) will affect different commodities differently. Producers of grains, oilseeds, and livestock are expected to benefit. Growers in the Upper Colorado/Great Basin region and in the western Great Plains should be favored. Producers of high-value vegetable and fruit and other labor-intensive crops will face increased competition. Although the future effects of liberalized trade on fruit and nut producers are unclear, growers of produce that can be canned or frozen likely will be affected adversely. The effects of NAFTA and GATT on fresh fruit and vegetable markets are less predictable. Farmers in fruit and vegetable growing regions may be better able to adapt because there is more opportunity to shift crop mix in response to changing circumstances than in regions where only field and forage crops are grown.

Although federal price support and water development policies will not favor irrigated agriculture, federal policies can help agriculture adapt to changing circumstances. Examples of adaptive institutions and policies that could be developed include policies and institutions creating a consistent and certain regulatory environment; policies relying on market-like forces and incentives; policies facilitating the establishment of well-functioning water markets, with appropriate protection for third parties; and policies encouraging substantial public and private investment in agricultural research and development. Western growers would be well served by working to develop policies and institutions helping them adapt instead of resisting the changes that seem inevitable.

Experience in the Pacific Northwest and California illustrates how irrigated agriculture in these regions has become more productive despite past declines. In both regions, the ability of growers to alter crop mix in the face of changing markets and diminishing water and land availability has resulted in increased income and productivity. In the Upper Colorado/Great Basin and the Great Plains, irrigated agriculture has become more productive over the past two decades even though the possibilities for altering crop mix have been constrained as growers have used innovative techniques to manage water and other inputs. The ability of western growers to respond effectively to rapidly increasing energy prices in the 1970s and the 1980s also illustrates their capacity to adapt to unforeseen changes.

In the future, irrigated agriculture in the West is likely to use fewer natural resources. Irrigated acreage will decrease, as will total consumptive use of water by agriculture. Irrigated agriculture will become more environmentally benign as western growers adopt practices limiting the contribution of agriculture to air and water pollution. The past two decades have demonstrated that western growers are resourceful, resilliant, and can achieve significant increases in productivity without bringing substantial tracts of new land under irrigation. The next two decades should demonstrate that western growers can achieve substantial increases in productivity while using less land and water.

1 Introduction

Irrigated agriculture in the western United States is under stress. Competition for water from rapidly growing urban areas and for environmental purposes, uncertainty over Native American water rights, concerns about the contribution of irrigated agriculture to air and water pollution, increasing globalization of the agricultural economy, and progressive withdrawal of federal support for western water development all indicate that major changes are likely for irrigated agriculture. Historically, irrigated agriculture and the processing and manufacturing linked to it have constituted the largest single industry in most states of the semiarid West. Moreover, irrigated agriculture, which has been somewhat more stable economically than many other industries in the West, has provided buffering in times of recession. Irrigated agriculture thus remains a central and significant part of these economies although it is not as large a component as it was historically.

Irrigation now is practiced to some degree in almost every region of the country, but this report focuses on irrigated agriculture in the West. The facts that intensive agriculture cannot be practiced profitably in most areas of the West without irrigation and that irrigated agriculture remains important to the economic welfare of the region suggest that the consequences of a significant decline in agriculture may be more important and pervasive here than elsewhere in the nation (Figure 1.1). In addition, the changing demographics and economic base of the West suggest that irrigated agriculture may not be as viable and sustainable as in the past. The potential consequences of a major decline in western agriculture include impacts on the nation's supply of food and fiber, on the welfare of rural communities built on agricultural enterprises, and on the economies of western states. Yet, as this report will show, these concerns should not be overstated.

Western growers have adapted to change before and undoubtedly will adapt again. The energy crisis of the 1970s sharply increased the costs of pumped irrigation water in some regions. Growers responded by employing water conserving technologies and strategies and by substituting capital and labor for energy. Growers throughout the West always have been subject to the vagaries and uncertainties of commodity markets. They have responded by growing different crops and by finding less expensive ways of producing crops that may have become less profitable. Irrigated agriculture is highly competitive. This fact perhaps more than any other has compelled growers to innovate and adapt to keep operations profitable. The tradition of innovation and the ongoing search for new ways of maintaining a competitive edge equip those in irrigated agriculture to respond to change.

In this report, both the factors likely to stress irrigated agriculture and the factors allowing it to adapt

Figure 1.1. Historically irrigated agriculture has been a core component of the economies of the western states. Photo courtesy of Pam Fabry.

are identified and analyzed. The industry's capacity to adapt should allow it to prosper under new conditions and to remain highly productive and competitive. Western irrigated agriculture is quite heterogeneous, however, and some regions will be better able to adapt than others. In some localities, irrigated agriculture may decline sharply or disappear altogether in response to changing circumstances. Consequently, this report includes a series of regional assessments intended to show how declines in available water supplies, intensified competition for water, concerns about environmental quality, changes in government agricultural policy, and evolution of global markets will affect irrigated agriculture.

The report is divided into five parts: (1) a description of the historical and current setting of irrigated agriculture in the West; (2) a discussion of the changes likely to affect irrigated agriculture's future; (3) an identification and analysis of the various mechanisms through which irrigated agriculture can adapt; (4) a series of regional assessments analyzing the likely future of irrigated agriculture in the important domains of the West; and (5) a final assessment of how irrigated agriculture is likely to fare over the next several decades, in the face of change.

2 The Setting: Historical and Current

Historically, economic growth in the western United States has been tied to agricultural development. From early times, settlement of the semiarid portions of what is now the western United States depended on the development of reliable water supplies. The practice of irrigating crops existed among Native Americans of the arid Southwest as early as 100 B.C. (Council for Agricultural Science and Technology, 1988). The stable food supply provided by irrigated agriculture allowed these peoples to develop permanent settlements, which could not have been developed under hunting and gathering regimes. Similarly, the rapid settlement and development of the West by European Americans, which began in the midnineteenth century, depended greatly on irrigated agriculture.

Throughout much of the United States west of the 100th meridian (longitude 100° west), in the center of the Great Plains, average annual precipitation totals less than 20 inches (in.), which usually is considered the minimum necessary for profitable dryland farming. In addition, the seasonal patterns and spatial distributions of precipitation in much of the West are matched poorly with the seasons and places that favor cultivation. Precipitation frequently occurs in the winter, as rain or snow, and at high elevations, where soils are poor and the growing season is short. As a result, successful irrigation on anything but a modest scale requires the development of storage and transport facilities to capture water in wet places and times and to move it in dry seasons to locations in which agriculture can prosper. Where surface water development is not feasible, ground water supplies frequently have been exploited for irrigation. The scale of irrigated agriculture resulting from the system of surface and ground water supplies that has been developed over the last century and a half is impressive. By 1987, in the 17 western states, approximately 40 million acres were irrigated, representing more than 80% of all irrigated lands in the United States (U.S. Department of Commerce, 1992).

The development of irrigation in the West was not uniform through time or among regions. Political, economic, and institutional forces interacted to encourage and sometimes to inhibit irrigation development (Hundley, 1988). Generally speaking, there have been two distinct eras of development. The first era, which began about 1880 and ended about 1960, is characterized by expansion; the second is characterized by relative stability of irrigated acreage (Young, 1986). The factors currently affecting irrigated agriculture suggest that this second era is about to end if it has not ended already and that it will be followed by a third in which irrigated acreage in the West declines modestly.

The era of expansion in western irrigated agriculture began with the early mining bonanzas and the rise of the cattle industry. Irrigated agriculture in the West was pioneered primarily by Mormon settlers, who established colonies throughout the Intermountain region and southern California beginning in about 1850. Although early Mormons were not the only irrigation pioneers, irrigated acreage grew relatively slowly before 1880, when fewer than one million acres were irrigated throughout the West. Much early agricultural development of the 1870s and early 1880s did not rely on irrigation at all. During this period, many settlers were attracted to dryland farming, particularly on the Plains and in parts of California. The attraction of dryland farming lay in the facts that it was cheaper than irrigated agriculture and that an extraordinary period of wet years beginning in 1882 made dryland farming profitable in many previously unprofitable regions (Hundley, 1988).

In the late 1880s, irrigated agriculture began to grow more rapidly (Figure 2.1). With the end of the wet cycle and the advent of a prolonged drought, dryland farming ceased to be profitable in many areas, and farmers were forced off the land. Where water could be developed inexpensively, irrigated acreage began to expand. For the most part, the development of irrigated farms was supported with private capital. Generous federal land disposal laws and emerging systems of state water rights, which favored the development of irrigated agriculture, created an incentive for the private development of irrigation facilities. By the end of the century, however, most prof-

Figure 2.1. Early irrigation facilities were supported with private capital. Photo courtesy of the Water Education Foundation.

itable private investment opportunities in irrigated agriculture had been exhausted (Fite, 1968). Although much irrigable land remained, the costs of getting surface water to it exceeded what the private sector was willing or able to pay. Beginning at about the turn of the century, the federal government played an increasingly important role in the expansion of irrigated acreage.

The major objective of many federal laws and policies related to natural resources in the latter half of the nineteenth century was to facilitate the private development of land and other resources. In particular, the Homestead Act of 1862 was designed to put federal lands under the private ownership of yeoman farmers. Early experience with the Homestead Act showed that it was not well suited to the semiarid lands of the West. As documented by John Wesley Powell, lack of water in the West made it impossible for a family to survive on a 160-acre homestead (Stegner, 1954).

Although local governments and irrigation districts had begun to play important roles in the development of additional irrigated lands in the late nineteenth century, federal involvement entailed little more than a generous land disposal policy and a hands-off attitude designed to facilitate state and private development of irrigation. The Desert Land Act of 1877 and the Carey Act of 1894 both were designed to stimulate private and state participation in irrigation's development. The federal government allocated 320- and 640-acre parcels for homesteading if state and private interests would develop the facilities needed to irrigate the lands. For the most part, however, these acts failed to induce settlement in much of the semiarid West, and by 1902 it had become evident that more aggressive federal programs would be necessary to promote irrigated agriculture and the settlement of much of the rural West (Bernardo and Whittlesey, 1986).

The Reclamation Act of 1902 signaled a major new involvement by the federal government in the development of irrigation. Under the terms of the act, the federal government was to provide the capital and expertise necessary to construct water storage and distribution facilities. Farmers who received the water developed under the terms of this act were obliged to repay the costs of the project *without interest* over a specified period and were not allowed to irrigate more than 160 acres (later, 320 acres for husband and wife) with project water.

Although the reclamation program expanded rapidly and resulted in significant increases in irrigated acreage, repayment of project costs proved a chronic problem. In the three decades after the act's passage, additional legislation progressively extended repayment periods from 10 to 40 years. Other legislation provided that proceeds from the generation of hydroelectric power at reclamation facilities could be used to help defray costs allocated to irrigation. And, in 1939, legislation limited repayment to what growers were able to pay. Thus, by subsidizing the costs of large-scale water projects, the federal government profoundly affected the extent of irrigated acreage in the West (Robinson, 1979) (Figure 2.2).

Other federal policies had a complementary effect on irrigation. Laws and policies that were focused on the stabilization of agricultural commodity prices, the development and application of agricultural science and technology, the prevention of soil erosion, and the provision of electricity to rural areas, for example, made irrigated agriculture both profitable and attractive. Consequently, by 1971, a little more than 8.8 million acres were irrigated with water developed under the Reclamation Act. Total costs of the reclamation program were estimated at $12.1 billion, with a little more than half allocated to irrigation (U.S.

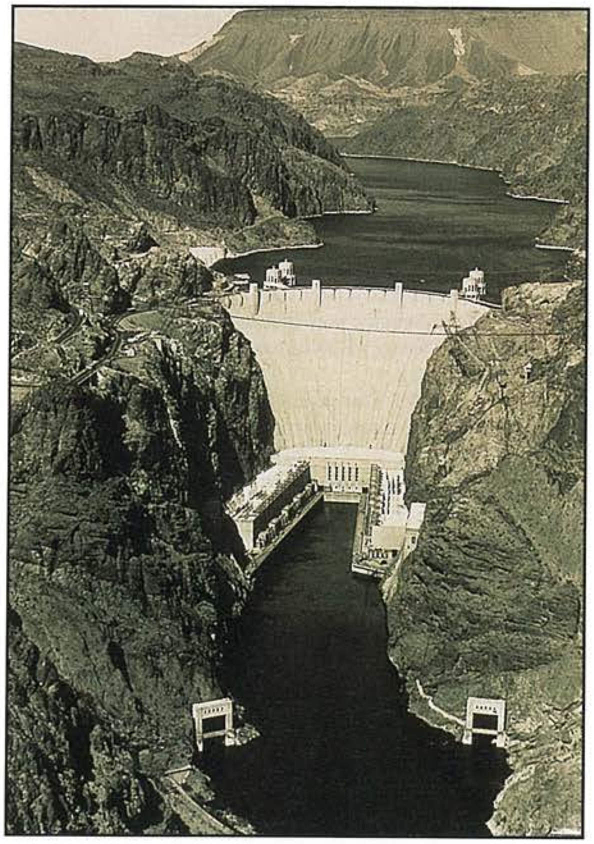

Figure 2.2. In the first two-thirds of the twentieth century federal construction of large-scale water facilities such as Hoover Dam on the Colorado River permitted irrigated acreage to expand throughout the West. Photo courtesy of the Water Education Foundation.

Bureau of Reclamation, 1972). One estimate suggested that the gross annual value of crops grown on Bureau of Reclamation projects exceeded $5.1 billion annually by 1969 (U.S. Bureau of Reclamation, 1970).

Although the Reclamation Act had a substantial effect on the development of irrigation in the West, acreage irrigated with reclamation water represented only about 25% of total irrigated acreage in the 17 western states by 1970 (U.S. National Water Commission, 1973). Technological advances that made irrigation increasingly affordable resulted in significant growth in privately financed irrigation development. During the 1920s and the 1930s, turbine pumps, which made possible the exploitation of vast ground water reserves previously inaccessible throughout the West, were developed, and substantial acreage was irrigated with ground water on the Great Plains, in central Arizona, and in California. Between 1940 and the late 1960s, most new lands irrigated with nonfederal water relied on ground water. As areas irrigated with ground water developed, it was not uncommon for rates of extraction to exceed those of recharge. The resulting decline in water tables led to increased pumping costs and, in some areas, to substantial land subsidence. In several regions, this led to calls for the development of supplemental surface supplies by the federal government to offset ground water mining (Vaux, 1986).

During the era of expansion, agricultural production increased enormously in the West. Irrigated acreage grew from virtually nothing to approximately 40 million acres. By the end of the era, irrigated agriculture accounted on average for more than 85% of the consumptive water use within the region, and agriculture and related processing activities constituted the largest single industry in most western states. But despite the importance of irrigated agriculture in the West, by 1960 new forces were at play that would result in a gradual cessation of expansion and the beginning of an era characterized by fairly constant irrigated acreage.

During the decades of the 1960s and the 1970s, the political and economic environments of irrigated agriculture began to change. Most storage sites that could have been developed at reasonable cost had been developed or were in the process of being developed. New storage facilities could be built only at sites that either were quite remote or entailed large construction and operating costs. Thus, the costs of such facilities escalated quickly beyond ranges previously considered reasonable. Competition for public funds intensified, and the public became increasingly less willing to defray the costs of large civil works projects. In addition, public preferences for environmental amenities had begun to grow, and civil works projects had begun to be perceived as damaging to the environment (Mann, 1984).

The period of the 1970s and the 1980s was one in which acreage devoted to irrigated agriculture remained relatively stable throughout the West. Federal funding to support new projects declined, and there even was one unsuccessful effort, by the Carter Administration, to stop a number of projects. Increasing energy costs during the 1970s boosted the expense of operating irrigation systems, especially where water had to be pumped. In the 1980s, the federal government sought to decentralize responsibilities for water management and development. Although very modest expansion of irrigated acreage occurred in areas with accessible ground water, expansion was more than offset by areas taken out of production because of declining ground-water tables.

To concerns about environmental damages associated with water development projects were added concerns about the impact of irrigated agriculture on water quality. These were heightened in the early 1980s with the discovery that selenium laden irrigation drainwaters were associated with increased waterfowl mortality and birth defects. Subsequent studies revealed that selenium contamination was but one example of a broad range of irrigation induced water-quality problems (Council for Agricultural Science and Technology, 1994; National Research Council, 1989).

Populations of the western states continued to grow rapidly. Most growth settled in urban areas, leading to growing demands for water supplies to serve municipal and industrial uses (Figure 2.3). The competition for available supplies intensified; but, because western statehouses were becoming dominated by urban interests, agriculture was not well situated to compete politically or economically.

In the course of a single century, irrigated agriculture had grown from virtually nothing to the region's largest industry, and in a relatively short period the industry had stabilized. By the early 1990s, the Census of Agriculture reported nearly 109 million acres of harvested cropland on irrigated farms. Of this total, perhaps 75 million acres were irrigated fully. Total farmgate crop value on these fully irrigated lands approximated $28 billion, with processing and transport of food and fiber products accounting for perhaps another $80 billion (U.S. Department of Commerce, 1992). Although irrigated agriculture and related activities remain among the West's largest industries, a number of factors threaten to change both the nature and extent of irrigated agriculture.

Figure 2.3. **The increasing urbanization of the West has fueled demands for additional water for municipal uses such as landscape irrigation. Photo courtesy of the Water Education Foundation.**

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3 Factors Affecting the Future of Irrigated Agriculture

Introduction

Irrigated agriculture, like virtually every other industry in the United States, must adapt to changing circumstances. Developed water supplies available for irrigation are likely to grow scarcer, and the manner in which such supplies can be used may change. Federal policies, which in the past have been favorable to both irrigated agriculture and agriculture in general, are changing in response to new fiscal and political realities. The agricultural economy itself is undergoing significant changes as the world economy becomes more global and less insular. These economic changes will affect the demand for food and fiber produced in the western United States. All these factors will combine to create a new environment for irrigated agriculture in the West.

Future Availability of Water for Agriculture

In 1990, irrigated agriculture accounted for approximately 85% of developed water supply use throughout the West. Several factors suggest that agriculture cannot continue to use water as extensively as it has. These include supply depletion resulting from prolonged ground water overdraft, competition from other sectors for developed water customarily used by agriculture, and possible changes in water price.

Ground Water Mining

Current and past levels of water use for irrigated agriculture in some regions of the West have depended on persistent *ground water overdraft*, which occurs when water is extracted from an aquifer at a rate greater than that at which it is replenished. Most aquifers are replenished or recharged from waters percolating below the root zone. These waters can originate with precipitation or where water applied to overlying lands percolates below the root zone. In many regions of the West, irrigation practices themselves contribute to significant ground water recharge. In some instances, irrigation is practiced so as to contribute to ground water recharge, thereby taking advantage of the natural storage capacity of underlying aquifers.

Under some circumstances, aquifers are not recharged naturally. In these instances, the geological substrate is sufficiently impermeable to percolating waters so that recharge either is completely absent or occurs on an insignificant scale. Under such conditions, *any* pumping of ground water results in overdraft because the water is essentially a nonreplenishible stock which, when used, is gone forever. The most prominent example of nonrecharging aquifers is found on the western Great Plains (see Chapter 5 for a discussion of the region), but there are localized examples elsewhere throughout the West.

Ground water overdraft frequently may be economical as long as economic returns to overdraft outweigh present and future costs, appropriately discounted, to all users of a lowered water table. Thus, for example, during periods of drought, irrigators often will increase ground water pumping to offset the temporary loss of surface supply (Figure 3.1). When the drought ends, rates of pumping decline and ground water tables tend to be restored to predrought levels. In this way, ground water resources can be an important buffer against the sometimes severe but usually temporary effects of drought. When overdraft is persistent and occurs without regard for the increased pumping costs imposed on neighboring users, however, it ultimately intensifies water scarcity.

Irrespective of whether ground water is subject to periodic replenishment, the principal impact of persistent overdraft is a progressive increase in the depth of the water table and an associated increase in the costs of pumping water to the surface. Ultimately, costs increase until it is uneconomical to pump, users stop pumping, and overdraft ceases. When it no longer is economical to pump ground water, agricultural users must find an alternative source of supply, convert to dryland farming, or switch to a different land use. In many regions of the West, persistent

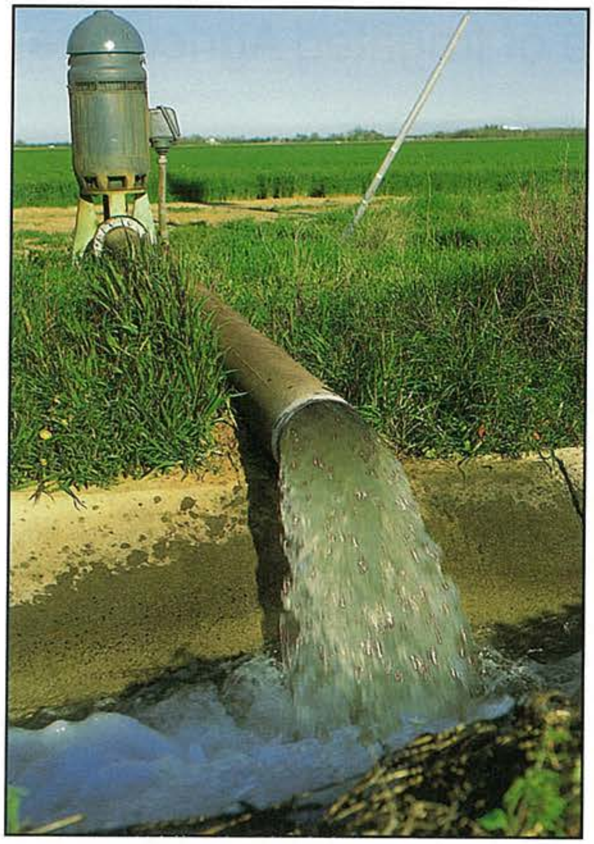

Figure 3.1. **Ground water can be an important buffer against temporary shortages in surface water supplies caused by drought. Photo courtesy of Jack Kelly Clark.**

overdrafts have led to the development of supplemental surface supplies to substitute for increasingly costly ground water (Vaux, 1986). As new surface water supplies become more costly and difficult to develop, however, substituting surface water for ground water will become less feasible. In the absence of new water supplies, some or all of these areas ultimately will go out of production or, in some instances, be converted to dryland farming.

Increasing Competition for Developed Water Supplies

For the past two decades, the populations of most western states have been growing faster than the national average. Most new residents have settled in urban areas, thereby changing the character of the West from rural to urban. Urbanization throughout the West is expected to continue and has at least two important implications regarding the availability of developed water supplies for irrigated agriculture. First, the demand for developed water to serve new and expanding municipal and industrial uses will grow. Second, urban populations have strong preferences for the environmental amenities associated with free-flowing water and are reluctant to support water development projects that are viewed as having adverse environmental effects. It therefore is becoming difficult, if not impossible, to develop new water supplies to serve growing urban populations, and the transfer of developed water supplies from the agricultural to the urban sectors likely will figure in the support of future urban growth.

Environmental demands for instream flows have grown dramatically since the 1970s (Adams et al., 1993; Daubert and Young, 1981; Loomis, 1987). Although only about one million acre feet of water have been reallocated from agricultural to environmental uses to date, major reallocations are expected in the next decade. The Endangered Species Act is a major force driving demand for allocations of water for environmental purposes. Whooping cranes in Nebraska, salmon in California and the Pacific Northwest (Figure 3.2), and Delta smelt in California are among the species for which water is most likely to be reallocated. Existing estimates of water needed to support species currently identified as threatened and endangered total several million acre feet (Johnson and Adams, 1988). Although the extent to which water will have to be reallocated from consumptive uses to support environmental uses is unclear, the potential magnitude of such reallocations is larger than the likely magnitude of potential reallocations from agriculture to support urban and industrial uses.

Figure 3.2. **Instream flows may have to be augmented to support salmon in the Pacific Northwest and California. Photo courtesy of the Water Education Foundation.**

In the increasing competition for water throughout the West, agriculture frequently is seen as an attractive supplier. This is true in both a political sense, because agriculture uses such a great quantity of the developed water supply, and in an economic sense, because the value of water in agricultural uses generally is less than that in municipal and industrial, energy generation, or certain environmental uses. It is difficult to generalize about the economic value of water in alternative uses because values tend to differ significantly from case to case, and there sometimes is no agreement on how they should be measured (Gibbons, 1986). There is virtual agreement, however, that the value of most municipal and industrial uses at the margin exceeds that of most agricultural uses at the margin. This means, for example, that with marketlike institutions for the transfer of water, urban areas almost always will be able to acquire from agricultural users the water they need, even for marginal uses such as landscape and golf course irrigation.

Nevertheless, even if agriculture became the sole supplier for growing urban demands, the aggregate impact of such transfers on agriculture likely would be modest for several reasons. First, because agricultural water use accounts for such an overwhelmingly large proportion of developed water use in most areas, only modest reductions in the levels of this use will be needed to meet prospective urban demands (Vaux and Howitt, 1984). Assuming, for example, that irrigation consumptive use averages 2 acre feet/acre throughout the West and assuming that the typical urban dweller uses 100 gallons/day, a little more than 55,000 acres would have to be retired to serve an additional one million urban residents. The urban population of the 17 western states grew by 12.6 million between 1980 and 1990. Should this rate of growth continue, about 700,000 acres of irrigated land would have to be taken out of production *each decade* if all increases in municipal use were to be accommodated from existing agricultural use without adjustments in water-using technologies. Although this represents a decrease of only about 1.6% in irrigated acreage throughout the West, competition for water may have important impacts in specific, localized areas.

Second, institutions governing the marketlike transfer of water are not well developed. Because such institutions are likely to develop slowly over time, marketlike transfers are unlikely to have sudden or dramatic effects on western agriculture at large. Thus, agriculture and the industries dependent on it are likely to have time to adapt to decreases in available water supplies.

Third, the need to account for at least the most significant third-party impacts of water transfers has been documented in a number of studies (Carter et al., 1994; National Research Council, 1992). Third parties are groups or individuals who are not the primary parties to a transfer, but who nevertheless are affected by it. Third-party impacts include adverse effects on areas of origin, such as loss of economic activity and tax base; adverse impacts on the environment, such as those on water quality and instream flows; and adverse impacts on ethnic communities that may be particularly dependent on or have a religious/cultural relationship with water (National Research Council, 1992). To the extent that water transfer institutions evolve to account for important third-party impacts, the adverse effects of transfers on western agriculture are likely to be attenuated. Specifically, it is likely that third-party protections would ameliorate severe impacts in local areas, with the result that aggregate impacts would be spread out over larger and more diversified regions.

Under plausible scenarios of population growth, probably no more than 2 to 3% of lands currently irrigated would need to be taken out of irrigation to support the growth anticipated in urban populations over the next two decades. Impacts could be significant in specific regions and locales, however. Although competition from growing urban areas is unlikely to have a major impact on agriculture in the aggregate, substantially larger quantities of water could be lost to reallocations for environmental purposes. The extent of such losses may depend crucially on the federal policies to be discussed.

The Costs of Irrigation

Irrigation, like other productive activities, remains viable so long as its returns exceed its costs. The future viability and profitability of western irrigated agriculture depends critically on the price received for crops produced and the costs of production. Crop prices are market driven and likely to become more variable as the agricultural economy becomes more globalized. Under these circumstances, grower survival will depend on the ability to avoid sharp increases in irrigation costs, which themselves depend on a number of factors that are difficult to predict. Crucial factors include the input prices of seed, fertilizer, pest control, labor, energy, irrigation equipment, water, and water management.

Historically, water prices have been fairly stable, in part because of the presence of many long-term

Global Climate Change and Irrigated Agriculture

Global climate change could have significant, if uncertain, impacts on western irrigated agriculture. A number of studies suggest that increasing concentrations of carbon dioxide and other "greenhouse" gases could lead to global warming of 3° to 6°C and to increased precipitation (Houghton et al., 1992; Smith and Tirpak, 1989). Such climate changes would be expected to affect human and natural systems both positively and negatively. On a global scale, however, the magnitude and even the direction of these effects are uncertain. Uncertainty increases when efforts are made to forecast the impacts of global warming for specific regions such as the western United States (Adams, 1989; Knox and Scheuring, 1991; Rosenberg et al., 1988).

Forecasts based on climate modeling studies generally indicate that temperatures will be warmer in various U.S. regions. Forecasts of regional changes in precipitation and runoff disagree, however. For agricultural regions that depend greatly on irrigation, changes in crop water demand and water supply availability are likely to be the most important features of any climate change. This will be particularly true in the 17 western states, where competition between agricultural and nonagricultural users is increasing. The long-term decline in regional water availability suggested by some climate change studies could require major shifts in existing policies and regulations governing allocation. These shifts, in combination with the direct effects of warmer weather on crop water demand and yield, could lead to agricultural practices and to regional cropping patterns very different from those now observed (Adams, 1989; Adams et al., 1988).

Several recent studies focus on the potential effects of climate change on irrigated agriculture. Adams et al. (1990) used climate change forecasts based on general circulation models to estimate the effects of changes in crop yield, crop water demand, and water supply on U.S. agriculture, including western agriculture. Data indicate that total irrigated acreage in the United States could be decreased substantially. This estimated decrease is attributable both to declines in available water supplies and to higher crop yields in moister regions where agriculture is rainfed. Within the western United States, the Pacific Northwest likely would benefit from climate change, with both warmer temperatures and slight increases in runoff. By contrast, the Southwest and the southern Plains would experience sharply decreased agricultural activity because of declining yields and restricted water availability. Although the results of such climate change studies and forecasts are very uncertain, they do suggest that western irrigated agriculture is sensitive to global warming. The potential sensitivity of water supplies and irrigated agriculture underscores the need to develop flexible and adaptive systems for managing water resources.

contracts between wholesalers, such as the Bureau of Reclamation, and purchasers. Even when water is not delivered under long-term contracts, prices have tended to move in concert with general price levels. Significant increases normally occur only in response to rising operation and maintenance costs or, in some instances, on renewal of long-term contracts. There is, however, growing political pressure to remove or to decrease the capital cost subsidies that many irrigators who obtain water from the Bureau of Reclamation have enjoyed. In some regions, irrigators are faced with major investments to overcome drainage problems or to manage other environmental problems (Natural Research Council, 1989). These factors could result in significant real increases in purchased water costs for some districts over the next few decades. The timing and magnitude of such increases, however, are difficult to predict.

Energy prices are perhaps the most important irrigation cost variable because they are potentially volatile and the crucial determinants of water's cost anywhere water must be pumped. Energy costs account for greater than half the total irrigation costs for some deep-well irrigators, for example. Historically, energy prices have been quite volatile. Diesel fuel prices paid by farmers increased in real terms by 275% between 1970 and 1981 but by 1993 had declined to the point at which they were only about 50% higher, in real terms, than in 1970 (U.S. Department of Commerce, 1994). Electricity prices have been more stable over time but differ substantially from region to region. Regions heavily dependent on hydroelectric power may be particularly vulnerable to price increases if river management regimes are changed to accommodate environmental objectives.

The most likely future scenario may be for stable or slightly increasing real water-prices. There are many uncertainties, however. Political instabilities underlying the world energy market could lead to dramatic increases on relatively short notice. In addition, reductions in the availability of hydroelectric power that are occasioned by the need to manage rivers such as the Columbia to preserve threatened or endangered species also could cause the real price of energy to rise sharply in some regions. Anything other than temporary energy price shocks could have a strong effect on the viability and profitability of irrigated agriculture in areas relying on ground water or on imported surface supplies requiring extensive pumping for conveyance. Irrigators relying on gravity-fed systems will be comparatively unaffected.

To some extent, price increases can be offset by improvements in technology and management practices, both of which tend to decrease cost. Technological improvements can change pumping costs per unit of water and also can change the amount of water required to produce a fully irrigated crop. Recently, dramatic changes have been achieved by decreasing pressure requirements for sprinkler irrigation and by improving both irrigation scheduling and irrigation-water application uniformity. For example, pressurization requirements for center pivot sprinklers totaled 75 to 80 pounds per square in. (psi) when the technology was introduced in the 1960s, but the development of low-energy precision application (LEPA) systems in the intervening decades decreased pressurization requirements to approximately 20 psi, with concomitant savings in cost (Gilley and Supalla, 1983).

Improved irrigation scheduling and water application practices also have led to dramatically lower irrigation costs per acre of production. Improving the uniformity with which irrigation water is applied can decrease significantly the quantities of water applied, often without any adverse effects on yield. Irrigators in southwest Nebraska, for example, apply about 40% less water today than in 1970, to produce the same crops. Without having a discernible effect on yield, irrigation scheduling can decrease the amounts of water applied. In some areas, scheduling advantages cannot be realized without significant investment in facilities permitting water to be delivered on demand rather than for preset periods.

Crop yield improvements also can counter the effects of higher input costs to irrigated agriculture. Historically, crop yields have increased with advancing technology, with irrigated yields increasing more rapidly than dryland yields. Although differing widely with variations in cropping patterns throughout the West, the effects of yield changes on the economics of irrigation can be substantial. Irrigated corn, the dominant irrigated crop in the United States, has shown yield improvements of approximately 2.5 bushels/acre/year since 1950 (Hanway et al., 1982). The advent of agricultural biotechnology holds promise for continued improvements in crop yield, some of which could be dramatic.

Although the future costs of irrigated agriculture may be difficult to predict, there seems little reason—aside from a major disruption in world energy markets—to suspect that costs will be sharply higher. Yet most analysts expect revenues from irrigated agricultural production to decline as a consequence of both less favorable government policies toward agriculture and increased global competition in the production of food and fiber. Even modest increases in irrigation costs could result in less profitable or unprofitable irrigated agriculture. But revenue declines need not lead inevitably to diminished returns. Rather, continued investment in agricultural research and development holds the prospect of stabilizing or lowering the real costs of production so that net returns to irrigated agriculture need not shrink and may grow. Thus, although shifts in demand for crops and changes in input prices can have dramatic effects on the structure of agriculture, irrigated agriculture in the aggregate should remain profitable.

Government Policies Toward Agriculture

Historically, three types of government policy favored irrigated agriculture and made important contributions to the growth of agriculture in the West. Federal policies aimed exclusively at supplying water for irrigation in the West, general agricultural policies initiated during the New Deal, and state water laws and policies in the West all have been favorable to agriculture. Changing political and fiscal realities probably will lead to policy changes, some of which will become less favorable to agriculture.

Federal Water Policies

The Reclamation Act of 1902 and subsequent amending legislation created a program that made water available for irrigation at extremely favorable state water laws. Unlike state water rights, federal rights cannot be forfeited due to nonuse, and the date of priority is the date on which the reservation was established—*not* the date on which water use was initiated. In many western river basins, Native American reservations were established before the dates of creation of all but the most senior water rights. Thus, quantification of Native American water rights can, in some instances, threaten the seniority of established states' rights, many of which pertain to agriculture (National Water Commission, 1973).

The Supreme Court also has reaffirmed, most recently in the 1963 decision*Arizona v. California*, that the quantity of water to which tribes are entitled is to be determined by the amount of "practicably irrigable" acreage on reservation lands. Although other methods may be used to quantify Native American water rights when the purpose of creating the reservation involved the maintenance of fisheries or other activities, these purposes, like agriculture, tend to involve very large volumes of water (Hundley, 1988). Consequently, potential Native American water claims in the West are very large. The estimate shown in Table 3.1 exceeds 44 million acre feet throughout the West, and whereas it is unlikely that Native Americans ever would succeed in claiming the entire potential, claims ultimately could be very large (Western States Water Council, 1984). The effects of such claims on agricultural water users also may be great, for a disproportionate share of water rights throughout the West are held by agricultural users.

Although the uncertainties posed by unquantified Native American water claims complicate water planning and cause less than optimal investment in complementary water use facilities, such claims likely will not be settled quickly. There are several reasons for this observation. First, many tribes lack access to the legal and scientific expertise needed to settle water rights disputes successfully. Second, many tribes also lack the capital necessary to develop water that they might lay claim to and thus see little gain in pursuing settlement. Third, the costs to both existing water-right holders and tribes associated with losing a claim could be very high. Where such costs are perceived as large, tribes, states, and current right holders are reluctant to assume the risks of settlement proceedings, preferring uncertainty to the possibility of an adverse outcome. For these reasons, the pace at which claims have been filed and settled has been very slow and is likely to remain so. In short, uncertainties surrounding the security of many rights held by agricultural users will persist.

Table 3.1. Potential magnitude of Native American water rights (Western States Water Council, 1984)

State	Potential claim (acre feet/year)
Arizona	31,273,343
California	269,282
Colorado	NA
Idaho	762,721
Montana	6,632,902
Nebraska	26,481
Nevada	210,565
New Mexico	328,333
Oregon	450,000
Utah	630,007
Washington	3,371,805
Wyoming	477,292
Total	44,432,731

NA = Not available.

Nevertheless, even if tribal claims tend to be settled in favor of Native Americans in the long term, the impact on irrigated agriculture is not likely to be large. Inasmuch as the basis for most claims is "practicably irrigable" acreage on reservation lands, claims settled in favor of tribes likely will result in the development of irrigated agriculture on tribal lands. This impact is illustrated in Chapter 5, which describes how growers displaced by urban expansion in central Arizona have leased tribal lands along the Lower Colorado River to continue production. Additionally, it is possible that Native Americans will secure the right to sell or to lease water for use by non-Native Americans on nonreservation lands. Although the resulting transfer of wealth would have some negative impact on low-valued agriculture, the overall impact on western irrigated agriculture likely would be quite small.

International Economic Pressures

Agriculture, like many other industries in the United States, is and will continue to be subject to the pressures of the global marketplace. The benefits of relatively unrestrained trade include enhanced economic growth, decreased costs for both producers and consumers, and increased per capita income (Figure 3.4). These benefits tend to be diffuse whereas the costs to certain subsectors of the industry may be high. There is concern that the agricultural trade liberalization made possible by the recent North American Free Trade Agreement (NAFTA) and the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) may work in some instances to the severe disadvantage of some irrigated agriculture in the western United States. Because of the sharply lower wage rates prevalent in Mexico, there is particular concern about labor-intensive crop production.

Existing studies suggest that the impact of NAFTA on the agricultural economy of the United States will be both positive and large (Joshing, 1992). Nevertheless, there seems to be general agreement that the benefits of NAFTA will fall on the producers of grain, oilseeds, and livestock whereas the producers of vegetables and some fruits will bear a disproportionate share of the costs. Although the net benefits of NAFTA are estimated to be overwhelmingly positive, costs thus could fall disproportionately on the very crops that otherwise promise to be most competitive in the irrigated agriculture of the future. Existing assessments suggest that Mexican exports of melons, cucumbers, peppers, and tomatoes are likely to increase substantially. Avocados will be cheaper to produce in Mexico if Mexican disease problems can be overcome, and exports of frozen orange juice from Mexico are forecast to increase substantially (Joshing, 1992).

Figure 3.4. The agricultural economies of the West likely will benefit from liberalized rules in international trade. Photo courtesy of Jack Kelly Clark.

Although there seems little disagreement about the likely increase of vegetable exports from Mexico, the evidence with respect to fruits is more ambiguous. One study forecasts that exports of fruit from the United States to Mexico actually may increase (American Farm Bureau, 1991). There also is agreement that increased Mexican exports of frozen orange juice will be at the expense of Florida or Brazil and may have little effect on citrus growers in the Southwest (Council for Agricultural Science and Technology, 1993). These reports suggest that Mexican producers are likely to be especially competitive when produce can be canned or frozen. The impact of GATT on fresh fruit and vegetable markets, in which western growers sell, is much less clear.

Should Mexico develop a significant comparative advantage in the production of certain commodities, western growers could face difficulties. The technological superiority enjoyed by western growers and the significantly higher productivity of U.S. agricultural labor suggest, however, that there will be a substantial transition period allowing adversely affected growers to adjust. As a general rule, because of their enhanced capacity to adapt and to adjust to changes in international markets, regions exhibiting flexibility in the types of crops that can be grown are less likely to be affected adversely than other regions. Although the fruit and vegetable growing regions of the West are those with the greatest capacities to alter crop mix, regions in which grains predominate are more likely to benefit from the liberalized trade rules of NAFTA and GATT.

Summary

United States agriculture and western irrigated agriculture have been confronted with significant and sometimes unforeseen changes. The confluence of so many important elements of change seems to create very uncertain prospects. Water supplies are unlikely to be as secure or as plentiful as they have been. In areas completely dependent on ground water overdraft, affordable supplies may disappear altogether. Competition from growing municipal and industrial as well as environmental uses will tend to impose higher costs or higher opportunity costs on agricultural water users. These cost increases could be compounded by increases in the costs of other irrigated agriculture inputs. Energy costs are of particular concern because world energy markets can be disrupted quickly and without warning.

Simultaneously, governmental policies related to both water and agriculture are likely to be much less favorable than they have been. Although these policies are unlikely to become punitive, the western agricultural sector probably will not enjoy protection from pressures to increase the price of water and to compete effectively in a global economy. Neither will it enjoy exemptions from environmental regulations; in fact, it well may become a target of such regulations. Moreover, the federal government is unlikely to move to resolve the uncertainties created by "federally reserved rights" on a broad scale. These uncertainties will remain especially troublesome in regions with Native American reservations. The successful resolution of these uncertainties in favor of Native Americans is unlikely to affect irrigated agriculture in the aggregate. The settlement of individual disputes in favor of Native Americans could affect adversely the supply of water available to agricultural users in particular communities, however.

Finally, western producers and food processors will have to manage change in a more competitive environment characterized by liberalized trade rules and a globalizing economy. New competitive pressures will require those engaged in or dependent on irrigated agriculture to be as innovative and as efficient as possible. At hand are a number of means of responding that should help western irrigated agriculture remain competitive in circumstances far different from those historically prevalent.

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4 Dimensions of Adaptation

Introduction

Despite the substantial changes likely to beset irrigated agriculture, the industry can adapt in many ways. Collective decisions and societal actions will affect crucially the range of options available for responding to change at the farm level. Thus, whereas individual growers will have relative freedom in selecting the crop mix and management regimes to be employed in utilizing scarce resources, the availability of suitable cultivars, new technology and management regimes, and an environment permitting quick and effective response to change will depend on off-farm action. For example, the level of investment in agricultural research and development and the fashioning of policies promoting and enhancing adaptation will have significant effects on the capacity of western agriculture to adapt to the array of changes facing it. The dimensions of adaptation, then, encompass not only actions taken by individual growers at the farm level but also actions taken by the industry itself and those taken by the larger society. The dimensions of adaptation are discussed in this chapter.

Farm-Level Adjustments

Throughout the history of American agriculture, growers have demonstrated a substantial capacity to respond to changing circumstances. The primary causes of farm-level innovation have been changes in prices and costs and favorable agricultural and water policies. Conceptually, most factors identified in the previous section can be viewed either as changes in the availability and prices of various inputs used in irrigated agriculture or as changes in the prices received by growers for the food and fiber that they produce. Growers respond to changing prices and costs by changing crops and the methods by which they grow them.

When an input is limited, farmers tend to devote available supplies to the most valuable uses—those for which the value of the limited input is highest at the margin. A number of studies document the fact that growers respond to drought and other water shortages by using the available supplies of water to produce the highest-valued crops, and low-valued crops either are not produced at all or are produced on a sharply decreased scale (Hamilton et al., 1981; Howitt et al., 1979; U.S. Army Corps of Engineers, 1993). One obvious measure of adaptation to intensifying water scarcity therefore will be a shift from low-valued to high-valued crops. The likelihood of such a shift will depend on prevailing climates, soils, and market conditions for the crops in question.

(When changes in crop mix occur, physical measures of inputs such as crop acreage or water quantities used to grow crops are poor indicators of the economic health of the farming sector. Typically, irrigation water shortages, whether caused by drought or other factors, lead to a less than proportional decrease in crop value, as do declines in irrigated acreage that result from water shortages.)

Growers also will have the option of changing the way in which they manage irrigation water (Figure 4.1). The evidence suggests that when price or opportunity cost of water increases, growers respond by investing in irrigation technology and irrigation management techniques economizing on the use of water. Investments in closed conduit irrigation technologies

Figure 4.1. Older methods of irrigation may result in evaporative losses that can be avoided with closed conduit irrigation technologies. Photo courtesy of Henry Vaux, Jr.

The Water Conservation Morass

The idea of conserving on agricultural water use has generated much confusion and controversy in the past two decades. Many observers have argued that water scarcity in the West could be ameliorated greatly if agricultural water users would conserve and decrease use by as little as 5 to 10%. Others respond that saving on agricultural water use does not normally make water available to other users. Part of the confusion stems from a lack of agreement about the meaning of the term *conservation*. Confusion also may be attributed to the fact that water use frequently is interdependent. That is, water diverted to a farmer's field may run off ultimately and become the supply of a neighboring farmer or may deep percolate to an aquifer, thereby recharging the source of supply for someone else. In these scenarios, conserving water by decreasing runoff and/or deep percolation serves only to diminish someone else's supply. Controversy and confusion can be avoided only by agreeing upon the definition of the phrase *agricultural water conservation* and by understanding that only certain kinds of conservation produce water available for reallocation or use by others.

Agricultural water conservation frequently is defined as using less water diverted from a stream or applied to a field. Yet merely decreasing the amount of water diverted or applied does not guarantee that additional water will be available for use by others, for water frequently is reused and sometimes is reused many times. If conservation results simply in the saving of water that otherwise would be reused, there is no net savings since the supply "conserved" ultimately must be replaced. Net savings in water use occur only when the *consumptive use* of water is decreased. By definition, water is used consumptively only when it is unavailable for reuse. Reductions in consumptive use can be achieved only by decreasing the water actually used by the crop (through evapotranspiration) or by decreasing the amount of water that flows to a *saline sink*, such as the ocean, from which it cannot be reused.

Growers conserve on water when it is profitable to do so. Such conservation will result in net savings when growers switch to less water-intensive crops or manage water in ways decreasing evaporative losses or losses to sinks from which the water cannot be recovered for reuse. When growers attempt to economize on water use in response to higher prices or increased scarcity, they frequently will conserve on water not used by the crop or not affecting crop productivity otherwise. Thus, agricultural water conservation practices may not result in any net savings of water. Public policies and regulations failing to recognize the distinction between *water saved* and *net savings of water* almost always fail and may impose extra costs on growers without making additional supplies of water available to other users (Council for Agricultural Science and Technology, 1988).

allow water to be managed with increased precision. Where water is not delivered on demand, investment in facilities permitting such delivery can lead to more efficient water use. Programs permitting the timing and duration of irrigation applications to be managed precisely and effectively also can lead to relatively efficient water use (Vaux et al., 1990). But although certain actions result in economizing on water at the farm level, they may not make additional quantities of water available for use elsewhere. Because water users often are interdependent, additional water becomes available for use only when economizing on water decreases consumptive use (see sidebar).

Technological Change

Throughout most of the twentieth century, U.S. agriculture has prospered as a consequence of continuous and sometimes revolutionary technological change, which frequently has been induced by changes in the agricultural environment. Water shortages, policy changes, and new or altered regulations and price shifts all provide incentives for developing innovative technology. In a very real sense, change or shocks to the system tend to generate their own technological solution. It therefore is reasonable to expect that one important dimension of adaptation will be the development and use of new technologies.

Because it is embodied in the tools and machines used to grow crops, in the plants themselves, and in the management systems used to coordinate crop, machine, and worker, technology frequently is difficult to characterize. Although they are difficult to categorize technological improvements likely will involve changes in hardware, innovations in biotechnology, and development of superior management systems.

Hardware

Since the end of World War II, innovation in irrigation hardware has allowed growers to match with increasing precision both the quantities of irrigation water applied and the timing of applications to the water demands of crops (Figure 4.2). Included among the most important innovations are drip and microsprinkler technologies, Low-Energy Precision Application (LEPA) sprinkler systems, and laser leveling techniques and surge flow applications—both of which improve the performance of surface irrigation systems. Recent developments include both multifunctional irrigation systems permitting fertilizer and pesticides to be applied with irrigation water, and subsurface drip irrigation systems decreasing water applications significantly while maintaining crop yields (Council for Agricultural Sciences and Technology, 1988; Roberts et al., 1986).

Although further developments in irrigation application hardware undoubtedly will occur, promising hardware (and software) innovations likely will involve computerized irrigation systems and remote sensing technologies. Several promising remote sensing technologies measure plant canopy temperatures, which can in turn be interpreted in terms of plant moisture stress. These technologies can be combined with computerized irrigation systems to provide completely automated irrigation. The use of such systems likely will decrease both the labor and the management costs of irrigation although it remains to be seen whether substantial irrigation water savings can be obtained (Council for Agricultural Science and Technology, 1988).

Figure 4.2. Linear-move irrigation systems are among the technological innovations of the last twenty years. Photo courtesy of Henry Vaux, Jr.

Biotechnology

Some of the most astonishing technological gains in agriculture have resulted from crop breeding programs and the development of superior varieties. Breeding programs of the past have focused primarily on improving yield and quality of produce, but there also have been significant successes in the development of crops resistant to pests. Impressive as these gains have been, however, they ultimately may be dwarfed by the opportunities provided by biotechnology, which include interspecies gene transplants, designer crops, and an array of new approaches to weed, pest, and fertility management (Council for Agricultural Science and Technology, 1991).

The biological revolution is likely to provide unique opportunities to develop crops that are more efficient users of water and can be managed in ways responsive to other environmental pressures (Figure 4.3). Already there is a search for varieties that respond well to deficit irrigation and for varieties that successfully integrate natural rainfall with additional irrigation. According to at least one study, crops resistant to water stress could become available in the last few years of this century (U.S. Office of Technology Assessment, 1992).

Although biotechnology offers the prospect of important and innovative means of adaptation to new constraints on water availability and to others posed by environmental regulations, the prospect remains uncertain, for the biological revolution is still young. Moreover, the willingness of consumers to accept biological technology is somewhat in doubt, and much needs to be done to educate the public and consumers specifically about the promise of biotechnology and its possible adverse side-effects. Developments in biotechnology nevertheless likely will provide western growers with important means of adapting to constraints on water availability and use.

Management

Managerial innovations entail new ways of organizing, controlling, and thinking about farming op-

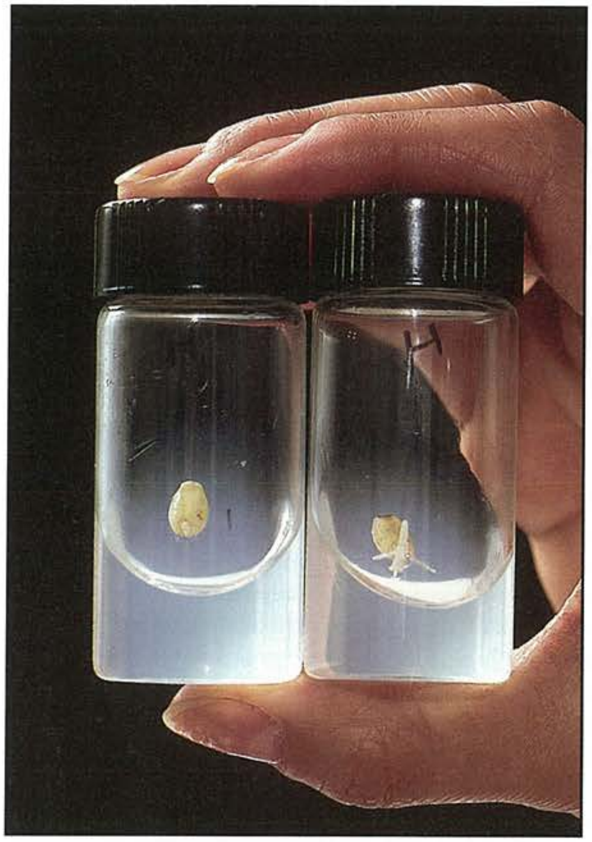

Figure 4.3. **Agricultural biotechnology will help irrigated agriculture to remain competitive in the globalizing agricultural economy. Photo courtesy of Jack Kelly Clark.**

erations. In many instances, managerial innovations are linked inextricably to hardware and to biological innovation. United States growers in general and western growers specifically have a long history of aggressive and successful managerial innovation. The increasing presence of agricultural support firms providing services and advice on matters ranging from pest control and fertilization to irrigation scheduling should help ensure that growers adapt operations to take advantage of new scientific information and technology.

The evolution in the structure of agriculture will tend to favor larger firms and lead to more vertical integration because economies of scale will be important in utilizing new technologies profitably. Small, specialized farms will continue to do well in niche markets. Midsized operations likely will be under pressure to compete successfully under these circumstances.

Research and Development

The success of American agriculture is partly the result of an unparalleled research and education system, which has produced scientifically sophisticated farmers and researchers who lead the world in productivity. Public investment in agricultural research and extension activities has yielded returns unmatched by other industries over comparable periods (University of California Agricultural Issues Center, 1994). Notwithstanding, levels of both federal and state investment in agricultural research and development are falling in real terms, and the outlook suggests further declines. The availability of future innovations—technical, biological, or managerial—will depend critically on the willingness of both the public and the private sectors to invest in research and extension. Without such investment, many of the innovations needed to cope with the new realities of irrigated agriculture will fail to materialize. Indeed, the ease with which irrigated agriculture is able to adapt likely will be related directly to future levels of investment in agricultural research and development.

Institutions and Public Policies

Many of the changes that will need to be confronted by those in irrigated agriculture will be embodied in institutions, laws, and public policies. Yet the extent to which irrigated agriculture adapts will depend in part on the development of complementary changes in institutions and public policies permitting growers to respond quickly and effectively to new circumstances. Many institutions and policies influencing water and agriculture have been developed to promote irrigated agriculture. These institutions and policies are suited poorly to an era in which premiums will be placed on efficient water use and on flexibility and adaptability.

State water laws, which confer water rights in most western states, are ill suited to an era of scarcity. These laws were designed to emphasize security of tenure and thereby to foster western settlement. But by ensuring security of tenure, the laws tend to lock water into existing uses. In the absence of compensating actions, then, water may be unavailable to serve high-valued uses even while lower-valued uses are being served fully. In some parts of the West, most notably in California and Idaho, certain classes of water rights are not even quantified formally. This situation creates confusion over quantities that might be potentially transferrable in water markets and, in

The Edwards Aquifer

The Edwards Aquifer, located in south central Texas, is the sole source of water for the city of San Antonio, population approximately 1,000,000. The aquifer lies in a band that is 180 miles long and ranges between 5 and 40 miles in width. Total storage in the aquifer has been estimated at between 11 million and 55 million acre feet. Recharge is related directly to rainfall and averages more than 630,000 acre feet annually. In some respects, the Edwards Aquifer behaves like an underground river with an average lateral rate of movement of 14 feet/day although rates as high as 2,100 feet/day have been observed for short distances. The high rates of lateral flow reenforce the tendency to treat ground water as a common property resource. Under Texas law, land owners have the right to use underlying ground water. The high rates of lateral flow mean that the law of capture prevails, for failure to pump water makes it available to neighboring "downstream" users.

In addition to being the sole source of supply for municipal and industrial uses in San Antonio, the Edwards Aquifer also provides water for irrigated agricultural and recreational uses and supports significant environmental uses. Average annual extractions total just more than 500,000 acre feet, of which 58% is devoted to municipal uses and 40% to irrigated agriculture. Although total extractions are less than average annual recharge, the situation is complicated because significant natural discharges support important environmental amenities. Natural discharges occur from the aquifer at five major springs, and the resulting flows support as many as five endangered species. Discharges from all but one of the springs have been interrupted by drought at least once in the past 50 years. As the San Antonio region has grown, increased extractions from the aquifer occasionally have decreased water levels and spring flows below the threshold required to support threatened and endangered species (State of Texas, 1990).

This situation led, in 1991, to a lawsuit prompting a federal court to appoint a master to monitor pumping from the aquifer and to develop an emergency withdrawal reduction plan to protect endangered species. Although the Texas legislature responded by creating an Edwards Aquifer Authority to develop procedures for metering, monitoring extractions, and issuing pumping permits, the Authority has been subject to continuing legal challenges crippling its ability to manage extractions. The situation was complicated further in 1995, with the filing of a suit against the U.S. Department of Agriculture (USDA). The suit, which alleges that federal farm programs cause growers to pump more water than they would in the absence of such programs, remains unresolved. Thus, widespread uncertainty persists about the quantities of water available from the Edwards Aquifer to support various uses over the long term.

The absence of a comprehensive ground water law clearly defining ground water rights in Texas has led to a situation in which prolonged litigation will be necessary to allocate the waters of the Edwards Aquifer. Substantial uncertainties stemming from the lack of enforceable ground water rights diminish the ability of growers who depend on the aquifer to respond to the various changes likely to affect irrigated agriculture. Experience with the aquifer also illustrates how agricultural water use ultimately becomes entwined with other water uses in regions characterized by rapid population and economic growth (Todd, 1992).

the extreme, has led to the overallocation of water in specific streams (Governor's Commission to Review California Water Rights Law, 1978).

Similarly, many laws governing ground water provide no incentives for effective management. In California, for example, one secures the right to pump ground water merely by extracting the water and by putting it to "continuous, beneficial use." Arizona's ground water management regulations postpone until the distant future the ultimate day of reckoning, when extractions must be brought into balance with demand. Ground water law in Texas is being made effective only gradually and then on an ad hoc basis (see sidebar on the Edwards Aquifer). Other states have ground water laws that although potentially adequate are sometimes ineffective due to poor enforcement and monitoring. In many areas of the West, yearly and seasonal variations in the availability of surface water supplies could be managed more effectively by the employment of sophisticated conjunctive use schemes involving storage of surplus surface flows in aquifers for subsequent extraction during low-flow periods. The full promise of conjunctive use cannot be realized in the absence of effective ground water laws and their attentive enforcement.

Water markets have become an increasingly attractive way of securing reallocations of relatively fixed supplies to serve new, high-valued water uses. Markets have the distinct advantage of facilitating reallocation by strictly voluntary means. Where market transfers occur, both buyer and seller benefit. Buyers benefit because they can acquire water from the least expensive source, and sellers because they receive compensation exceeding the returns from devoting the water to the most valuable use available to them. The reallocation of water through markets is advantageous also because it tends to ensure that water is put to its highest-valued use. The widespread adoption of water markets in the western United States almost certainly would increase the efficiency and productivity of state and regional economies, thereby strengthening their position in the global economy (National Research Council, 1992).

If the benefits of marketing are to be realized fully, many state laws will need clarification and sharpening. Existing state water laws frequently fail to specify unequivocally who has the right to buy and to sell water and what quantities can be bought and sold. Additionally, some state laws lack provisions that account for the third-party effects attending many water transfers. At least one study suggests that water transfer laws should account in a balanced way for the need to compensate for major third-party effects and for the need to moderate water-transfer transaction costs (National Research Council, 1992). Modifications in federal laws also could facilitate water transfers. Current policies governing transfer rights or entitlements to federal project water are unclear. Specifically, the policies fail to address both the third-party problems that may arise from the transfer of federal water and the issue of whether federal waters can be sold at a profit, thereby creating the perception of windfall gains to entitlement holders. Significant impediments to the transfer of federally developed water throughout the West will remain unless these problems are addressed.

Federal laws that facilitate the marketlike exchange of water between states also would promote allocative efficiency and flexibility. State laws that encourage the marketing of water will enhance greatly the use of markets to facilitate water exchange. Nevertheless, significant benefits and efficiencies in water use will be lost if the transfer of water between states remains impeded by inadequate federal laws. In addition, federal court rulings have created some confusion about whether ground water can be exchanged between states. Federal legislation authorizing interstate transfer of ground water subject to appropriate protections for affected third parties also will promote efficient water use. Failure to effect this kind of reform undoubtedly will hamstring the use of water markets, and a promising form of adaptation to scarcity will not be used to its full potential (National Research Council, 1992).

The concept of water marketing remains controversial in some quarters (Brown and Ingram, 1987; Sax, 1994). Western irrigated agriculture accounts for a majority of consumptive water use in the West, and some of that use is relatively low-valued. As agriculture comes under increasing stress from competing uses, political and economic pressures for reallocation of some water used by the sector to industrial, domestic, and environmental uses will grow. Ultimately, it seems highly likely that some water will be transferred—with only the means of transfer to be decided upon. Reform of state and federal water laws will be difficult because many individual water users have a vested economic interest in preserving existing law. Yet legal reform ultimately will be essential if agricultural and other water-users are to develop the flexibility needed to manage both hydrologic uncertainty and progressively intensifying scarcity. Failure to reform state water laws legislatively or in some other consensual way will invite resolution by the courts, which will increase the probability of mandated reallocations and could result in the imposition of rigid water-use doctrines. Under such circumstances, flexible allocation will be difficult to achieve (Getches, 1988).

Policies relying on market forces or creating marketlike incentives also will become increasingly important. For more than 50 years, farm policies have tended to protect and to subsidize both agriculture and agricultural water users in the West. As these policies are changed or eliminated, they will need to be replaced with policies providing individual growers with maximum flexibility to respond to market forces and to environmental regulations. Policies harnessing the entrepreneurship of individual growers while mandating compliance with environmental, safety, and other regulations are best suited to fostering effective pursuit of both overarching societal—including environmental—goals and private returns from farming.

It will be critically important to modify old policies and institutions and to develop new ones so as to promote reasonable certainty in policy and regulatory environments. Farming is a risky enterprise: weather, disease, and pestilence frequently are beyond the control of growers. Globalization of the agricultural economy will exacerbate risk for western growers, as will uncertain policies and regulations in the face of large-scale change.

Finally, public policies supporting investment in agricultural research and development will help determine the capacity of western agriculture to adapt, especially over the long run. Public policies encouraging private investment in agricultural research and development could be very important in helping agriculture adapt to change. Simultaneously, however, policies should provide for and underwrite public investment in basic research and in research yielding benefits that cannot be appropriated exclusively by individual growers. Rates of both private and public investment in agricultural research and development in the United States are below those in other developed countries. Failure to invest in the research needed to maintain U.S. agriculture's position as the most productive in the world will complicate greatly the challenge of adapting to the change confronting western agriculture.

Conclusions

There are numerous means of adaptation available to western irrigated agriculture. When water supplies are constrained, growers can be expected to cultivate high-valued crops and to invest in water-saving irrigation technologies. Stresses imposed by changing circumstances are likely to spawn new technology. Innovative hardware, biotechnology, and new management regimes all should help western growers adapt. Their ability to do so also will hinge on the development of new institutions and policies better suited to an era of water scarcity than existing policies and institutions are. Revisions in state and federal water law, development of markets through which water can be reallocated voluntarily, fashioning of policies that harness market forces, and development of a consistent and certain policy and regulatory environment are among the institutional and policy changes that would be very helpful to irrigated agriculture. Willingness of the agricultural sector and of U.S. taxpayers to invest in agricultural research and development also will be critical.

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5 Regional Assessments

Introduction

Effects of change in the relative scarcity of water, in the policies governing agriculture and water resources, in the costs of irrigation, and in the emerging global economy will not by felt equally throughout the regions of the West. For example, in the Pacific Northwest, competition from in-stream uses of water will affect agriculture greatly whereas ground water mining will have a relatively small impact. By contrast, irrigated agriculture in portions of the western Great Plains will be altered fundamentally by ground water mining. Similarly, the ability of growers to adapt to change will differ from region to region. Regions with favorable climates and soils, and regions that can grow a wide variety of crops profitably both will adapt more easily than regions with short growing seasons, shallow soils, and limited crop substitution possibilities. In this chapter, the effects of change and the prospects for adaptation are surveyed for the major regions of the West in which irrigated agriculture is practiced.

The Pacific Northwest

The Pacific Northwest includes all the U.S. portion of the Columbia River Basin, as well as the irrigated portions of Oregon and Washington not lying within the basin. These latter areas are mainly the coastal regions of Oregon and Washington. The region, as shown in Figure 5.1, is dominated hydrologically by the Columbia River, which originates in the Canadian Rockies and flows southward into Washington, eventually forming the border between Washington and Oregon before reaching the Pacific Ocean. The Columbia River and its several tributaries drain an area of 668,000 square kilometers (km)^2 (259,000 mi^2), about 85% of which is located in the United States. This area includes most of Idaho, all of eastern Washington, eastern Oregon, western Montana, and smaller parts of Utah, Wyoming, and Nevada. As shown in Table 5.1, the mean annual (average) flow of the Columbia River above its confluence with the Snake is 114,000 cubic feet/second (c.f.s.). At the confluence, the Snake River adds another 46,000 c.f.s. Other tributaries to the Lower Columbia River add to the mean annual flow, which reaches 240,000 c.f.s. at its mouth, near Astoria, Oregon.

The flows of the Columbia are not as variable as those of many other western rivers. Nevertheless, variation, as summarized by data presented in Table 5.2, complicates water management and water allocation in the Columbia Basin. During years of average and above-average flows, water supplies are adequate to serve all uses. In years of below-average flows, however, which occur about one year in five, competition for available supplies is keen. Upstream storage in the Columbia River system is small relative to annual flows, and thus the extent to which flows can be smoothed and equalized between seasons and years is limited. The Columbia River also has a distinct seasonal flow pattern, with flows of the late summer and midwinter smaller than those of the late

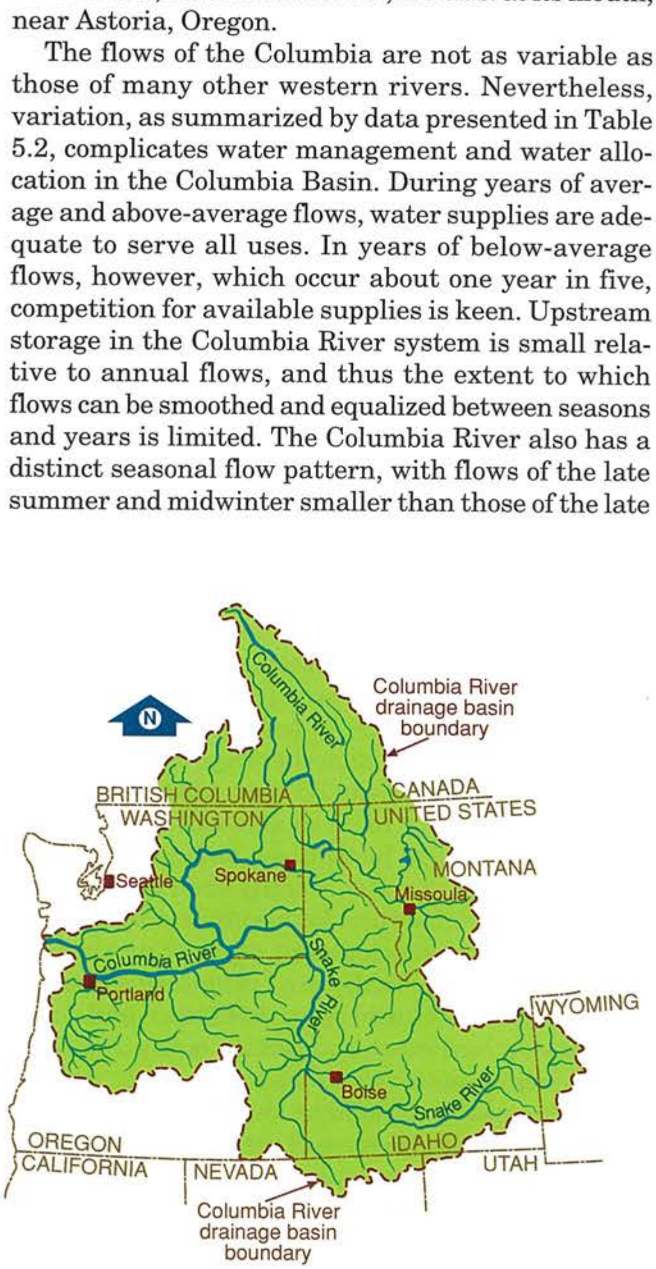

Figure 5.1. Map of the Pacific Northwest (Butcher et al., 1986).

Table 5.1. Water supply and stream flow in the Columbia and Snake Rivers (Pacific Northwest River Basin Commission, 1979)

	Mean flow at selected sites			
			Mean annual flow	
River	Location	Drainage area (mi^2)	(million a.ft/yr)	(k.c.f.s.[a])
Snake	King Hill (Upper Snake)	35,800	6.2	9
Snake	Ice Harbor Dam (Lower Snake)	108,500	33.3	46
Columbia	Priest Rapids	96,000	82.6	114
Columbia	Bonneville	240,000	128.4	177
Columbia	Mouth	259,000	173.5	240

[a] k.c.f.s. = 1,000 cubic feet/second = 1,000 c.f.s.

spring and early summer.

Ground water is used extensively for irrigation in the region. Most aquifers have direct hydrologic connections to surface streamflows, which provide substantial levels of recharge. For example, more that one million acres in southern Idaho are irrigated from ground water directly linked to spring flows affecting the Snake River (Figure 5.2). Approximately 200,000 acres in eastern Washington are irrigated from ground water sources not hydrologically linked to the Columbia River system. Ground water overdraft, especially in Washington, eventually will result in the removal of some lands from production because they have no alternative sources of water.

Table 5.2. Variablity in Columbia River flows at the Bonneville Dam (Pacific Northwest River Basin Commission, 1979.)

Variability	Annual flows (million a. ft)	Momentary flows (k.c.f.s.[a])
Maximum	179.1	1,240
Mean	128.4	177
Minimum	95.1	35

[a] k.c.f.s. = 1,000 cubic feet/second = 1,000 c.f.s.

Figure 5.2. The Snake River in southern Idaho. Photo courtesy of the Idaho Department of Water Resources.

Throughout the Pacific Northwest, water quality generally is quite good, and problems stemming from salinity, or other factors that may inhibit crop production or impair soil conditions, are few. On the major rivers, large volumes and rapid flows provide ample capacity to assimilate most waste. This does not mean that the region is without water-quality problems, however. Large irrigation withdrawals in some stretches of the Columbia affect water-quality adversely by depleting the river's capacity to assimilate waste. In some streams such as the Yakima River and the middle reaches of the Snake, water quality is impaired greatly by pollutants found in irrigation return flows. Such pollutants include nutrients, animal wastes, chemicals, and sediment. In the Yakima Basin and in other isolated instances, sediment and nutrients in irrigation return flows increase the costs of maintaining ditches and canals and preclude the use of certain sprinkler and drip irrigation systems.

One pervasive water-quality problem in the basin is caused by high water-temperatures, which affect fisheries adversely. Elevated temperatures are attributable to storage reservoirs that impede water flow, water withdrawals that deplete flows, and warm irrigation return flows. Effective management of stream temperatures ultimately may be required as part of a comprehensive program to maintain and to enhance salmon runs.

Irrigated Acreage

In the Pacific Northwest, irrigation consumptive use ranges from 15 million to 20 million acre feet annually, accounting for more than 95% of total consumptive use in the region. Irrigated agriculture accounts for about 70% of the total value of all crop production in the region and contributes significantly to the value of livestock production. Irrigated acreage is shown, by state, in Table 5.3. Total land irrigated approximates 8.2 million acres, of which Washington accounts for about 1.7 million acres, Oregon for about 1.9 million acres, and Idaho for about 3.7 million acres. There are almost 1 million additional acres in western Montana.

Table 5.3 also shows the distribution of irrigation systems in the region. Gravity flow irrigation systems compose approximately 44% of total irrigated land in the Pacific Northwest, with various forms of sprinkler and drip systems accounting for the remainder. Gravity systems are found on about 50% of the irrigated acreage in Idaho and Oregon, but on only 25% in Washington. Closed conduit sprinkler systems permit water to be managed more efficiently, and the use of such systems continues to grow throughout the region in response to pressures for increasingly efficient water-management.

Climate and growing seasons differ widely among the states and subregions of the Pacific Northwest. Forage crops account for about 50% of total irrigated acreage, followed by grain crops, which account for about 30% (Figure 5.3). Field crops, fruits, and vegetables cover the remaining irrigated acreage. Growing seasons differ greatly within each state, and the mix of crops grown in each also is distinctive. Washington has the largest percentage of high-valued fruits, vegetables, and field crops and the lowest percentage of forage crops. On the other hand, the existing crop mix in Montana shows a high proportion of forage crops and virtually no fruit or vegetable crops. Oregon and Idaho fall between these extremes, with forage crops dominating in both states.

Figure 5.3. Barley is among the field crops found throughout the Pacific Northwest. Photo courtesy of *California Agriculture*.

One unusual feature of agriculture in the Pacific Northwest is the fact that significantly less than half the cropland is irrigated. In Table 5.4, irrigated acre-

Table 5.3. Irrigated acreage by region and state in the Pacific Northwest[a]

		Acres irrigated by system (%)				Crops (%)			
State/region	Total acres irrigated	Gravity	Side roll	Center pivot	Solid set	[b]Forages	Grains[c]	Field crops[d]	Fruits/ vegetables[e]
Washington	1,724,000	25	42	24	10	30	33	20	17
Oregon	1,878,200	49	38	11	2	64	21	5	10
Idaho	3,664,100	52	35	13	1	43	39	14	5
Montana	948,600	44	18	38		89	10	1	
Pacific Northwest	8,214,900	44	35	18	3	50	30	12	8

[a] Source: Majoro, 1990.

[b] Forages: alfalfa hay and pasture.

[c] Grain: small grains and field corn.

[d] Field crops: beans, potatoes, and other row crops.

[e] Fruits and vegetables: all fresh and processed fruits and vegetables (including sugar beets).

Table 5.4. Percentage of total cropland irrigated, by state, in the Pacific Northwest (U.S. Department of Commerce, various years)

State	1978	1982	1987
Idaho	52.9	53.2	47.8
Oregon	36.6	34.5	31.5
Washington	20.0	20.0	18.6

age is shown as a percentage of total cropland for the three primary states in the basin. The fact that rain-fed agriculture can be practiced profitably west of the Cascade Range limits the lands that must be irrigated in Oregon and Washington. Although irrigated acreage has increased very little in the region during the past decade, the value of crop production on irrigated lands continues to increase. The value of crop production in the three primary states of the region in constant 1992 dollars is shown in Table 5.5. On average, these values have grown 4 to 6% annually since 1978, with increases in value reflecting an increased share of high-valued crops grown on irrigated lands. These crops include processing vegetables, tree fruits, and grapes. The trend of increasing high-valued crop share is expected to continue.

Competing Water Uses

Competition for water supplies in the Columbia River Basin focuses on the need to maintain and augment river flows so as to support three important instream uses. Water diverted to support irrigated agriculture decreases these instream flows, and agriculture thus is seen as a direct competitor with instream uses. The three major instream uses require water to generate hydroelectric power, to support fisheries, and to permit navigation on the mainstem of the Columbia and the Snake. These uses will be considered in turn.

Table 5.5. Total value of irrigated crops sold on all harvested cropland irrigated in the Pacific Northwest, in 1992 dollars (x 1,000) (U.S. Department of Commerce, various years; index used is from U.S. Department of Agriculture, 1992[a])

State	1978[a]	1982[a]	1987
Idaho	727,247	423,965	1,047,082
Oregon	418,558	447,022	682,387
Washington	1,011,880	1,092,995	1,462,078

Hydroelectric Power

The Pacific Northwest benefits from a large supply of cheap hydropower produced at dams along the Columbia and its tributaries. From 1960 to 1980, hydroelectric generating capacity doubled; current generating facilities can produce 110 billion kilowatt hours (kwh) of electricity/year under critical, low-flow conditions. This figure increases to about 140 billion kwh in years of average flow. Construction of additional hydroelectric generating facilities is very unlikely, and thus future levels of hydropower production will depend entirely on the magnitude and timing of streamflows (Figure 5.4). Generating capacity would be affected adversely if it became necessary to increase springtime flows for the benefit of *anadromous*, or migratory, fish.

During the 1970s, the Pacific Northwest began a transition from hydropower to thermal power. The high cost of the latter (more than ten times that of the former) led to sharp increases in both wholesale and retail electricity rates. This experience has heightened competition for cheap hydropower from the region's rivers. Its public and private utilities and aluminum companies, and California's utilities all seek to secure rights to cheap federal hydropower and to shift the costs of thermal power to other users.

Figures presented in Table 5.6 show the opportunity cost of diverting water for consumptive uses at various locations along the Snake and the Columbia Rivers. For example, 1 acre foot diverted and used consumptively on the Upper Snake River entails a loss of $55 in foregone electricity production. This opportunity cost of consumptive diversions diminishes with proximity to the mouth of the Columbia. At the same

Figure 5.4. Bonneville Dam and Power Plant on the Lower Columbia River. Photo courtesy of the U.S. Army Corps of Engineers.

Table 5.6. Opportunity cost of diverting water from hydropower production, selected Pacific Northwest areas, 1990 (Whittlesey, 1996)

Diversion area (dam)	Cumulative head (ft)	Energy loss[a] (kwh/a. ft)	Opportunity cost[b] ($/a. ft)
SE Idaho (American Falls)	2,094	1,822	54.55
SW Idaho (Swan Falls)	1,336	1,162	34.86
Columbia Basin (Grand Coulee)	1,117	1,015	30.45
Lower Columbia (The Dalles)	242	211	6.33

[a] Based on 0.87 kilowatt hour/acre-feet/foot of head.

[b] Estimated "avoided" cost of lost hydropower is $0.03/kilowatt hours.

time, alteration of the streamflow regimes of the Columbia and the Snake could increase opportunity cost at certain times of the year. Widespread public understanding of this tradeoff has led to growing resistance to any proposal that would increase diversions of water for consumptive uses, including irrigation.

Fisheries

In its undeveloped state, the Columbia River Basin was the site of enormous salmon and steelhead spawning runs. It is estimated that as many as 16 million salmon and steelhead traveled up the Columbia each year to spawn (Peterson, 1995). But the construction of dams in the basin blocked many traditional spawning areas. The depletion of streamflows associated with operation of the dams to supply water for irrigation also contributed to the decline of anadromous fisheries. Moreover, major generating facilities have impeded salmon runs further by injuring or killing juvenile fish migrating to the ocean. These and other factors including excessive fish harvests and common logging practices have combined to decrease runs on the Columbia to approximately two million fish per year above the Bonneville Dam. Less than half of these are wild stock.

Restoration programs now call for doubling the total number of anadromous fish in the Columbia Basin and for reestablishing several wild stocks to viable levels. But these efforts may require alteration of streamflow regimes in the Columbia at some expense to hydroelectric power production. In addition, it may be necessary to decrease diversion to irrigated agriculture during critical low-flow periods to maintain and to augment streamflows (Adams et al., 1993; Johnson and Adams, 1988). Demands for maintenance of instream flows to support anadromous fish therefore will compete at times with the demands of both irrigated agriculture and hydroelectric generation.

Navigation

Ocean-going vessels travel 100 mi. up the Columbia to Portland (Figure 5.5). Barge traffic moves another 350 mi. along the Columbia and Snake Rivers, through a series of locks and reservoirs to Lewiston, Idaho. Barges carry mostly grain and wood products downriver and petroleum and fertilizer back to river terminals. Some efforts to restore natural spawning fish to the Columbia River system threaten to interrupt navigation on the Snake for several months each year (Hamilton et al., 1992). Streamflow augmentations may be required to prevent interruption of navigation. Reallocations of water from agriculture are, to many, the most logical means of preserving the flows required for year-round navigation on the Snake.

Future of Irrigated Agriculture

It is now recognized widely that the water resources of the Pacific Northwest are committed fully and that any increase in one use must decrease water availability for other uses. Federal and state investment in irrigation has ceased, and private investment in the development of new irrigated lands has been virtually nonexistent for more than a decade. The central issue is how to maintain current levels of irrigation in the face of competing demands for instream uses so as to support the recovery of threatened and endangered salmon species while simultaneously mini-

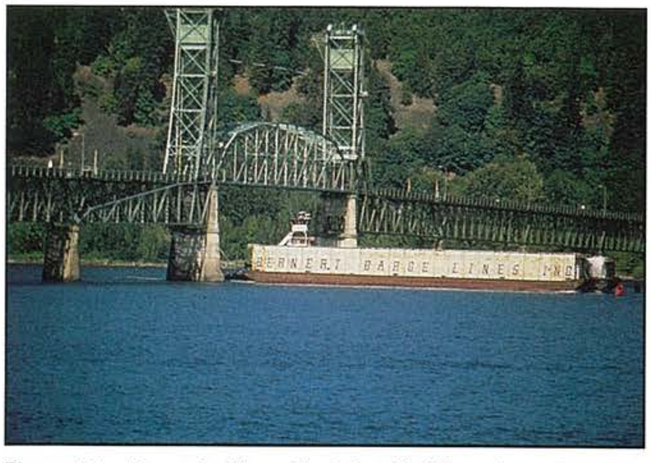

Figure 5.5. Barge traffic on the Columbia River above Portland. Photo courtesy of the U.S. Army Corps of Engineers.

mizing negative effects on navigation, resident fisheries, recreation, and hydroelectric power production. Expansion of irrigated acreage under these circumstances seems unlikely, and declines in irrigated acreage are quite possible because competing demands for the three instream uses are strong.

Historical priorities of water allocation no longer serve the region optimally. Future competition for the region's water supply will be intensified by rising concern about energy costs, demand for increased streamflow, listing of some salmon and steelhead species as threatened or endangered, increased recreational use of water, tightened water-quality standards, and the ongoing needs of irrigated agriculture. Relative abundance of water supplies and ease of irrigation development, both of which characterized the period of expanding irrigated agriculture in the West, no longer are the norm. Several factors are likely to have major effects on the future of irrigated agriculture in the Pacific Northwest.

Water Markets

In years of average and above-average runoff, the Pacific Northwest has sufficient water to serve all uses. During drought, water supplies are inadequate, and allocative issues become paramount. Agriculture now receives its full share of water during every year, leaving insufficient water to serve fisheries, hydropower, and navigation in years of less than average runoff. The value of water for instream flows in the Columbia during low-flow years is high compared with that for irrigated agriculture (Hamilton et al., 1989). This disparity points to the creation of marketlike arrangements facilitating the transfer of water from agriculture to instream uses. One possible arrangement would entail the development of long-term contracts requiring agricultural water users in selected areas to decrease consumptive use by as much as 50% during drought (perhaps 1 year in 5), thereby providing additional supplies to support instream uses.

Under these arrangements, water transferred from agriculture most likely would be that used in the production of relatively low-valued grain and forage crops. The efforts of the National Marine Fisheries Service to restore endangered salmon species in the Columbia River Basin could affect water supplies for several million acres of irrigated land in the Snake River Basin of Idaho (Hamilton and Whittlesey, 1996; Peterson et al., 1994). Inasmuch as the transfers would occur only in years of lower than average flows, the total base of irrigated land would remain unaltered, and all high-value crops still would be produced even in years of water transfer. Gains in hydropower value would be more than sufficient to compensate agriculture for the lost value of crop production.

Water markets would increase allocative flexibility in the region although they would do so by creating additional uncertainty about the reliability of agricultural water supplies. This additional uncertainty probably would not lead to declines in farm income and likely would improve the welfare of the region, however. Some growers would bear increased risks, but marketlike arrangements would ensure that losses were more than fully compensated for.

Water Quality

Water pollution control strategies have focused on the control of problems originating from point sources. Nonpoint sources have been largely neglected, and thus water pollution regulations have had a minimal effect on irrigated agriculture despite the fact that irrigation return flows diminish water quality. Recent evidence suggests that future gains in water quality can be achieved most efficiently by emphasizing nonpoint source pollution control (U.S. General Accounting Office, 1990).

Indeed, the U.S. Environmental Protection Agency (EPA) has indicated that emphasis will be placed on the control of nonpoint sources. This focus likely will require agriculture to manage water more carefully so as to minimize pollution. Certain irrigated areas will be forced to improve water and nutrient management to decrease water pollution from return flows. Although irrigated acreage may not be affected, greater restrictions on choice of irrigation technology, crop selection, and water and nutrient quantities used could be imposed. At times, costs of production will rise or profits from farming fall as the costs of pollution are internalized.

The Profitability of Irrigated Agriculture

Many factors affect the profitability of agriculture in the Pacific Northwest. Several factors outside the control of individual irrigators may have negative effects on farm profits. Over the next two decades, the price of energy needed to pump irrigation water is expected to increase at about the rate of inflation. Rising concerns over threatened and endangered species and water quality will increase the cost of crop production in some areas. Federal commodity programs are being phased out, and the resulting changes likely will cause farm income to vary more widely. Some irrigated agriculture served by the U.S. Bureau of Reclamation in the Pacific Northwest may have to pay more for water if the federal government decreases subsidies and recovers a larger portion of total project costs. Globalization of the agricultural economy will serve as a two-edged sword having different effects on different commodities.

Growers in the region will be able to employ a number of strategies when responding to change. As irrigation technologies improve and international commodity markets develop, the trend of replacing lower-valued grain and forage crops with higher-valued fruit and vegetable crops will continue. Foreign exports of fresh and processed commodities produced in the Pacific Northwest likely will expand. Agriculture will have to rely more on market conditions as federal programs are withdrawn, possibly causing more variability in net farm income, but forward contracting and vertical integration will mitigate these effects. Despite pressures, irrigated agriculture in the Pacific Northwest will remain viable and relatively profitable over the next two decades.

Although irrigated agriculture will face new pressures, there is no reason to expect it to decline significantly in the Pacific Northwest. Urban expansion will continue to erode irrigated acreage in certain areas, but this will have a relatively small total effect. Some areas relying on high ground-water lifts could face marginal declines in irrigated acreage as energy costs increase, aquifer levels decline, or instream users are able to bid water away from agriculture. Some irrigation water rights likely will be purchased and retired to permit the improvement of critical fish habitat. Competition for regional water supplies will require agriculture to become more efficient. Although agriculture will use less water, no more than 300,000 acres are likely to be taken out of production permanently over the next two decades; this acreage, which is less than 4% of total irrigated acreage, is likely to be dispersed widely throughout the entire region. Progressive shifting to higher-valued crops, increases in productivity made possible by technological innovation, and enlightened public policies should permit irrigated agriculture to adapt successfully to changing circumstances.

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California's Central Valley

The Central Valley of California is one of the largest contiguous areas of irrigated agriculture in the world. As shown in Figure 5.6, it encompasses both the Sacramento and the San Joaquin Valleys, stretching more than 500 miles from north to south and averaging 70 miles in width. The valley is bordered by the Coast Range to the west and the Sierra Nevada Mountains to the east, by the Klamath and Trinity Mountains to the north and the Tehachapi Mountains to the south. Its Mediterranean climate is characterized by hot, dry summers and mild, rainy winters.

As in the rest of California, rainfall in the Central Valley is skewed heavily to the north. On the valley floor, mean annual rainfall ranges from 22 in. at Red Bluff in the north, to 13.4 in. at Stockton in the center, and declines to 6.4 in. at Bakersfield in the south. Much of the runoff that fills the storage dams in the Sierra Nevada and northern mountains is the result of relatively high precipitation in the mountains. Because it delays runoff for several months—effective-

Figure 5.6. California's Central Valley (California Department of Water Resources, 1987).

ly adding to the capacity of dams, which play the dual role of flood protection and water storage, the mountain snowpack is an important component of the extensive reservoir system serving the valley. The seasonal and spatial distribution of water makes dryland agriculture impractical during all but the wettest periods. Consequently, valley agriculture depends on irrigation. Valleywide, 60% of irrigation water supply comes from surface water sources. The remaining 40% comes from ground water, which is available in most locations.

Surface and Ground Water Development

The development of water in the Central Valley can be characterized in terms of five main stages. First, limited private companies developed from 1890 to 1930; second, the government assisted in large interbasin transfers dominating development from 1930 to 1970 (Figure 5.7); third, development stagnated from 1970 to 1982; fourth, existing supplies were reallocated structurally; and fifth, nonstructural water market evolution evidently began in 1991, with the introduction of the Emergency Drought Water Bank. This last stage continues with the 1992 Central Valley Improvement Act.

The various coalitions influencing water development in each stage were brought together by the lure of profits from water development and the combination of costs, technologies, and political institutions giving rise to profits. When technology or cost structure changed, the existing water coalition was replaced by a different coalition and different technologies better serving the economic and political goals of the time (Howitt and Vaux, 1995).

The early years of local and private development were based on simple technologies of earth lined canals and plentiful riparian water sources. As these sources of water in the northern part of the valley became increasingly separated from the more productive regions in the south, the need for interbasin transfers became evident. But the scale, technology, and financing for large interbasin projects required the active participation of government development agencies. The main political stimulus for federal water development projects was the Reclamation Act of 1902. This envisaged using federal water development to stimulate large areas of Jeffersonian family farms as a bulwark against a radical proletariat (Roosevelt, 1911). Initially, the federal irrigation projects led to the development of such communities in some areas, but large landowners dominated the service areas of certain later projects and used federal subsidies to decrease operating costs.

In the 1970s, the combination of federal subsidies and environmental damage caused by continued project development on some rivers in northern Cal-

Figure 5.7. One of the many canals delivering water to agriculture in California. Photo courtesy of Jack Kelly Clark.

ifornia stimulated opposition to additional surface water development from newly emerging environmental interest groups. The last major water storage facility built for the Central Valley was the New Melones Dam on the Stanislaus River. This project was completed in 1979, but filling of the reservoir was delayed several years by environmental activists.

Throughout the era of arrested development from 1970 to 1982, the role of conservation and demand modification in balancing state water supplies was debated hotly. The problems of drainage accumulation and toxic levels came to the fore in the early 1980s, with the discovery that naturally occurring selenium in drainage waters was being bioconcentrated by waterfowl, which were evidencing increased rates of birth defects and mortality. The resulting drainage standards caused a substantial shift in irrigation practices and technology in regions along the west side of the San Joaquin Valley. In these regions, the quality of drainage water was affected by the build-up of pollutant concentrations in subsurface drainage-waters and by selenium-rich subsoils (National Research Council, 1989).

In addition to environmental objections to water development, the fundamental economic cost of large surface-developments was increasing rapidly. Figure 5.8 shows the actual and projected costs of water development in the Central Valley. Additional surface water development beyond the stalled 1982 level would be at a sharply increasing marginal cost. If projects were financed on an incremental cost basis, high water-costs would discourage agricultural use. If average-cost pricing was applied to these additions to existing state and federal projects, average cost to all contractors would shift upwards. This average-cost increase caused by additional water supplies provides strong incentives for existing contractors to resist project expansion, which would be largely at their expense. Simultaneously, the profitability of field crops justifying additional irrigation development became doubtful because available soil types were of poorer quality and because planned locations for development required increasing amounts of energy to convey water to valley lands. These three factors transformed the stage of arrested development from a progressive halt to a search for alternative means of balancing state water supplies.

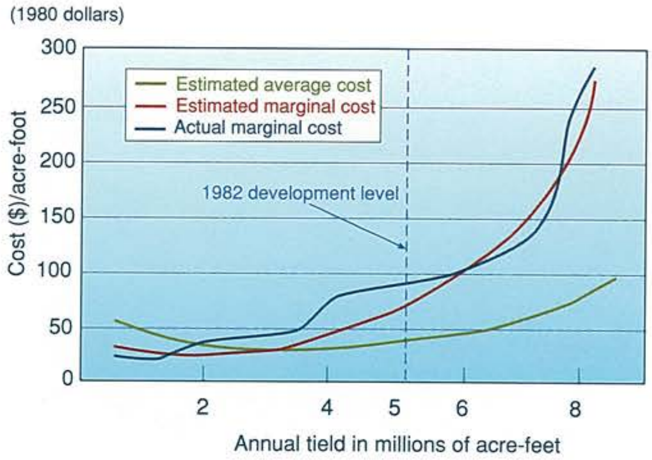

Figure 5.8. **Marginal and average cost of surface water in California (Howitt and Moore, 1994).**

By the late 1980s, it became clear to environmentalists that merely stopping future development would not maintain existing fish populations in the Sacramento and the San Joaquin Rivers and their associated Delta, through which all water stored in northern reservoirs is exported. A reallocation of certain developed supplies to fishery and wildlife protection was proposed in several initiatives and in prospective legislation. Water supplies were reallocated with passage of the Central Valley Improvement Act of 1992 and with a state-federal agreement on the reallocation of waters flowing into the joint Delta of the Sacramento and the San Joaquin Rivers.

Irrigation Development

The irrigation development of the southern and central parts of the valley relied on the interbasin transfer of very large volumes of water. The two major transfer systems are the Federal Central Valley Project (CVP), with an average delivery capacity of 8.5 million acre feet of water, and the State Water Project (SWP), with a designed delivery capacity of 4.2 million acre feet. In its current stage of development, the SWP has a normal delivery capacity of only 2.2 million acre feet, and any growth in this capacity seems unlikely. These projects were designed to serve both agricultural and municipal and industrial uses. The key dams for the projects, the Shasta (CVP) and the Oroville (SWP), are located in the northern Sacramento Valley. Water is transferred south by means of the natural conveyance channels of the Sacramento River and the Delta. Water is extracted from the Delta by pumps and conveyed through canal systems running along the west side of the San Joaquin Valley. Agricultural deliveries are made from both projects throughout the San Joaquin Valley, and major municipal and industrial deliveries are made from the SWP, in which water is pumped over the Tehachapi Mountains into the Los Angeles Basin.

Approximately 60% of the Central Valley's water supply comes from local surface sources and interbasin transfers. In years when precipitation is average or better, the remaining 14 million acre feet of applied water comes from ground water sources. In drought years, however, ground water pumping increases by approximately 7 million acre feet to compensate for decreased surface supplies (Figure 5.9). Although the ground water basins in the north of the valley are in balance with natural recharge, some in the south are overdrafted significantly. Overdrafting continues at the average rate of approximately one million acre feet/year (California Department of Water Resources, 1994) and is exacerbated by the absence of any adjudicated ground water rights. In most places, there is not even an obligation to meter the quantities pumped.

Irrigated Acreage

Figure 5.10 shows the growth in total irrigated acreage from 1930 to 1990. This growth reflects expansion of markets for California produced field, fruit, and nut crops, as well as the availability of additional water supplies from major new project developments. Irrigated acreage peaked at 9.8 million acres in 1980 but has declined steadily since because of decreasing government support for crop prices, increasing water costs, and increasing restrictions on the supplies of federally subsidized water. By 1990, irrigated acreage had declined to 9 million acres, and there has been a subsequent additional decline of 370,000 acres, which is attributable to the drought of 1987 to 1992. Despite this decline of nearly 12% in irrigated acreage, the value of California produced food and fiber increased by 34% over the same period, as growers abandoned marginal land, employed the most modern irrigation technologies, and switched to higher-valued crops.

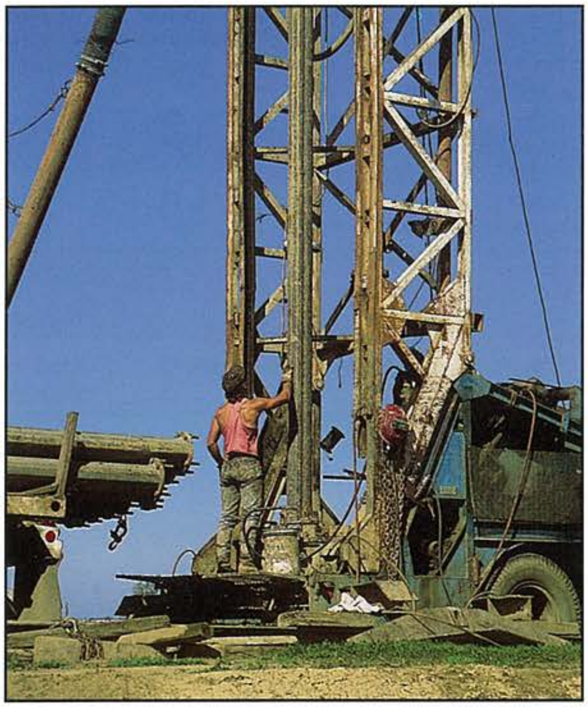

Figure 5.9. **Ground water pumping increases dramatically during times of drought in California. Photo courtesy of Jack Kelly Clark.**

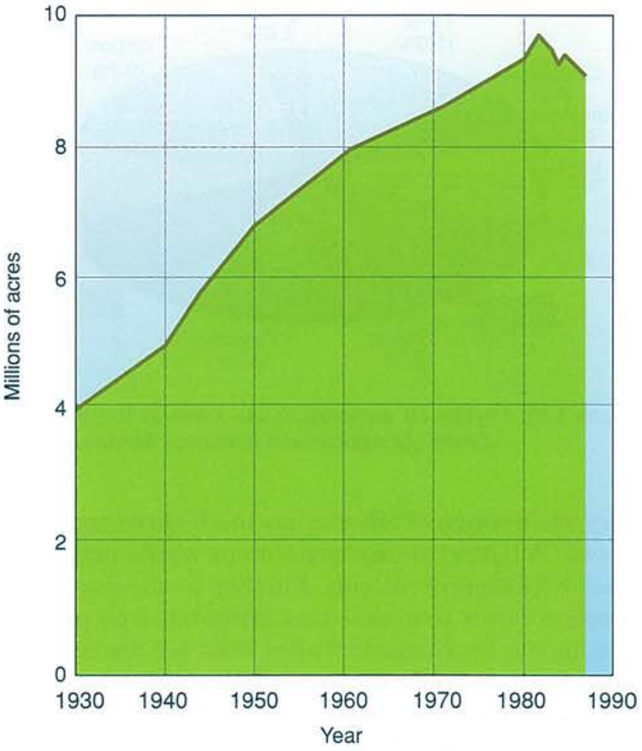

Figure 5.10. **Irrigated acreage in California, 1930–1990 (California Department of Water Resources, 1987).**

Cropping patterns in the Central Valley depend mostly on local climate, soil type, and water availability. Current cropping patterns are shown on an acreage basis in Figure 5.11. The three main groupings of irrigated crops include high-value fruit, nut, and vegetable crops; field crops with a wide range of values, from processing tomatoes to barley; and forage crops dominated by alfalfa hay but also including corn silage, irrigated pasture, and a small amount of native-grass based hay. Cropping patterns typically change along the north-south direction in the Central Valley. In the dominant area of the central San Joaquin Valley, cotton is the staple field crop, comprising 40% of the acreage planted in many regions. Additionally, a

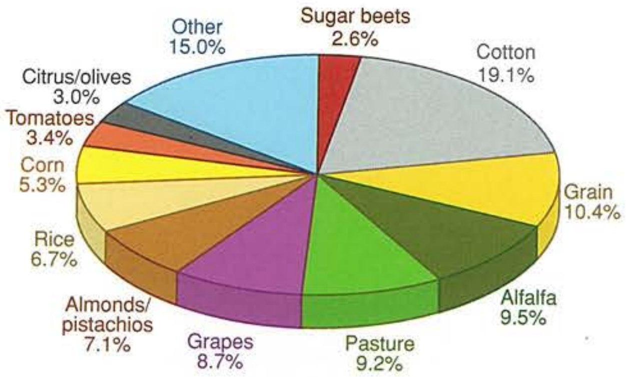

Figure 5.11. Irrigated acreage in the Central Valley, 1990 (California Agricultural Statistics Service, 1990).

very wide range of other crops in all three groups is grown. A listing of important crops would include at least 30 different entries. Farther to the north, because of lower temperatures, irrigated crop production in the Sacramento Valley does not include cotton, but there are large areas of rice production based on a plentiful water supply and heavy soils.

Over the past 10 years, cropping patterns in the Central Valley have shifted somewhat. Land placed in federal set-aside programs has increased, predominantly in conjunction with rice and cotton crop enrollment in price support programs under the Food Security Act of 1985. Cotton and rice acreage has declined slightly from the peaks reached in the early 1980s. The steady decrease in irrigated pasture acreage has continued under pressure of rising water-costs. This decrease is expected to continue.

Despite the contraction of total irrigated acreage in California, some crops have increased in acreage. Vegetable crops have grown rapidly in terms of both acreage and production value. Vineyards and deciduous orchards also have made smaller but notable increases in total acreage, driven by the long-run change in food consumption patterns towards fruit, nut, and vegetable crops. These high-value crops have significant short-run fluctuations in price, but the long-term fundamental demands look promising despite increased international competition in the production of these crops.

Production and Farm Income

Although fruit, nut, and vegetable crops comprise only about one-third of irrigated acreage in California, they contribute as much as two-thirds of gross production value. Table 5.7 shows the relative importances of different crops in terms of acreage, water use, and economic value. Three of the five crops with the highest total production values are fruits, nuts, and vegetables although they account for relatively modest proportions of total acreage. Table 5.8 compares, over different periods and commodities, annual growth rates, production values, and return vari-

Table 5.8. Growth rate and variability for California's crops and livestock, 1960–1990 (California Agricultural Statistics Service, 1960-1990)

	Annual growth rate	Mean production value ($ billion)	Coefficient of variation
1960–1971			
All crops	4.04	2.48	5.45
Livestock and others	4.68	1.67	0.05
1972–1990			
All crops	6.13	8.78	7.86
Livestock and others	5.10	4.27	5.19

Table 5.7. Californa irrigated crops, 1990

Crop	Acres[a] (thousand)	Output value[b] ($ million)	Output/a. ($)	Consumptive[b] water/a. (a. ft)	Output value ($/acre-foot)
Cotton	1,115	1,032.7	926	2.1	441
Alfalfa hay	960	852.4	888	3.5	254
Grapes	639	1,692.1	2,468	2.5	1,059
Wheat	614	157.6	257	2.0	129
Almonds	411	480.9	1,170	2.5	468
Rice	385	190.2	494	3.5	141
Tomatoes (processed)	310	586.4	1,892	2.5	757
Barley	200	26.5	133	2.0	67
Corn	160	78.1	488	2.5	195

[a] Source: California Agricultural Statistics Service, 1990.

[b] Sources: California Department of Water Resources, 1986; California Department of Water Resources, 1991.

abilities. The table also compares the importance and the growth rate of cropping and livestock sectors. Between 1960 and 1971, growth rates for crops and livestock production were very similar. In the years 1972 to 1990, the growth rate of the cropping sector increased by half and overtook that of livestock. This faster growth rate and shift in cropping patterns also resulted in greater variability of output, especially within the livestock sector.

Growth rates and variabilities for the three main crop groups are compared, for three time periods, in Table 5.9. Fruit and nut crops had the lowest rate of growth in the 1960s (4.53%) but the highest rate in the 1980s (8.61%). The growth rate for vegetable output slowed 45% although there was a significant upturn in the 1970s. The growth rate for field crop production declined from 10.8% in the 1960s to 2.28% in the 1980s. Variability in the level of output for all crops declined slightly between the 1960s and the 1980s. The period 1972–1982 was one of very high variability for fruits, nuts, and field crops, however (Figure 5.12).

Figure 5.13 shows the trend from 1960 to 1988 in the value of crops (measured in constant dollars) in California. The two plots show the dramatic growth in value of the fruit, nut, and vegetable sector. Until 1976, the production values of field crops and specialty crops were similar in magnitude and growth. Between 1976 and 1988, however, the output of specialty crops grew rapidly and that of field crops stagnated. By 1988, the dollar value of specialty crop output was twice that of field crops. Although there are annual fluctuations, this trend shows no sign of reversing.

Agricultural income fell in the mid-1980s, reaching its low point in 1987. Since then, there has been a slight upward trend in net returns to farming despite the recent 5-year drought that decreased net income slightly in the most severe year of 1991. The incomes

Table 5.9. Growth rate and variability for California's crops, 1960–1990 (California Agricultural Statistics Service, 1960-1990)

	Annual growth rate (%)	Mean production value ($ billion)	Coefficient of variation
1960–1971			
Fruit and nuts	4.35	0.74	7.07
Vegetables	6.74	0.68	7.61
Field crops	10.81	0.88	6.38
1972–1982			
Fruit and nuts	10.22	2.29	15.50
Vegetables	9.35	2.02	4.79
Field crops	6.28	2.28	17.26
1983–1990			
Fruit and nuts	8.61	3.93	2.64
Vegetables	3.66	3.31	4.31
Field crops	2.28	2.42	5.29

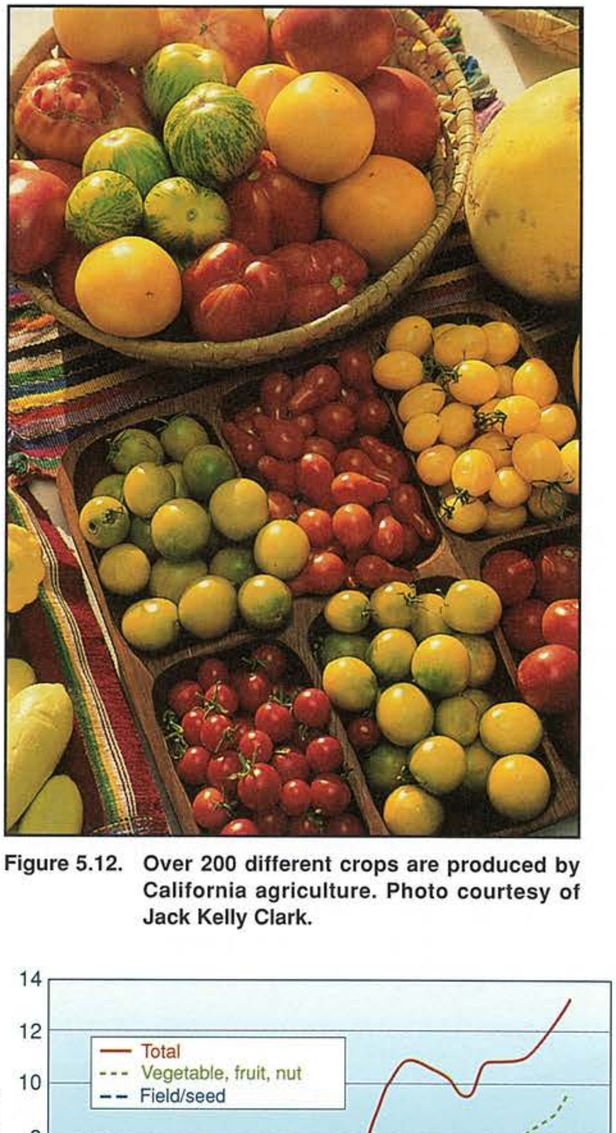

Figure 5.12. Over 200 different crops are produced by California agriculture. Photo courtesy of Jack Kelly Clark.

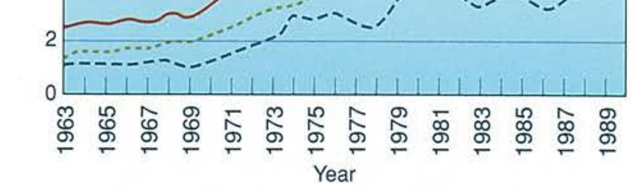

Figure 5.13. Trend values of crops in California, 1960–1988 (California Agricultural Statistics Service, 1960–1990).

of farm business suppliers, communities, and farm labor decreased more during the drought than those of farmers did. Land values have increased since the 1987 low point but have not regained the high level observed in the early 1980s. Irrigated agriculture in California produces a higher ratio of export crops than it does in other Western states. Although exports depend on exchange rates and international markets, California normally exports one-third of its crop production value. This production typically is achieved on 20 to 25% of irrigated acreage.

Welfare of Rural Communities

California has a strong tradition of rural community development. Much federally subsidized water development was justified on the basis of creating small family-farms and associated communities. But enforcement of the acreage limitations specified in the federal Reclamation Act of 1902 has been so lax that small rural communities have not developed in response to later projects bringing a reliable source of surface water to the western San Joaquin Valley. In other areas of the state, rural communities are an integral part of irrigated agricultural development. The trend in farm size is similar to that in other agricultural regions, with a gradual consolidation of larger farms and a growth in the number of small farms (Figure 5.14). It generally is thought that the growth in small farms is related more strongly to the rural residential values associated with country living than with increasingly profitable small-scale farming (Johnston, 1990).

At the other extreme, there has been a shift in farm structure away from the very large farming operations owned by publicly held corporations. Over the past decade, these very large irrigated farming operations, spawned by the water development programs of the 1960s, generally have downsized to large but more manageable units. Although there probably are economies of scale in the financing and marketing of specialty crops, there are distinct diseconomies of scale in the primary production processes for very large operations of more than 10,000 acres. Growth in the number of very small and midsize farms, along with a contraction in the small number of very large corporate farms, is likely to continue (Johnston, 1990).

Figure 5.14. The number of small farms in California has grown steadily. Photo courtesy of Jack Kelly Clark.

Residents of rural communities are concerned about both the new trends in reallocating irrigation water by market, and the outright surface-water supply cuts due to environmental regulations. In rural communities, many believe that irrigation water has a social as well as a private economic value. Failure to account for such social value could lead to reallocations of water that are less than economically optimal for rural communities. Recognition of the social value of water implies that sales and transfers should be within regional guidelines limiting the quantities of water that can be transferred or reallocated outside the region (Howitt, 1994).

Future Challenges to Central Valley Agriculture

California agriculture always has existed on a fertile but fragile resource base. The hot climate and the constructed water systems permitting high yields and allowing crop diversity inevitably lead to adverse environmental side effects. Competition for limited water supplies among the urban, agricultural, and environmental sectors has intensified, and pressures to reallocate water from agriculture to other sectors are growing. These developments will be considered next.

Integrating Irrigation and Environmental Effects

Many of the disruptive influences of irrigated agriculture are manifested through the water delivery and drainage system. Natural and regulatory droughts have buffeted the San Joaquin Valley for nearly a decade. Whereas the effect of natural droughts has been largely contained by the use of ground water and water transfers, the growing impacts of regulatory droughts caused by river flow modification for wildlife preservation are more serious threats. The problem of drainage water quality in the Central Valley has been downplayed by the reduction of water applied during drought years. Decreasing drainage volumes by decreasing applied water does not solve the long-term salt balance problem in the west side of the San Joaquin Valley. Approximately 4.5 million acres of irrigated cropland in California is affected by saline soils or by saline irrigation water (Figure 5.15). A significant proportion of this land is in the San Joaquin Valley, and unless means can be found to export salt from the Valley or to isolate it completely, perhaps as much as 200,000 acres could go out of production in the next 20 years (Letey et al., 1986).

Weather conditions favorable for the growth of high-value crops are equally suitable for producing ozone air pollution from the precursors generated by power plants, vehicles, and local oil industries. Ozone in the southern San Joaquin Valley now reaches an ambient level high enough to decrease some crop yields by as much as 15%. The crops most susceptible to ozone damage, e.g., grapes, citrus, cotton, and lettuce, often are those with the greatest returns per acre. Damage from ozone in the Central Valley is estimated to be in the order of $75 million/year (Winer et al., 1990).

The rate of ground water depletion remains relatively high in the San Joaquin Valley. For example, in Kern and Fresno Counties, regional ground water recharge programs have accelerated the rates at which ground water levels recovered after the last two droughts. In Stanislaus and Madera counties, however, overdraft is a persistent problem exacerbated by the periodic droughts occurring with regularity in California's climate (California Department of Water Resources, 1994). The lack of effective laws and regulations governing ground water extractions throughout the Central Valley retards the development of recharge programs and facilities.

Figure 5.15. Failure to manage salt balances at the field level decreases yields and ultimately makes the soil unproductive. Photo courtesy of *California Agriculture*.

The Emergence of Water Markets

The 1987–1992 drought caused a quantum change in water institutions. Faced with the dire effects of a 4-year cumulative drought in the early part of 1991, the Governor had the unenviable task of choosing between reallocating some of the state's meager supplies by executive fiat and taking the politically risky step of instituting an emergency water bank. He chose to implement an emergency drought water bank and instructed the State Department of Water Resources to purchase and to resell water released by crop fallowing, surplus storage, and ground water exchange. Despite the rapidity with which the water bank had to be established, results were very encouraging in that farmers sold substantially more water to the bank than anticipated (Coppock et al., 1994).

Both supply and demand elasticities for water from the water bank were greater than predicted. Thus, for example, the urban users and high-value agricultural producers who bought water bought far less than had been predicted at the fixed price of $175/acre foot. The bank's success suggests that emergency water banks will become a permanent part of California drought management. In addition to the state sponsored bank, several private water trades have been consummated in the past 5 years. Most agreements take the form of contracts contingent on the availability of water in a given year. Some require that the net gain in water be generated from conservation while others require that crops be fallowed or grown with decreased water applications.

In some parts of the Central Valley, water cost now constrains the types of crops that can be grown profitably and the types of soils that can be irrigated profitably. Areas served with water developed by the Bureau of Reclamation are evidencing sharp price increases driven by changes in pricing structure specified in the Central Valley Improvement Act, by large fixed-cost components, and by dwindling water supplies. In other parts of the southern valley, the cost of energy to SWP contractors is causing the cost of water in areas with higher lifts to exceed the returns that can be made from areas with lower cotton yields. Forage crops such as alfalfa or corn are grown only where rotational benefits are well established.

The Future of Irrigation in the Central Valley

California's Central Valley will continue as one of the preeminent regions for irrigated crop production. Despite the list of problems facing irrigated agriculture in the area, ample reason exists to believe that the industry can adjust to the changing conditions of its economic and resource base. The main reason for this confidence is that demand is growing for crops in which the Central Valley has a comparative advantage. Extrapolating data from the past 20 years shows a continuation of the trend of increasing fruit and vegetable crop production in the Central Valley. Demand for these crops is income elastic and shows steady increases despite growing foreign competition. This favorable demand shift will enable California irrigated agriculture to continue to grow in terms of output value and profitability despite decreased water availability, deteriorating air quality, and urban-

Managing California's "Great Drought"

California's experience in managing the drought of 1987–1992, the most severe on record, illustrates how a number of adaptive strategies can be used to moderate the effects of significant shortfalls in surface water supply. Net returns from irrigated agriculture and related urban industries were decreased in only 2 of the 5 years of drought and, then, by a far smaller proportion than available surface supplies were. By altering institutions and establishing the Drought Water Bank in 1991, the state helped ensure that very high-valued, critical uses received sufficient water. For example, through the Water Bank, growers who relied on surface water to cultivate permanent crops and who lacked access to ground water were able to obtain sufficient supplies to save their crops. Individual growers also responded to the drought by altering crop mix and by adopting improved water-management technologies and practices.

In average or better-than-average water years in California, the lowest one-third of gross agricultural production accounts for roughly two-thirds of water used by agriculture. The crop shifts that California growers chose to make in response to the drought emphasized decreasing acreage in forage and grain crops. In 1991, the most critical year of the drought, growers decreased the acreage devoted to production of barley, corn, and wheat by between 23 and 30% of that devoted to such production in the 2 years before the drought. Cotton and rice acreage decreased 8 and 12%, respectively. All these acreage reductions were relatively small given that surface water supplies were decreased by 40% or more in many areas. Despite decreased surface water supplies and sharply declining acreage in feed and forage crops, gross production value fell by only 15% between 1990 and 1991. For the four initial drought years—1987 through 1991, the gross value of field crop production rose each year, peaking in 1991 at $3.185 billion, the fourth highest value of output on record.

Rising production costs attributable to water scarcity during the drought caused farmers to reassess their technology and management regimes for applying water at the field level. In some instances, closed conduit irrigation systems such as drip and microsprinkler systems were installed so that water could be applied with precision. For other crops and areas, improved water use was achieved by employing additional labor and managing existing irrigation systems more intensively. Some growers, for example, shortened furrow lengths from 0.5 to 0.25 mi, and some constructed tailwater reuse facilities on furrow irrigated fields. For crops that could not be grown readily with high-technology systems, additional increases in efficiency were obtained by laser leveling fields, thereby allowing delivery with surface irrigation systems to be managed more carefully. Laser leveling was used widely in the few rice-growing regions in which water was sold through the Bank and fields were fallow for a year.

Where surface water supplies were unavailable or curtailed sharply, growers often were able to substitute ground water for surface water. The resulting increase in ground water overdraft was eliminated when surface supplies returned to normal, and experience with earlier droughts suggests that the ground water levels will return to predrought levels after several wet years. Ground water is the main buffer against drought in California and elsewhere in the West, and overdraft during times of drought rarely is of concern, for extractions are decreased and ground water levels restored during periods of adequate surface water supplies. Ground water overdrafting is not sustainable in the long run, however, and therefore cannot be relied upon to offset long-term scarcity in surface water supplies. The importance of ground water during drought and the need to manage it with sophistication underscores the importance of developing clear and enforceable laws and policies governing the rights to and the use of ground water.

ization, all of which have decreased yields and irrigated land area in the past and probably will continue to do so.

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The Lower Colorado River Basin

The Colorado River is the largest U.S. river flowing through predominantly arid lands (Figure 5.16). Nearly 1,500 miles long and draining a basin of 629,312 km^2 (244,000 square miles), the river includes parts of seven states and Mexico. The Colorado's waters are allocated according to the "Law of the River," a series of compacts, court decrees, and treaties. The Colorado River Compact, one of the fundamental instruments of allocation, divides the river into an upper basin and a lower basin at Lees Ferry, Arizona. The lower basin, as shown in Figure 5.17, drains nearly all of Arizona, as well as parts of Nevada, California, and Mexico (Hundley, 1975). Waters from the lower basin are allocated among the three states according to the 1963 Supreme Court decision *Arizona v. California* (373 U.S. 546) and to Mexico according to the Mexican Treaty of 1944.

The Lower Colorado provides water capable of supporting significant irrigated acreage in central and southern Arizona and in California's Imperial Valley. The lower basin also supplies water to the greater Los Angeles metropolitan area through the Colorado River Aqueduct and to the Phoenix and Tucson metropolitan areas through the Central Arizona Project. Additionally, river flows support irrigated agriculture in the Palo Verde and the Coachella Valleys of California and in the Parker and Yuma areas of Arizona. Despite its length and the relatively large area that it drains, the flows of the Colorado River are rather small (National Academy of Sciences, 1968). Supplies available to Lower Colorado River Basin users have been fully allocated—some would say overallocated,

Figure 5.16. The lower Colorado River basin is among the most arid regions in the United States. Photo courtesy of the Water Education Foundation.

Figure 5.17. **Map of the Lower Colorado River Basin (Weatherford and Brown, 1986).**

and any growth in demand for water likely will require reallocation.

Most irrigated farming in the Lower Colorado River Basin takes place in central and southern Arizona and in the Imperial Valley. Historically, ground water has supplied between 40 and 60% of Arizona's irrigation demands whereas the Imperial Valley has relied exclusively on Colorado River flows. In Arizona, declining water tables, strict controls on ground water pumping in most irrigated areas, and the advent of the Central Arizona Project—which delivers Colorado River water to the central and southern regions of the state—have increased the surface water supplies available to irrigated agriculture. The Imperial Valley, by contrast, currently enjoys ample supplies of surface water, but urban water users in the Los Angeles metropolitan region will compete more intensively for these supplies.

Central and Southern Arizona

Arizona's population growth rate has been one of the highest in the nation, and most new residents live in the Phoenix and Tucson metropolitan areas. Arizona's population grew from 1.3 million in 1960 to 3.7 million in 1990, and demographers expect the state's population to reach 5.2 million by the year 2000. At most, the state has only 7,000 farms and ranches, including many hobby farms. Residential, industrial, and recreational demands compete with agriculture for the state's limited water supplies. Urban users are better able to pay for the rising costs of water than farmers are, and urban interests have been reflected in legislation limiting the amount of water available for cropland. In 1960, agriculture accounted for 93% of consumptive water use in Arizona. Today, agriculture accounts for only 78% of total consumptive use, and state water authorities expect this figure to fall to 73% by the end of the century (Ayer and Hoyt, 1992b).

Arizona's cropland lies in the flat desert regions of the state, at elevations ranging from 100 feet below to 4,000 feet above sea level. All cropland must be irrigated because the sparse rainfall tends to come during the monsoon season of the late summer months. Cotton, the predominant crop, requires between 3 and 5 feet of water/acre and uses approximately 45% of all

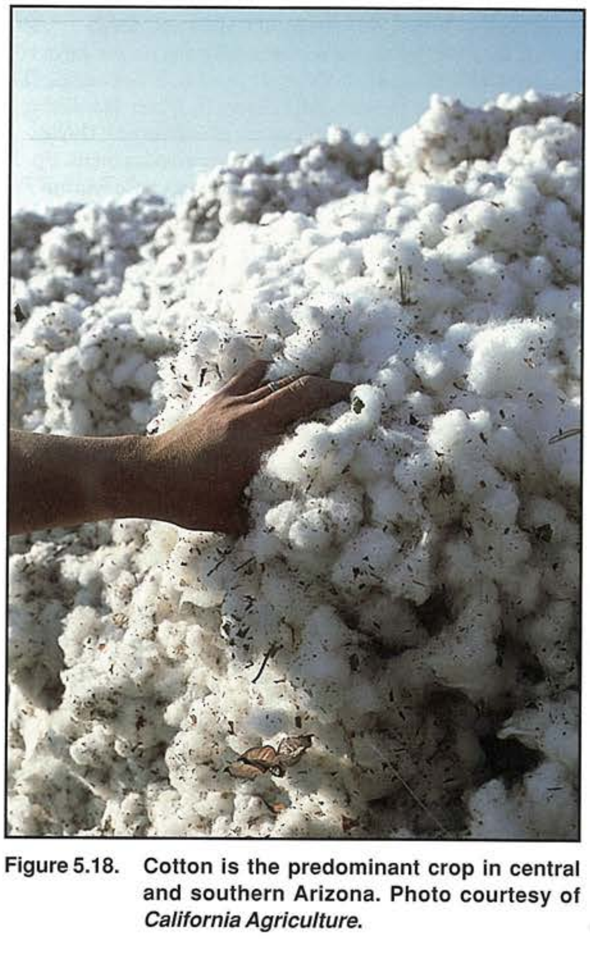

Figure 5.18. **Cotton is the predominant crop in central and southern Arizona. Photo courtesy of *California Agriculture*.**

irrigation water (Figure 5.18). Alfalfa uses more than 8 feet/acre and accounts for 30% of agricultural water use. Other important crops include citrus, pecans, and winter vegetables (Ayer and Hoyt, 1992a).

In 1980, ground water sources supplied nearly 60% of the state's irrigation water; surface sources, 40%. Heavy ground water overdrafting and the associated decline in ground water tables, coupled with the availability of additional surface water supplies from the Central Arizona Project, caused these percentages to reverse by 1992 (Ayer, 1987). The cost of irrigation water differs greatly from region to region. Surface waters from the Colorado River, which are used to irrigate lands in the western part of the state, and waters supplied from Bureau of Reclamation facilities north of Phoenix are quite inexpensive (usually $5 to $10/acre foot). In some ground water areas, pumping costs remain modest, largely because long-term federal contracts with irrigation districts establish electricity rates at only a fraction of the market prices for electrical power. In other areas, however, ground water is quite costly. Water tables often lie 300 to 600 feet below the surface, and where current market prices for electricity prevail, irrigation water costs sometimes reach 40% of the total variable costs of crop production (Ayer and Hoyt, 1992b).

The newly completed Central Arizona Project delivers Colorado River water to the central and southern regions of the state, some 3,000 feet higher than and 300 miles away from the Colorado River (Figure 5.19). Costs of this water range from $13 to $53/acre foot, not including capital assessment fees. High water-costs have caused some irrigation districts to refuse water contracts, and other districts that did contract for water now face bankruptcy because growers cannot afford the assessment for capital costs and the cost of the water itself (Ayer and Hoyt, 1992a; Wilson, 1993). More than 80% of Arizona's irrigation water is applied through gravity irrigation systems. In response to rising water costs, however, growers have laser leveled approximately 40% of the state's cropland, and a few have installed closed conduit, low-volume, drip irrigation systems on a wide variety of crops, including cotton and wheat, in an effort to decrease water applications and to increase crop yields.

Figure 5.19. The Central Arizona Project Canal near Scottsdale. Photo courtesy of the Water Education Foundation.

Both state and federal water laws have had a great impact on irrigated agriculture in Arizona and are likely to be important determinants of future irrigation patterns in the state (McGinnis, 1991). To eliminate or to decrease overdraft by the year 2025, the Ground Water Management Act of 1980 established Active Management Areas (AMAs) and Irrigation Non-Expansion Areas (INAs) in critical ground water regions. The AMAs include about 60% of Arizona's irrigated acreage. The Act prohibits expansion of irrigated areas in both the AMAs and the INAs and requires that growers in AMAs decrease water applications over time as water-saving irrigation technologies become profitable. Native American water rights also help determine location and availability of irrigation water. The Winters Doctrine of 1908 allows tribes water claims based on the potential irrigated acreage of their reservations (Checchio and Colby, 1993). Reservations occupy 20 million acres, or 28% of Arizona's landbase, and some observers believe that Native American water claims ultimately may exceed the entire surface water supply of the state. Both the Ground Water Management Act of 1980 and Native American water rights have shifted some irrigated acreage to reservations, where most newly irrigated lands in Arizona likely will be.

Irrigated Acreage

As a result of the rising costs of pumped ground water and the high costs of surface water delivered from the Central Arizona Project, irrigated acreage in Arizona declined from a high of 1.4 million acres in 1975 to 940,000 acres in 1992. The decline in total irrigated acreage was accompanied by a shift in cropping patterns, as illustrated in Figure 5.20. Acreage of the state's principal crop, upland cotton, as well as that of wheat and feed grain, has declined significantly over the past 15 years. Cotton acreage declined because water costs increased and the real price of upland cotton decreased. In contrast, the acreage of Pima cotton, a long-staple variety commanding a premium price, has expanded sharply along with vege-

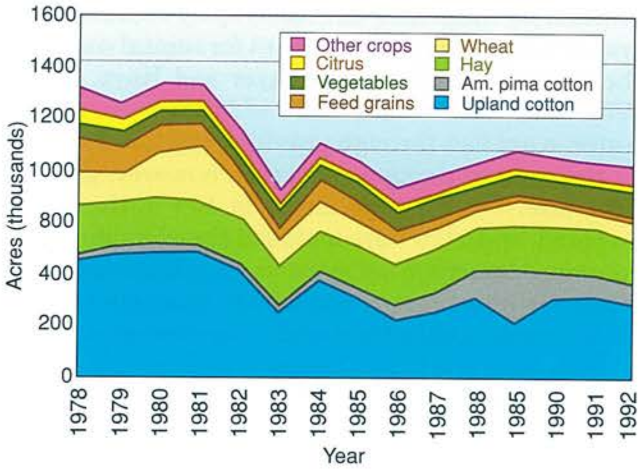

Figure 5.20. **Arizona's crop acreage, 1978–1992 (Arizona Agricultural Statistics Service, 1978–1993).**

table acreage since the mid-1980s. Hay (mostly alfalfa) acreage, however, has remained constant, at about 20% of total cropped acreage over this period (Arizona Agricultural Statistics Service, 1980–1992).

Although precise information is unavailable, irrigated acreage on reservations expanded in recent years, and by 1992 more than 160,000 acres were irrigated on the state's 20 reservations (Leckband, 1993). The existence of irrigable lands and the availability of inexpensive water obtained through water entitlement settlements are expected to increase irrigated acreage on reservations by tens of thousands of acres in the coming years. For example, the Colorado River Indian Tribes irrigate approximately 82,000 acres but possess entitlements of 6.5 acre feet of water per acre to irrigate a total of 107,000 acres (Aillery, 1985; Kindgon, 1990).

Farm Income

The real value of cash receipts for crops declined along with irrigated acreage from the late 1970s until the mid 1980s, rose through the last half of the 1980s, and declined again. As shown in Figure 5.21, cash receipts in 1992 dollars were approximately $1.5 billion, $1 billion, $1.3 billion, and $1.1 billion in 1979, 1985, 1989, and 1990, respectively. Changes in the value of upland cotton sales accounted for most, but not all, change in total crop sales. While acreage and price of upland cotton have declined, Pima cotton acreage has expanded and prices have been considerably higher than those for upland cotton. Pima cotton yields also increased with new, higher yielding varieties and improved management practices. The value of winter iceberg lettuce, Arizona's principal vegetable crop, increased sharply during the last half of the 1980s but declined during the early 1990s. Throughout most of the 1980s and the early 1990s, cotton program payments ranged from 7 to 25% of the total value of cotton lint marketings, and Arizona farmers enrolled about 80% of their cotton acreage in the federal cotton program.

Even with the 1996 Farm Bill, which eliminates nearly all production and related subsidies, total crop acreage will not be affected greatly. The new federal program drops past base-acreage restrictions and acreage reduction programs to help offset the loss of production related price and income subsidies (Taylor, 1995; Transtad, 1995). And, as illustrated elsewhere in this report, Arizona's farmers show considerable ability to adjust to changing conditions. The Arizona Agricultural Statistics Service, for example, shows estimated spring 1996 plantings of cotton some 48,000 acres below 1995 levels, but farmers have increased their plantings of durum wheat by 40,000 acres (Arizona Agricultural Statistics Services, 1996).

Water Quality

Only a few perennial rivers flow through Arizona, and irrigation results in surface water contamination in only a few locations. Runoff usually is not a problem in the desert, but along the lower reaches of the Colorado River irrigation water does leach through the soil and drain into the Colorado, increasing its salt content. Treaties with Mexico limit the salinity levels of Colorado River water flowing into Mexico. In response, the United States has built a costly desali-

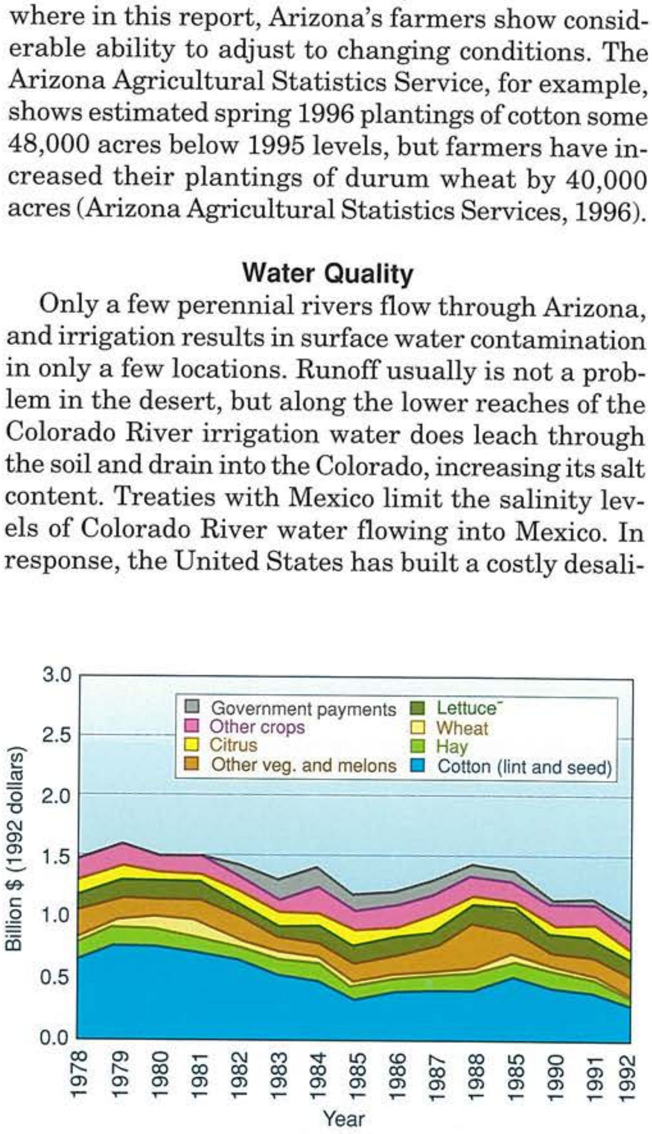

Figure 5.21. **Real value (1992 dollars) of cash receipts to Arizona agriculture, 1978–1992 (Arizona Agricultural Statistics Service, 1978–1993).**

nation plant to treat irrigation return flows to meet treaty requirements (Caporaso, 1993). The other principal source of surface water is the Salt River. The waters of the Salt arise in the higher elevations of the state and are not contaminated by percolation or runoff from irrigation of the state's lowlands.

Ground water in certain regions of Arizona is somewhat contaminated. Arizona farmers make some of the nation's heaviest applications of irrigation water, nitrogen fertilizer, and pesticides (Ayer, 1987; Ayer et al., 1990). On light soils, which are common, heavy irrigation leaches chemicals beyond the root zone. The extent of contaminant migration into ground water depends on the area. Many Arizona aquifers lie several hundred feet below the surface, and chemical transport to these aquifers may take decades. Thus, many aquifers not now contaminated may become so. In response to public concerns over potential ground water contamination, the state in 1986 adopted legislation designed to control nonpoint source pollution of ground water by agriculture. This legislation, considered one of the strongest state efforts to control nonpoint source pollution, requires growers to use recommended best management practices (BMPs) to control nitrogen leaching or else face severe penalties if water supply contamination is traced to their operations (Ayer, 1987).

Some Arizona waters contain relatively high levels of dissolved salts. Arizona growers have managed soil salinity successfully by applying extra water to drive salts below the root zone. Management of salt balances relies, however, on both adequate supplies of water for leaching purposes and adequate drainage. Salinity could become a major problem in some areas, especially in those irrigated with water from the Lower Colorado River, if irrigation water supplies decline. Salts also have been a problem for some of the few growers who have turned to drip irrigation to decrease water application costs and to increase yields. By blocking drip emitters and by concentrating in the root zone, salt may cause problems with germination and plant growth. Chemical treatment and leaching practices have countered these problems effectively (Wilson et al., 1984).

Welfare of Rural Communities on the Fringes

The USDA does not define any of Arizona's 15 counties as *agriculturally dependent.* Although some rural communities are more dependent on agriculture than others, none depend on agriculture for more than 15% of total income and employment (Leones, 1993). The three counties with the largest irrigated acreage, Maricopa, Pinal, and Yuma, are classified as metropolitan counties. Maricopa, the largest agricultural county, also is the location of Phoenix, Arizona's largest city. Businesses in the Phoenix metropolitan area meet many farm input and marketing needs, and rural towns surrounding Phoenix often depend on the urban more than on the agricultural economy. In Maricopa County, the impact of urban expansion on agriculture has been greater than agriculture's effect on the rest of the economy. Between 1964 and 1992, irrigated acreage in Maricopa County fell from 471,000 acres to 273,000 acres, largely because of urban growth.

Pinal County, which adjoins Maricopa County to the south, is more rural in character, but even here the economy is unusually diversified and should not suffer economic distress from declines or shifts in irrigated acreage. Yuma, population 51,000, is the center of one of the state's principal vegetable and citrus industries. Although these industries may decline over the long run as increased trade with Mexico increases competition in the production of labor-intensive citrus and vegetables, the economy of Yuma has diversified far beyond the local agricultural base.

Sparsely populated La Paz County, located on the western edge of the state, has been the focus of concerns about the adverse effects of water transfers on the county's economy. Numerous Arizona cities have purchased large farms in La Paz County to acquire the rights to water, which ultimately may be transported out of the county for use in urban communities. Studies show, however, that eliminating a large share of irrigated agriculture would have significant but not disastrous effects. A 20% decrease in irrigated acreage would decrease county employment by only 6.8%, personal income by 4.5%, nonutility revenues of the community of Parker by 2.5%, and county government revenues by 3.2% (Charney and Woodard, 1989). For the most part, then, the welfare of rural communities in Arizona does not depend significantly on agriculture, and the effects on rural communities of any great changes in irrigated acreage likely will be quite modest.

The Outlook for Irrigated Agriculture in Arizona

Arizona's dry climate dictates that all crops be irrigated and that growers apply large amounts of irrigation water, typically 3 to 5 feet/acre. Historically, surface water has been inexpensive because of the large reservoir and canal systems constructed and subsidized by the federal government. Similarly, in some areas, favorable electrical rates decreased the price of pumped ground water below what it otherwise would have been. Cotton usually has ranked first in acreage, water use, and value; but vegetables, citrus, and alfalfa also command large shares of cropland resources and crop sales. Irrigated agriculture accounts for approximately 78% of all consumptive water use in the state.

Irrigated agriculture has faced and will continue to face great obstacles. Arizona's population has increased faster than the population of most states, and many expect this trend to continue. Urban growth and the associated water demand for residential, industrial, and recreational uses will continue to compete with agriculture for limited water supplies. Many urban uses of water are high valued, and urban dwellers willingly pay more for their water than agricultural users can. Additionally, with increased urbanization—most Arizonans now live in the Phoenix and Tucson metropolitan areas, legislative power rests increasingly with urban voters. Much of the water formerly used to irrigate Pima County farms now goes to the city of Tucson, and much of the inexpensive surface water formerly used to irrigate large Maricopa County farms now serves the Phoenix metropolitan area.

Federal budget deficits and other constraints are likely to preclude future water subsidies, at least on the scale that prevailed historically. The state's Ground Water Management Act prevents expansion of irrigation in most of the state's best agricultural areas. Water from the major new Bureau of Reclamation Project, the Central Arizona Project, must be pumped up approximately 3,000 feet from the Colorado River to Arizona's primary agricultural areas; the costs of this water are so high that many farmers cannot afford to use it.

Arizona's irrigated agriculture nonetheless remains prosperous although irrigated acreage is smaller than it once was. Arizona's farmers have adapted to changing conditions in a number of ways: they have switched to more profitable and often higher-valued crops; they have pioneered in the adoption of water-saving irrigation technologies, including drip irrigation of some row crops and laser leveling of gravity irrigated cropland; and they have relocated from areas in which water has become scarce. In particular, irrigated acreage on reservations has expanded as Native Americans have gained rights to inexpensive surface waters.

These trends are likely to continue. Irrigated acreage may decline further, but growers will adapt to more costly water supplies and other pressures by adopting additional water-saving irrigation technologies, employing increasingly profitable crop mixes, changing the location of irrigated farming, and utilizing improved production, financial, and marketing management techniques. In short, irrigated agriculture will remain viable in Arizona.

The Imperial Valley of California

The Imperial Valley of California lies about 50 miles west of the Colorado River, as shown in Figure 5.22. The valley lies immediately south of the Salton Sea, which has no outlet, and immediately north of the Mexican border. The valley is surrounded by mountains to both the west and the east. Local water supplies are virtually nonexistent. Rainfall is sparse, averaging about 2 in. annually, and thus agriculture in the valley depends completely on the availability of irrigation water. There is no ground water, and local surface waters in the New and the Alamo Rivers, which flow from Mexico, are scant and of unreliable quality. Irrigated agriculture and the economy of the valley therefore depend entirely on Colorado River flows diverted from the mainstem below the Imperial Dam and transported to the valley through the All American Canal (Figure 5.23).

Between 1901 and 1904, the Imperial Valley was settled by people mainly of European descent. There followed a long and complicated history of efforts to perfect water rights and to develop reliable water delivery works (Hundley, 1975; Worster, 1985). These efforts culminated in the 1930s and the 1940s with the Imperial Irrigation District's securing of an annual right of high priority to some 2.91 million acre feet of Colorado River water. This right, coupled with the All American Canal, provided a secure and certain source of irrigation water to agriculture in the valley, which became enormously productive.

Approximately 500,000 acres of relatively flat land now are irrigated to produce a wide variety of crops. Nearly 80% of this acreage is devoted to production of field crops including alfalfa, Sudan grass, pasture crops, wheat, and sugar beets. These crops had a gross value in 1993 of nearly $270 million. The remaining acreage is devoted to the production of high-valued winter vegetable crops including lettuce and melons. The gross value of these crops totaled $428 million in 1993. The valley also is the site of significant livestock production, whose value totaled $261 million in 1993, and of fruit, nursery, and seed crops, whose value totaled nearly $60 million in the same year. Total value of agricultural production in the Imperial Valley exceeded $1 billion in 1993 (Imperial County, 1994) (Figure 5.24).

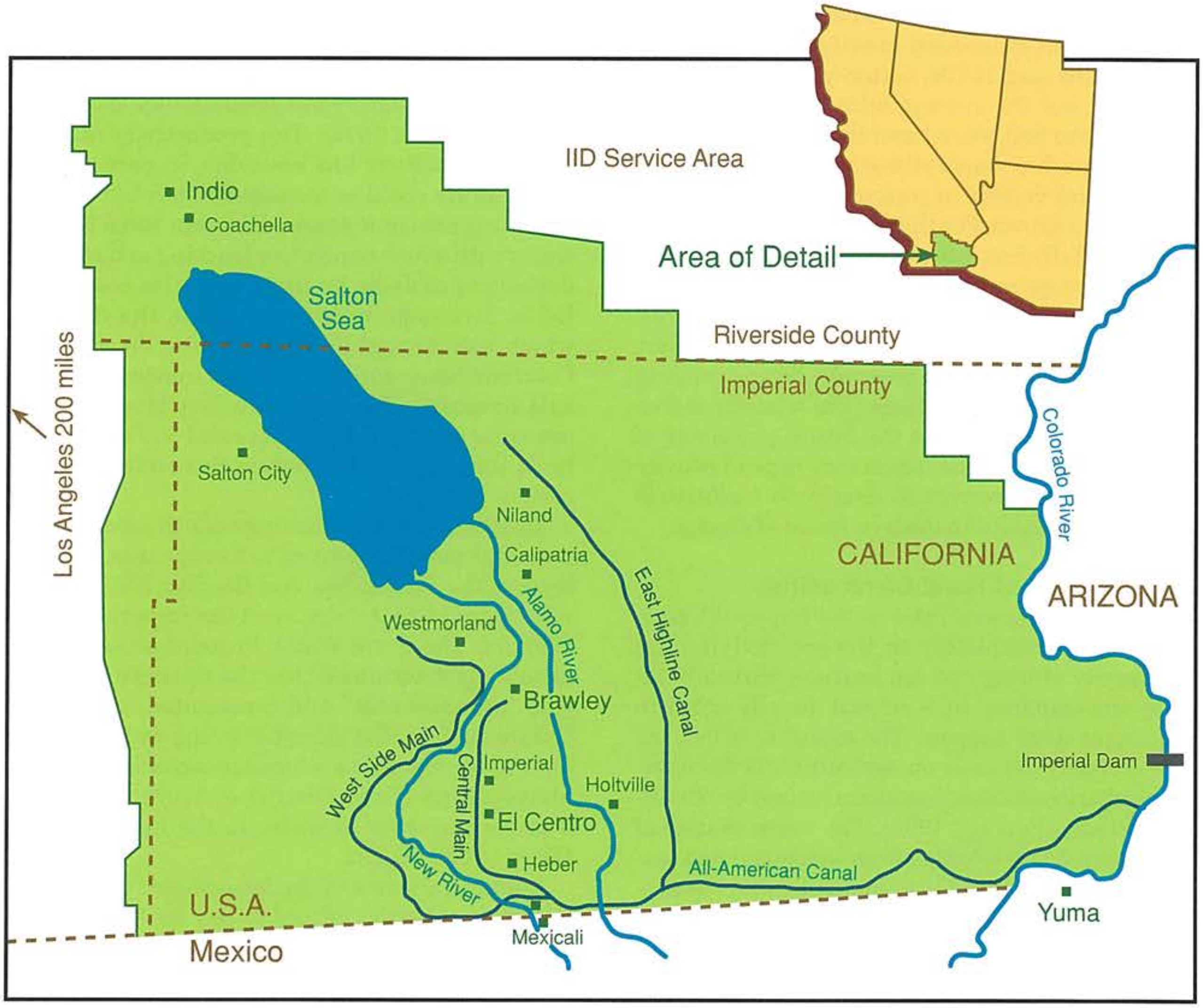

Figure 5.22. Imperial Valley and California desert region (National Research Council, 1992).

Figure 5.23. Colorado River water is delivered to the Imperial Valley through the All American Canal. Photo courtesy of the Imperial Irrigation District.

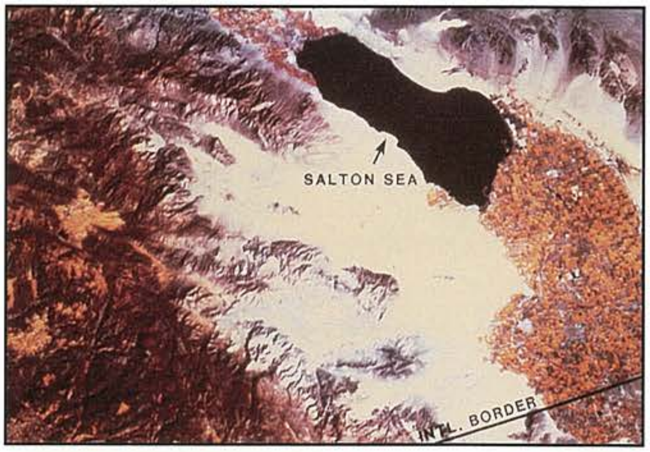

Figure 5.24. The Salton Sea and Imperial Valley from space. Photo courtesy of *California Agriculture*.

Historically, cropping patterns in the Imperial Valley have been influenced greatly by agricultural pests. Until the mid 1970s, cotton was a major crop in the valley, but the susceptibility of Imperial Valley cotton to the boll weevil and the difficulty of controlling it in such a warm climate led to a continual and substantial decline in cotton acreage so that today no cotton is grown. For the past several years, the silverleaf whitefly has inflicted major damage on Imperial Valley crops and on the region's economy (Figure 5.25). Means of controlling the whitefly have not yet been identified, so it is impossible to know what the ultimate impacts of the pest may be on cropping patterns and cultural practices. The whitefly serves as a reminder, however, that the future prosperity of irrigated agriculture in the region may depend heavily on the capacity of growers to deal with traditional problems as they adapt to modern forces of change.

Welfare of Rural Communities

The welfare of communities in the Imperial Valley depends almost completely on the productivity and the prosperity of irrigated agriculture. Virtually all industry and employment is related directly either to agriculture or to its support. The extent to which the valley's economy depends on agriculture is illustrated by the sharp economic downturn caused by the silverleaf whitefly (Perring, 1994). The warm climate of the valley and its remoteness from industrial and economic centers make it unlikely that the valley's economy could be diversified or built on nonagricultural industries.

Water Quality

Salinity and the need to manage it is a fact of life in the Imperial Valley. The salt content of Colorado River water below the Imperial Dam ranges from 600 to 850 parts per million (ppm). Thus, salt balances in the crop root zone must be managed on a continuing basis to avert significant productivity losses (Kaddah and Rhodes, 1976). The productivity of Imperial Valley agriculture has been due, in part, to the fact that salinity could be managed in a relatively simple and inexpensive manner. Growers have had ample water with which to practice leaching and have solved drainage problems by installing tiles beneath most fields. Drainage waters run off to the Salton Sea, which was created by an accidental diversion of the Colorado River and serves as an inexpensive sink for salt disposal. This and the fact that significant amounts of runoff from Imperial Valley farms also finds their way to the Salton Sea create potentially serious problems.

Figure 5.25. Silverleaf whiteflies on cotton. Photo courtesy of *California Agriculture*.

In 1980, a farmer arguing that the inefficient and wasteful management of tailwater was raising the level of the Salton Sea and flooding his land, which was adjacent to the sea, sued the Imperial Irrigation District. The State Water Resources Control Board ultimately determined that the district's use of water was "unreasonable" and constituted "waste" under California law. The threat of losing water caused the district to negotiate a unique agreement with the Metropolitan Water District of Southern California, a major purveyor of water to the Los Angeles-San Diego urban region.

Under the terms of the agreement, the Metropolitan Water District agreed to pay for both structural and nonstructural water conservation projects to conserve 106,000 acre feet annually. Much work entails the lining of canals to prevent seepage and the installation of automated water delivery systems. In effect, the arrangement permits the Metropolitan Water District to use the annual savings of 106,000 acre feet for 35 years and decreases drainage to the Salton Sea, thereby abating the flooding of adjacent land (National Research Council, 1992). Important opportunities clearly exist for improvements in water management practices in the Imperial Valley. Moreover, competition for the waters of the Lower Colorado is likely to provide incentives for Imperial growers to adopt such practices.

Competition and Water Transfer

The allocation of Lower Colorado River flows among California water users is governed by the so-called Seven Party Agreement. Summarized in Table 5.10, the agreement sets forth the priorities for delivery and the quantities to which various California users are entitled. The priorities of the Metropolitan

Table 5.10. Colorado River priorities for California (Ostrom, 1953)

Priority	Agency	Annual quantity (million a. ft)
1	Palo Verde Irrigation District	3.85
2	Yuma Project (California Division)	
3	Imperial Irrigation District	
	Palo Verde Irrigation District	
4	Metropolitan Water District	0.55
5	Metropolitan Water District	0.55
	City/County of San Diego	0.112
6	Imperial Irrigation District	
	Palo Verde Irrigation District	0.30
Total		5.362

Water District are preceded by those of the major California agricultural water users along the lower mainstem of the Colorado. This fact is important for two reasons. First, the vast majority of water delivered by Metropolitan is devoted to municipal and industrial uses, which are more highly valued than agricultural uses in the Lower Colorado Basin. Second, California's allocation of Colorado River water in the Supreme Court's decree *Arizona v. California* is 4.4 million acre feet, but the first five priorities, including both of Metropolitan's, total 5.06 million acre feet. Thus, to obtain their full allotments from the Colorado Basin, both the Metropolitan Water District and the City/County of San Diego must depend on surplus flows (Ostrom, 1953).

Historically, surplus waters have been available to California users because Arizona has been unable to use its full entitlement to lower basin flows. With completion of the Central Arizona Project, however, Arizona has developed the capacity to make full use of its entitlement, and southern California's urban users are faced with the prospect of losing a portion of their Colorado River allotment. Urban water users therefore have an incentive to acquire on a permanent or an intermittent basis some of the water allotted with higher priority to agricultural water users. Inasmuch as the Imperial Irrigation District is entitled to 2.91 million acre feet of the 3.85 million acre feet allotted among the top three priorities, the district is a particularly inviting source of water to support the growing urban areas of southern California.

At least one study indicated that the difference between the willingness to pay of urban water users in southern California and the value of water in Imperial Valley agricultural uses is sufficient to induce transfer of more than 1.2 million acre feet from the Imperial Valley to support urban growth in southern California (Vaux and Howitt, 1984). The 1.2 million acre feet capacity of Metropolitan's Colorado River Aqueduct imposes an upper limit on the quantities of water transferable from the lower basin agricultural users to Metropolitan. In a worst-case scenario, in which California's Colorado River entitlement was limited strictly to 4.4. million acre feet, the maximum amount transferable would be the combined fifth priority allotments of Metropolitan and the City/County of San Diego, which total 662,000 acre feet (Vaux, 1988).

The Bureau of Reclamation has identified measures that could result in the conservation of approximately 350,000 acre feet of water annually within the Imperial Valley. In addition, Congress has passed legislation authorizing the lining of the All American Canal, which would result in savings of an additional 100,000 acre feet (Figure 5.26). These actions suggest that most of the water needed to serve competing urban uses can be developed through structural improvements in the Imperial Irrigation District's conveyance facilities and through water conservation programs in the valley itself. Theoretically, the district would have the option either of undertaking these improvements itself and marketing the water or of allowing potential purchasers to pay for improvements and receive water in return. Legal and institutional factors imposed by the Seven Party Agreement and by other elements of the Law of the River complicate matters but do not pose insurmountable barriers to desired water transfers (National Research Council, 1992).

Competition from urban users probably can be accommodated by growers in the Imperial Valley if affordable improvements in water delivery and water management systems are made. These improvements would not decrease the water supply needed to irrigate the wide variety of crops grown in the valley, nor would they constrain valley growers in the management of salt balances. In short, by employing modern methods of irrigation water management, growers in the Imperial Valley could create surpluses that would be made available to serve the needs of competing urban users, who also draw their water from the Lower Colorado River Basin.

Outlook for Irrigated Agriculture in the Imperial Valley

Agriculture in the Imperial Valley has prospered because of the availability of reliable and inexpensive supplies of irrigation water from the Lower Colorado River Basin. The region's warm climate, year-round

Figure 5.26. Irrigation canal lining in the Imperial Valley. Photo courtesy of the Imperial Irrigation District.

growing season, and suitability for growing high-valued winter vegetables make it one of the most important agricultural regions in California. The Imperial Irrigation District enjoys a high priority for Colorado River water and therefore has had little incentive to employ very efficient water-management regimes. But competition for the water supplies of the Lower Colorado Basin is intensifying. Population growth in the Los Angeles-San Diego metropolitan region continues despite the fact that customary sources of water may be unavailable (Figure 5.27). By using modern water-management and distribution technologies, growers in the Imperial Valley can develop surplus water and make it available to competing urban users willing to pay prices substantially exceeding its value to agriculture. The prosperity of Imperial Valley agriculture likely will depend more on the conventional pressures of pests, disease, and commodity markets than on the availability of adequate water supplies.

Figure 5.27. Population growth is expected to continue in urban southern California despite questions about the availability of adequate water supplies. Photo courtesy of *California Agriculture*.

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The Upper Colorado/Great Basin Region

The Upper Colorado/Great Basin region includes the intermountain areas of the southwestern and Rocky Mountain states. As shown in Figure 5.28, the region extends from central Colorado to the Nevada/California border and includes western Colorado and most of Nevada and Utah. This region actually encompasses two hydrologically distinct basins. The Upper Colorado Basin, the portion of the Colorado River system above Lees Ferry, Arizona, includes western Colorado, southeastern Utah, and small parts of New Mexico and Wyoming. The Great Basin, which lies primarily in the western half of Utah, most of Nevada, and a thin strip of eastern California, is a closed basin characterized by streams with no outlet to the ocean. These streams terminate in lakes, including the Great Salt Lake, Mono Lake, and Pyramid Lake, remnants of a large prehistoric inland sea (Figure 5.29). For the purposes of this discussion, these two hydrologic basins have been combined because of similarities in geography, climate, water availability, and agriculture.

The topography of the region is quite variable, with elevations ranging from 3,000 to over 10,000 feet. Climate and water availability also are highly variable. The common feature of the region is a general lack of precipitation except at high elevations. In areas with arable land, rainfall levels generally are low, with the result that crop production is difficult or impossible in the absence of irrigation. Although the region is not a major contributor to the nation's food supply, it does contain important crop and livestock production areas. The production of forage crops is especially important.

The major source of water in the region is the snow pack found in the high mountains (Figure 5.30). Melting snow is captured for irrigation through direct stream diversions, storage reservoirs, and even transcontinental aqueducts, which divert flows from the Upper Colorado and its tributaries to watersheds across the Continental Divide, including the Platte and the Arkansas. Ground water resources are less important in the region although they sometimes are locally important. The primary constraint on irrigated agriculture in the Upper Colorado/Great Basin region is lack of water, a constraint accentuated by water-quality problems. Water in the upper reaches of river basins and watersheds usually is high in quality and fit for any instream or consumptive use. But water is used and reused as it moves downstream, and there are many opportunities for quality degradation.

Effluent from municipalities, mining and industrial sites, and irrigation return flows all are significant contributors to surface water degradation. Irrigation return flows are the major contributor to water-quality degradation because they tend to be quite saline. During periods of low flow, salinity levels in some streams are high enough to compromise the water's suitability for consumptive and instream uses.

Irrigated Acreage

Irrigated acreage in the region is relatively modest. Table 5.11 displays irrigated acreage in Nevada and Utah, for selected years. Acreage in other states that are part of the region is not included because of difficulties in partitioning acreage among river basins. Generally, however, the patterns of agriculture in Nevada and Utah reflect the prevailing patterns in western Colorado and elsewhere in the Upper Colorado River Basin. Acreage in Utah, Nevada, and western Colorado is quite small although there are a few significant areas of irrigated land in western Colorado close to the Upper Colorado River. Irrigated acreage peaked in the region in 1977 and has declined since, with Nevada experiencing a change of more than 50%. Several factors have contributed to this decline, including drought, urban encroachment, and placement of some irrigated lands in the federal government's CRP.

The importance of irrigation in the overall scheme of crop production is illustrated by the percentage of total cultivated acreage under irrigation, as displayed in Table 5.12. In Nevada, rainfed agriculture is not profitable, and virtually all cropland is irrigated. In Utah, more than 50% of cropland is irrigated. As shown in Table 5.13, ground water, although accounting for a small share of the total supply of irrigation water, has become proportionately larger in both states. Irrigation technologies are dominated by gravity flow surface systems in both states. Less than 25% of acreage in Nevada and 35% of that in Utah is irrigated with sprinkler systems. Low-flow systems are virtually absent in both states (*Irrigation Journal*, 1993).

Table 5.11. **Total irrigated acreage by state in the Great Basin (1,000 a.) (U.S. Department of Commerce, various years)**

State	1972	1977	1982	1987	1992
Nevada	1,300	1,305	1,306	1,306	572
Utah	1,400	2,034	1,203	1,215	1,151

Table 5.12. **Irrigated acreage as a percentage of cropped acreage in the Great Basin (U.S. Department of Commerce, various years)**

State	1978	1982	1987
Nevada	100.0	96.3	97.0
Utah	58.3	56.4	57.3

Irrigated Crop Production

Cropping patterns in the region are dominated by forage crops, as shown in Table 5.14. Livestock operations are extensive throughout the region, and forage crops are used to feed livestock between grazing seasons. Together, forages and grains account for more than 90% of irrigated acreage in Nevada, Utah, and western Colorado. Fruit and vegetable crops occupy a very small percentage of irrigated acreage. Although total acreage devoted to irrigation has declined recently, the value of irrigated crops sold in both Nevada and Utah has increased substantially, as shown in Table 5.15. This fact is somewhat surprising inasmuch as the shift toward higher-valued crops

Table 5.13. **Percentage of irrigated acreage served by ground water in the Great Basin (Bajwa et al., 1992)**

State	1984	1988
Nevada	24.74	34.20
Utah	11.65	18.77

Table 5.14. **Percentage of irrigated acreage, by crop, in the Great Basin, 1992 (*Irrigation J.*, 1993)**

State	Forages	Grains	Field crops	Fruits and vegetables
Nevada	93	4	2	< 1
Utah	72	25	1	2

Table 5.15. **Total value of irrigated crops sold in the Great Basin (thousands of constant 1987 dollars)[a]**

State	1978[b]	1982[b]	1987[b]
Nevada	60,700	63,584	75,685
Utah	79,526	89,149	104,915

[a] Source: U.S. Department of Commerce, various years.
[b] Index used is from U.S. Department of Agriculture, 1992.

Figure 5.28. Map of the Upper Colorado/Great Basin region (Houghton, 1976).

Figure 5.29. Mono Lake typifies the terminal lakes of the Great Basin. Photo courtesy of the Water Education Foundation.

Figure 5.30. The water supplies of the Great Basin are derived mainly from winter snowpack at high elevations. Photo courtesy of the Water Education Foundation.

that has occurred in other regions of the West is largely absent in the Upper Colorado/Great Basin region. The increase in crop production value can be explained at least partly in terms of the ability of regional growers to increase productivity in the cultivation of forage and grain crops (U.S. Department of Agriculture, 1992).

Competition for Water

Competition for water is keen throughout the region. Arid conditions mean that almost any expansion of agriculture would require additional supplies, which are unlikely to be available. Nevada and Utah already claim water rights exceeding available supplies. Under the terms of the Upper Colorado River Compact, which governs division of Colorado River flows among the upper basin states, Colorado and Wyoming have some remaining claims, which eventually might permit additional water to be diverted to support agriculture. Exercise of these claims would result, however, in the loss of instream values and downstream values that have evolved around existing streamflow regimes. Any additional diversion probably would lead to extensive litigation. Perhaps more important, competing uses throughout the region tend to be high valued.

In some areas, population growth is putting increasing pressure on available water supplies. Growing urban areas within the region, e.g., Reno, Nevada, have serious problems finding enough water to support continued growth. Urban growth along the eastern front range of the Rocky Mountains also is putting pressure on the region's water supplies as front-range communities seek remote supplies on the western slope of the range. Colorado, Nevada, and Utah all have sanctioned establishment of water markets permitting municipalities to purchase agricultural water rights for continued urban development and growth. Operation of these water markets already has removed some land from production, and it is quite likely that additional agricultural supplies will be transferred to support urban uses (National Research Council, 1992).

Figure 5.31. **Arches National Park illustrates the scenic beauty found in the Upper Colorado/Great Basin region. Photo courtesy of the Water Education Foundation.**

The Upper Colorado/Great Basin is noted for scenic beauty, and outdoor recreation contributes significantly to the region's economy (Figure 5.31). Many of the region's recreational opportunities are water based and require both stored water and instream flows. The legal rights to instream flow are highly uncertain. Historically, appropriative rights for irrigation diversion have superseded rights for instream uses. In times of drought, fisheries, wildlife habitat, and some recreational uses have been subject to substantial losses. Over the next several decades, additional allocations of water likely will be made to preserve instream flows. Inasmuch as agriculture accounts for the largest share of consumptive use in the region, reallocations of water to support instream flows are likely, at agriculture's expense.

Currently, water use for industry and mining is not significant within the region. Development of the extensive oil shale deposits of western Colorado, southern Wyoming, and eastern Utah, however, would require large quantities of water, some of which would have to be reallocated from agriculture. Moreover, such development could pose a major threat to water quality in the region. Oil shale is unlikely to be developed under foreseeable conditions, but changing circumstances in world energy markets could result in rapid development. In this scenario, water scarcity would be intensified in some areas, both because the energy industry would require large quantities and because water quality within the region might be affected greatly.

Potential claims for water rights by Native Americans are important in this region. It is difficult to predict the timing and the number of claims that might be asserted, and it is even more difficult to predict the outcome of subsequent negotiations, legislation, and judicial decisions. If Native American claims in the region are upheld, competition will intensify for an already scarce water supply. There is a real likelihood that if such claims were satisfied the agricultural sector would lose more water than other sectors would.

The Future of Irrigated Agriculture in the Upper Colorado/Great Basin

Although agricultural production in the Upper Colorado/Great Basin is modest compared with that in other areas of the West, agriculture remains the largest consumptive user of water in the region. The region does not enjoy a comparative advantage in the production of many crops. Growing seasons are short, water is scarce, and distances to major markets are great. Agricultural production is dominated by relatively low-valued forage and grain crops. The shift to higher-valued crops in response to changing economic conditions that has been observed throughout the West has not occurred in this region and is unlikely to do so inasmuch as growing conditions discourage such a shift. Moreover, although growers have become increasingly productive during the past two decades, irrigation still is accomplished predominantly with gravity-flow surface systems. There has been only a limited shift to more efficient, closed conduit systems.

Simultaneously, competition for the region's scarce water resources is intensifying. Growing urban areas within the region and along the Colorado front range continue to seek supplemental water supplies from agriculture. Some agricultural rights already have been purchased by expanding communities in anticipation of further growth. Although much of the water acquired through these purchases continues to be put to agricultural uses, it will be transferred to urban uses as growth occurs. Competition for scarce water also will intensify as additional efforts are made to restore, to protect, and to enhance instream flows throughout the region. Future policies governing the treatment of endangered species could decrease the quantities of water available for diversion. In addition, instream flows form the basis of the economically important recreation industry. Restoration and protection of instream flows therefore are likely to be driven by environmental and economic considerations. Competition for water could intensify further if oil shale and other minerals become commercially attractive, although stringent water-quality regulations may impede development of these industries.

Competition for water from other higher-valued uses and the relative lack of a comparative advantage in the production of many crops suggest that recent declines in irrigated acreage will continue. The decline may not be as rapid as over the past decade, but it is likely nonetheless. Further irrigated acreage development that might offset this decline is unlikely. Nowhere in the region are there water supplies—ground or surface—available to allow significant expansion of irrigated acreage. It also is unlikely that irrigated agriculture would disappear altogether or decline precipitously over the next two or three decades. The continuing importance of the livestock industry in the region and the remoteness of many irrigated areas from urban development mean that irrigated agriculture will survive indefinitely although somewhat decreased in extent.

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The Western Great Plains

The area known as the Great Plains is a sloping plateau lying between the Rocky Mountains on the west and the prairies of the Mississippi Valley on the east. The Plains are bisected by the 100° meridian (longitude 100° west), which coincidentally separates lands with average annual precipitation of more than 20 in. to the east from those with less than 20 in. to the west. Under normal circumstances, 20 in. of annual precipitation is regarded as the minimum necessary to sustain rainfed agriculture. Thus, irrigation is practiced widely on the western Plains (Figure 5.32) and less frequently east of the 100th meridian. As shown in Figure 5.33, the western Great Plains include the western parts of Nebraska, Kansas, and Oklahoma; the eastern parts of Wyoming, Colorado, and New Mexico; and the northwestern part of Texas.

The western Great Plains are flat and thinly vegetated. Trees are absent. Precipitation averages between 15 and 20 in./year, but because droughts are frequent, rainfall and thus irrigation tend to differ significantly from year to year (Bittinger and Green, 1980). Typically, rain falls in the summer months. The

Figure 5.32. Typical irrigated farm on the western Plains. Photo courtesy of Ronald Lacewell.

major rivers of the region—the Platte, the Republican, the Niobrara, the Smoky Hill, the Kansas, the Arkansas, the Cimarron, and the Canadian—flow eastward toward the Mississippi. In relative terms, these rivers are not large and thus supply water for irrigation on a modest scale, usually to lands in the immediate vicinity of the channel. Irrigation on the western Great Plains depends almost completely on water from the Ogallala formation, a vast aquifer underlying most of the region (Kromm and White, 1992b).

The Ogallala Aquifer underlies an area of about 134,000 mi², including all or parts of South Dakota, Nebraska, Colorado, Kansas, Oklahoma, New Mexico, Texas, and Wyoming. The aquifer is estimated to contain approximately 3.25 billion acre feet of water and is the largest aquifer in the world. Quantities of water available differ from state to state, however. Nebraska overlies almost two-thirds (65%) of the Ogallala's waters. Texas has access to 12%; Kansas, to 10%; Colorado, to 4%; Oklahoma, to 3.5%; and New Mexico, South Dakota, and Wyoming, to less than 2% each. Thus, more than 87% of the waters of the Ogallala underlie three states. Aquifer thickness averages 200 feet but ranges from less than 1 foot to 1,300 feet (Kromm and White, 1992b). It is characterized by low recharge rates, which are exceeded substantially by withdrawal rates. The Aquifer has been in overdraft since the 1950s (Kromm and White, 1992a).

Overdrafting has led to an almost continuous drop in water-table levels throughout the western Great Plains (Figure 5.34). Schemes to develop artificial recharge or to import supplemental water supplies have been studied for the last four decades, but none has proved economically feasible. In 1982, a study initiated by the Department of Commerce forecast that by the year 2020, Texas would have exhausted two-thirds of the supply potentially available from the Ogallala (High Plains Associates, 1982). Average levels of depletion across the western Great Plains were forecast to be on the order of one-quarter of available supply.

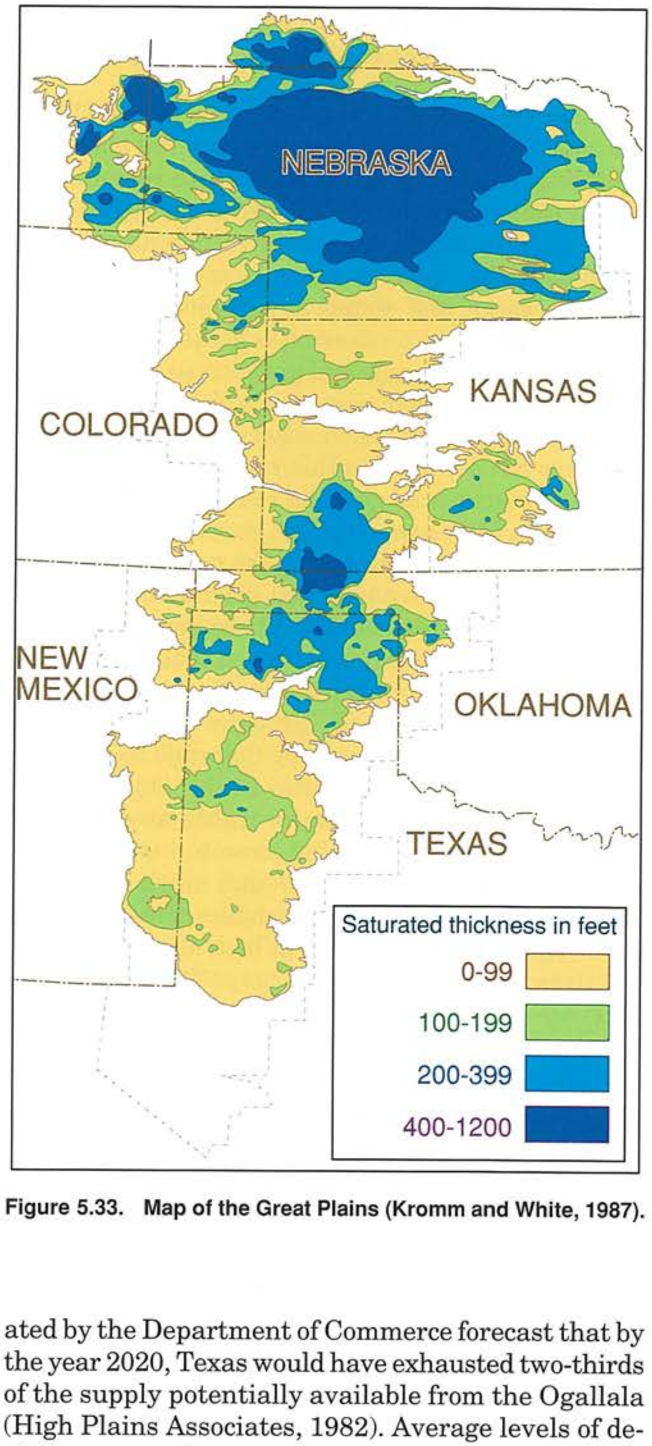

Figure 5.33. Map of the Great Plains (Kromm and White, 1987).

At the time of the 1982 study, there were few limits on ground water pumping in any of the states overlying the Ogallala. In more recent years, all states have adopted policies to limit withdrawals, including pumping quotas, well-spacing regulations, metering, and regulations prohibiting waste (Roberts, 1992).

Figure 5.34. Ground water overdrafting has led to declines in the water table throughout the western Plains. Photo courtesy of Ronald Lacewell.

Figure 5.35. Patterns created by center pivot irrigation systems are discernible readily from the air. Photo courtesy of Ronald Lacewell.

Since the 1980s, numerous water conservation initiatives have been implemented and policies adopted to preserve the Ogallala and to ease the transition to dryland farming. Examples include the provision of low-interest loans for more efficient irrigation equipment, the development of supplemental irrigation strategies, and the promotion of conservation tillage, precipitation management, and irrigation efficiency testing (Sweeten and Jordan, 1987).

Today, the outlook for irrigated agriculture dependent on water from the Ogallala Aquifer is brighter than in 1982. Although the low rates of recharge, which range between one and several inches annually, mean that agriculture cannot be supported indefinitely on its current scale, irrigation in most subregions of the Great Plains can be sustained for periods that now seem longer than those estimated in 1982. Water laws, institutions, and technologies better fit the realities of the situation now, and growers have adjusted by shifting irrigation technologies, installing water reuse systems, and adjusting cropping patterns in favor of more drought-tolerant crops (Nieswiadomy, 1985). Perhaps more than any other region of the West, the western Great Plains provide evidence of how agricultural water users can adapt to increasing scarcity and water supply costs.

Irrigation Development and Irrigated Acreage

The Ogallala Aquifer provides water for 20% of the irrigated acreage and supplies more than 30% of all irrigation water pumped in the United States (Figure 5.35). More than 95% of water pumped from the Ogallala is used for irrigation (Kromm and White, 1992b). The development of irrigation on the lands overlying it was particularly rapid in the 1960s and the 1970s. As shown in Table 5.16, irrigated acreage nearly doubled, from approximately 7 million acres to almost 13 million acres, between 1959 and 1978. Irrigated acreage in Nebraska, Kansas, and Colorado increased slightly more than twofold during this period, and irrigated acreage in Oklahoma increased nearly fivefold. Irrigated acreage in New Mexico remained relatively constant; acreage in Texas increased 10%. In 1959, Texas was the dominant user of Ogallala waters, but by 1978 it had been surpassed by Nebraska.

In the years between 1978 and 1987, irrigated acreage supplied by the aquifer declined by 20%, or by 2.5 million acres, in response to falling crop prices, increasing energy costs, and lowered water tables. Although irrigated acreage in all states declined in some years, the decline has been sharpest in Texas, where 1.8 million acres, or nearly 42% of the 1978 total, has been retired or converted to dryland farming. In Nebraska, by contrast, fewer than 100,000 acres, or 1.6% of the 1978 total, had been removed from irrigation by 1987. Between 1987 and 1995, irrigated cropland in Nebraska increased by an average of 35,000 acres annually. Changes in irrigated acreage are associated generally with the relative decline in underlying water tables, which has been quite large in Texas and modest in Nebraska.

The principal irrigated crops of the western Great Plains are wheat, grain sorghum, cotton, and corn. Although some high-value crops such as vegetables and sugar beets are grown, acreage is quite limited. Corn is the dominant crop, and during the expansion of irrigated acreage of the 1960s and the 1970s, corn production grew by almost 3 million acres. Although corn production has declined from a high of about 6.2

million acres in 1978, today it still accounts for more than 5 million irrigated acres on the western Great Plains. Wheat now accounts for about 1.5 million irrigated acres, and sorghum, cotton, and all other crops account for one million acres each. Virtually all the major crops grown on the Great Plains were, historically, eligible for government support payments. The dominance of corn as a Great Plains crop has been attributed, at least partly, to generous federal commodity programs (Council for Agricultural Science and Technology, 1996; Mapp, 1988). Even without these commodity programs, corn will remain a major crop because it is well suited to the growing conditions of the western Plains (Figure 5.36).

Irrigated acreage on the Great Plains probably will continue to decline modestly in Colorado, Kansas, New Mexico, Oklahoma, and Texas even though there has been modest growth in acreage during the 1990s in all states except Kansas and Texas. This modest growth in acreage has been possible because growers are becoming better water managers by taking maximum advantage of rainfall events and by shifting away from relatively low-valued and water intensive crops. Just as rapidly increasing energy prices in the early 1980s caused a decline in the acreage of high water-using crops such as corn and soybeans on the Texas High Plains, increases in the cost of water that are caused by lowered water tables will induce farmers both to adapt crop mixes to water scarcity and to employ innovative water management techniques and technologies (Lacewell and Lee, 1988; Nieswiadomy, 1985).

By 2020, these adaptations are expected to increase irrigated acreage above the current level of 10.4 million acres. The pattern of irrigated acreage projected

Table 5.16. Total irrigated area, by state, in the western Great Plains[a, b]

	1959		1969		1978		1987			
	Acres	Regional percentage	Acres	Regional percentage	Acres	Regional percentage	Acres	Regional percentage	% Change 1959–1987	% Change 1978–1987
Nebraska	1,937,036	28.1	2,620,382	28.5	5,046,815	39.1	4,967,607	47.8	+156.5	−1.6
Texas	3,921,189	56.9	4,379,471	47.6	4,496,514	34.8	2,616,446	25.2	− 33.3	− 41.8
Kansas	548,642	8.0	1,195,548	13.0	1,956,087	15.1	1,607,301	15.5	+193.0	−17.8
Colorado	253,186	3.7	492,147	5.3	890,241	6.9	746,975	7.2	+195.0	−16.1
Oklahoma	53,342	0.8	259,647	2.8	264,155	2.0	246,367	2.4	+461.9	− 6.7
New Mexico	226,435	3.3	253,456	2.8	269,519	2.1	209,728	2.0	− 7.4	− 22.2
Total	6,886,488		9,200,651		12,923,331		10,394,424		+50.9	−19.6

[a] Source: U.S. Census of Agriculture, 1959, 1969, 1978, and 1987 (Kromm and White, 1992b).

[b] Includes only acres in the Great Plains—not total irrigated acres in a state.

Figure 5.36. Corn is the predominant crop grown on the western Plains. Photo courtesy of Ronald Lacewell.

for 2020 differs, however, from the current pattern. Irrigated acreage will be lost in the southern parts of the region but will expand in the North. By 2020, the sharpest declines are likely to have occurred in New Mexico, Oklahoma, and Texas. Irrigated acreages in these states will differ significantly from year to year as irrigation increasingly will be used to supplement rainfall in dry years. In some areas of these states, irrigation will cease to be profitable and land will be taken out of production or converted to dryland farming. In contrast, irrigated acreage is likely to increase in Nebraska, where as much as 1.9 billion acre feet of water still may be available in 2020 (High Plains Associates, 1982). Projections also suggest that irrigated acreage in Nebraska could total as much as 11.9 million acres by 2020, more than all the acreage currently irrigated on the western Great Plains. Thus, whereas irrigated acreage will remain at roughly its current level for the region as a whole, substantial growth in irrigated acreage likely will occur in the northern Plains—especially in Nebraska, and irrigated acreage around the southern margins of the Ogallala will decline steadily.

Factors Affecting Irrigation from the Ogallala

A number of factors critically affect the profitability and the extent of irrigated agriculture on the western Great Plains. Primary issues affecting irrigation in the Ogallala region include low crop-prices, irrigation fuel cost, ground water depletion, streamflow depletion, water costs, government support programs, and a host of environmental problems including water pollution and lost wildlife habitat (Kromm and White, 1992a).

Aquifer Depletion

Although the Ogallala Aquifer contains sufficient water to fill Lake Huron and only about 5% of the total drainable water has been pumped, a declining water level affects many localized areas dramatically. The *saturated thickness,* or water table, has declined by more than 50 feet on more than one million acres and by more than 10 feet on more than 32 million acres. About 46% of the region has a saturated thickness of less than 100 feet (Kromm and White, 1992a). As the saturated thickness declines and pumping lifts increase, well yields decrease and the costs of pumping increase. One study reports that, where saturated thickness is limited, a 50% decrease in it could mean a 75% decrease in well yields (Sweeten and Jordan, 1987).

Decreased well yields also make water scarcer, even as pumping costs increase. If water tables and well yields are decreased further, a point will be reached at which the cost of pumping is greater than the value of the crop produced. The result is economic exhaustion of ground water for irrigation. The impacts of aquifer depletion are well illustrated in Texas, where irrigated acres declined from 8.1 million in 1974 to 5 million in 1984 (Kromm and White, 1992a). Lower water tables and well yields threaten nearly half the region overlying the Ogallala.

Costs of Irrigation

It has been suggested that the Ogallala has been treated as a common property resource. That is, it has been suggested that farmers have little incentive to conserve ground water because the water thus saved is available to competing users (Aiken, 1984). Yet the costs of pumping impose limits on the quantities of water pumped. For example, when the price of energy increases (pumping and distribution costs increase) and/or crop prices decline, the quantity of water pumped is usually decreased.

Costs of pumping and distributing irrigation water depend on equipment efficiency, lift, and pressure requirements. For example, the estimated fuel cost alone to pump one acre foot of water from 300 feet using natural gas priced at $3.50/thousand cubic feet (mcf) is approximately $50, depending on pump efficiency (Hardin and Lacewell, 1979). Irrigation labor and management, along with repairs and maintenance, would add to this cost. Petty et al. (1980) estimated that ground water irrigation on the Texas High Plains would decline 20% if fuel costs increased 40% and concluded that a tenfold increase in energy costs probably would result in economic exhaustion of the aquifer. Unless there are offsetting increases in crop prices, increases in irrigation costs will lead to decreased ground water withdrawal rates on the western Great Plains.

Farm Programs and Crop Prices

Most crops grown on the western Great Plains were subject to the provisions of federal crop support programs. These programs, which have changed dramatically with the 1996 Farm Bill, created a "price floor" that insulated growers from the adverse effects of low crop-prices. The agricultural policies of the federal government seemed especially important in terms of their influence on the extent of irrigated agriculture on the western Great Plains. Lee and Lacewell (1990), who analyzed the importance of federal farm programs in Texas, estimated that without government farm programs, farm level net income would be approximately 50% that of income levels associated with participation rates under the terms of the 1990 Food, Agriculture, Conservation and Trade Act. Lee et al. (1991) examined the likely impact of federal farm programs over a 50-year period and found that participation increased cumulative ground water extractions in sandy soils by 18% and in mixed soils by 73% when compared with rates under nonparticipation in farm programs. The study also illustrated how producers in the region rely on government farm programs for income support and risk management. By implication, in the absence of offsetting increases in open market price, under the terms of the 1996 Farm Bill, a decrease in price support levels of the federal farm program would decrease farm profitability and irrigation level.

The "Great Dust Bowl" of the 1930s illustrated the susceptibility of the Great Plains to wind erosion. Although adoption of conservation practices since the 1930s has dramatically decreased topsoil loss through wind erosion, the region still is susceptible to erosion. The Conservation Reserve Program (CRP) assigns it a priority rating that provides incentives to idle cropland and to engage in practices such as the establishment of grasslands, which decrease such erosion (Council for Agricultural Science and Technology, 1995). In 1992, approximately 9 million acres on the Great Plains were enrolled in the CRP. As illustrated in Figure 5.37, more than half the lands enrolled had been devoted to wheat production. Together, wheat, sorghum, and cotton accounted for almost 90% of lands enrolled. Great Plains acreage bid into the CRP was used primarily in dryland crop or marginal irrigation production. The program therefore has had little effect, from an aggregate point of view, on irrigation in the Great Plains. The program has had a dramatic effect, however, on agriculture and, in turn, on rural counties with highly erodible soils in which crops were produced under dryland conditions or with limited supplemental irrigation. For those regions with limited ground water for irrigation, the CRP effectively conserved the remaining water.

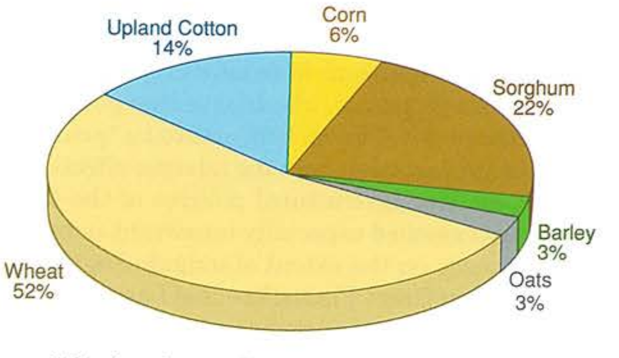

Figure 5.37. Lands enrolled in the Conservation Reserve Program (U.S. Department of Agriculture, 1992).

Most evaluations of the program have addressed economic effectiveness relative to soil conservation but have not considered the implications of ground water overdraft (Myers and Southerland, 1989; Opie, 1993). Should contracts not be renewed when they expire, the effects on water resources are unclear. Nevertheless, for most of the Great Plains, land is expected to revert back to dryland crop production as the program is downsized. Where irrigation was marginal before the CRP, economic barriers to reestablishing irrigation that are due to the initial investment in renovating old wells or drilling new ones do exist. Although a shift to dryland farming would have implications for wind erosion, water quality, and wildlife habitat, a smaller CRP probably would not have a significant effect on irrigation in the region.

Environmental Issues

Irrigated agriculture on the western Great Plains contributes to a number of environmental problems. Two recent studies of the status of water quality in the region concluded that agriculture is the principal contributor to nonpoint source water-quality degradation (Great Plains Agricultural Council, 1992; U.S. Environmental Protection Agency, 1990). Irrigated agriculture and confined livestock operations have been identified as the two most important contributors within the agricultural sector (Figure 5.38). The EPA (1990) reports that agricultural activity accounts for more than 60% of surface water pollution in the

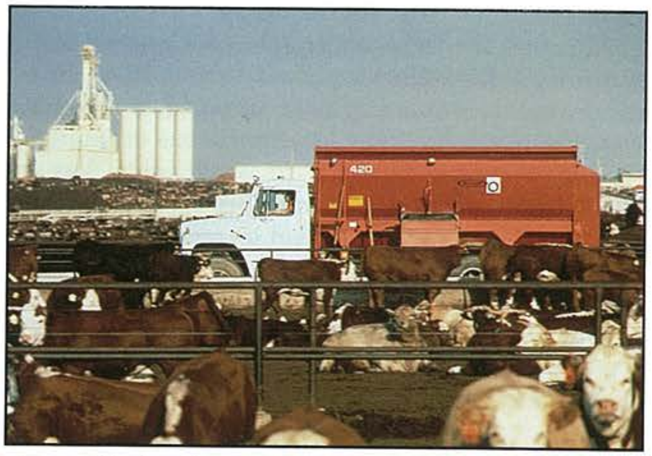

Figure 5.38. Confined livestock operations are one of the most important sources of income on the western Plains. Photo courtesy of Ronald Lacewell.

region. There also are problems related to the decline of streamflows, the disruption of riparian ecosystems, the contamination of aquifers and wells with pesticides and nutrients (primarily nitrogen in sandy lands), and the shrinkage of much water supported habitat for fish and mammals (Kromm and White, 1992a).

In some areas, intensive pumping of ground water has decreased surface streamflows. It is estimated, for example, that as a result of aquifer depletion 700 miles of streams that once flowed permanently in Kansas no longer flow. One consequence of decreased or eliminated river flows is the loss of habitat for fish and mammals. In Kansas, the legislature has responded with laws establishing minimum desirable streamflows and controlling new appropriation rights. These laws effectively limit the amount of water that can be pumped.

Water from the Ogallala generally is of high quality and suitable for consumption. Ground water contamination has become a concern, however, especially when recharge rates are high. The Nebraska Sandhills is a case in point. Agricultural chemicals—especially nitrate-nitrogen—are present in shallow wells. Regulations to protect ground water quality are likely and will affect the extent of irrigated agriculture and production practices where coarse soils or shallow water tables are present (Kromm and White, 1992a).

Listings under provisions of the Endangered Species Act also could affect irrigated agriculture on the western Great Plains. Such listings could result in further limitations on ground water pumping and force changes in agricultural practice. Uncertainty about the possible presence of endangered species as well as the ultimate fate of the act make it difficult to predict the likely effects on irrigated agriculture.

Welfare of Rural Communities

The western Great Plains contains a major concentration of counties that are dependent on farming and that have little or no alternative economic base. Between 1960 and 1990, the average population of these counties increased by only 4.7% (Kromm and White,

Managing Nitrate Pollution in Nebraska

In parts of central and southern Nebraska, the alluvial aquifers are subject to severe nitrate pollution caused by nitrogen fertilizers applied to farmlands. Growers responding to this problem in central Nebraska showed how locally based, collaborative approaches can solve environmental problems without decreasing the profitability of irrigated agriculture. In 1987, the Central Platte Natural Resources District (CPNRD) implemented a water-quality plan addressing the severe nitrate contamination problem. Under the terms of the plan, some activities identified as major causes of the problem, e.g., early fall fertilization, were prohibited. The plan also required growers to monitor the status of nitrates in the soil profile for each 40-acre field and to report annually on fertilization practices, water quantities applied, and grain yields.

Implementation of the CPNRD water-quality plan has led many growers to decrease substantially the quantities of nitrogen fertilizer and irrigation water applied to fields, thereby decreasing nitrate leaching to the aquifer. Despite this decreased use of water and fertilizer, however, grain yields have not been affected. Much remains to be done. Extensive research is underway to develop and to evaluate water and fertilizer management regimes minimizing or eliminating nitrate contamination in the region. Additionally, education and demonstration programs have induced growers to adopt best management practices (BMPs).

The central Nebraska experience illustrates how a local district, governed by an elected board composed primarily of irrigators, can develop and implement collaborative efforts to deal with environmental problems. Growers benefited inasmuch as water and fertilizer costs were decreased but yields maintained. In most instances, environmental problems can be solved effectively and economically when growers take responsibility for finding and implementing solutions. In contrast to centralized governmental regulation, where it is difficult to make rules both flexible (to accommodate variations in local conditions) and effective, local problem-solving permits local conditions to be accounted for. There will be many opportunities throughout the West where growers can and will respond to environmental problems by developing and implementing effective plans.

1992b). Thus, the economy of the entire region is dependent directly on the Ogallala Aquifer and its ability to support irrigated agriculture. Any major change in the extent of irrigated agriculture likely will have a profound economic impact on local communities, many of which already are in decline. Further depletion of locally available water resources will increase the dependence of rural communities on rainfall and dryland farming, making these communities more vulnerable to climatic variation and introducing further instability.

General population declines were projected to result from the agricultural downturn of the 1980s (Popper and Popper, 1987). Although the predicted declines failed to materialize, population fell in some regions, including south-central Nebraska, northwestern Kansas, eastern Colorado, and the eastern Texas Panhandle (Kroom and White, 1992a). Albrecht and Murdock (1985) showed that the smaller farms and increased capital intensity characterizing irrigated agriculture have an indirect but positive impact on population stability. Thus, those regions of the Great Plains that must make a transition from irrigated to dryland agriculture likely will lose population. Communities with populations of fewer than 5,000 will be especially at risk (Williford et al., 1976).

Possibilities for Adaptation

The two primary means available to growers on the western Great Plains for adapting to change are improvements in on-farm irrigation systems and water markets.

Improved Irrigation Farming Systems

Individual growers can adapt in a number of ways to the increasing costs of water and to other changes affecting irrigation on the western Great Plains. New technologies for improving the efficiency of water use may decrease the quantities of water that must be applied to crops. The use of innovative technology and management regimes does not always lead to reductions in ground water pumping, however. Improved technology and management increases the productivity of water, and in some instances this leads to accelerated rates of overdraft (Ellis et al., 1985). Growers will employ improved technology and management whenever it is profitable to do so—not necessarily when it results in less water use. On the western Plains, however, the net effect of more efficient water use has been to decrease ground water extractions in the aggregate.

Traditionally, growers on the western Plains have employed surface irrigation, including border, graded furrow, corrugation, level basin, and furrow dike systems. Over the past 15 years, these have been replaced with closed conduit sprinkler systems including the side roll, center pivot, and linear move systems. Table 5.17, which shows the distribution of irrigation systems in the region, indicates that by 1992 sprinkler systems were employed on nearly 57% of the acreage, with surface and gravity systems employed on only 43% of the land (Irrigation Survey, 1992).

In many circumstances, sprinkler systems permit water to be applied with improved uniformity, thereby decreasing the quantity that must be applied to irrigate all parts of the field adequately. Additionally, as pressurization requirements have dropped, sprinkler technologies have become more attractive, resulting in lowered energy requirements for system operation. Low Energy Precision Application systems operated in conjunction with furrow dikes have increased water application efficiencies to over 95% (Figure 5.39) (Council for Agricultural Science and Technology, 1988). Over the past decade, there has been a twofold trend of replacing surface systems with sprinkler systems and of replacing traditional high-pres-

Table 5.17. Distribution of irrigation systems on the western Great Plains (Irrigation Survey, 1992)

Irrigation system	Number of acres	Percentage
Sprinkler	12,538,800	56.6
Surface/gravity	9,519,120	43.0
Lowflow	94,325	0.4
Total	22,152,245	100.0

Figure 5.39. Blocked furrows help to ensure that water is used as efficiently as possible. Photo courtesy of Ronald Lacewell.

sure sprinkler systems with modern low-pressure systems. This trend is expected to continue and is but one of several on-farm options promoting efficient water use.

For growers who continue to use furrow irrigation, several alternatives are available to improve water-use efficiency. Installation of tail-water recovery systems permits irrigation run-off to be recycled to the field. For many crops, alternative furrow irrigation techniques have demonstrated improved water-use efficiency and increased yields with the same or less irrigation. Surge-flow application is designed to deliver large surges of water to the furrow on an intermittent cycle, thus decreasing percolation losses at the upper end of the field. In addition, shortened furrow lengths have improved irrigation efficiencies substantially (Lacewell et al., 1985).

Other strategies available to growers on the western Plains can minimize environmental damage and promote efficient farming. Minimum tillage preserves organic matter, decreases wind erosion, and improves soil moisture retention. *Prescription farming*, in which fertilizer applications are tailored to plant requirements and soil-fertility levels, decreases runoff, nitrate percolation, and fertilizer costs. Integrated pest management strategies de-emphasize the use of chemical pesticides. In short, these and other techniques can be used to protect and to preserve both irrigated agriculture and environmental quality across the western Great Plains.

Expansion of Water Marketing

Future economic development on the western Great Plains will depend on the ability of agriculture and industry to use water efficiently and to allocate limited supplies to the highest-valued uses. Agriculture is the major user of water in the region and in many, if not most, cases other high-valued uses are not proximate to irrigated areas. Thus, water quantities likely to be transferred to urban uses are small relative to quantities used for irrigation. Water marketing, however, has been accomplished in some areas. In certain states—most notably Texas, the rights of water and land have been separated; water thus has become an independent commodity that can be traded, leased, and/or sold. The cities of Amarillo, Plainview, and Lubbock, which rely on the Canadian River for municipal water supplies, have opted to purchase land in an effort to obtain rights to water needed to dilute contaminants in river water not meeting EPA water quality standards.

Even though arrangements to facilitate water transfers are in place in some states, the overall outlook for high-valued uses of water on the Great Plains is limited, and major transfers between agricultural and urban uses are unlikely. Water markets may be an important means of adaptation to water scarcity in specific locales but probably will not play an important role in ameliorating water scarcity regionally.

Summary

Expansion of irrigation in the Great Plains has helped stabilize productivity and boost income. Agricultural production has increased dramatically over the past four decades, and economic gains in counties dependent on irrigation have been significantly greater than in counties where dryland farming predominates. But persistent overdrafting has caused declines in irrigated acreage that are most severe on the southern margins of the region. By the year 2020, acreage irrigated with water from the Ogallala Aquifer is expected to decline in all states except Nebraska. Although irrigated agriculture may grow for the region as a whole, growth will be concentrated in the northern part of the basin, and substantial acreage on the southern margins will be abandoned or converted to dryland farming.

Many areas dependent on the Ogallala to support irrigated agriculture will need either to convert to dryland farming or to restrict irrigation substantially. The transition from full irrigation has important structural implications for agriculture. Profits can be expected to decline, leading to falling land prices. As productivity per acre declines, larger farms will be required for profitable operation. As farm size increases, some growers will be displaced. The *Six-State High Plains Ogallala Aquifer Regional Resource Study* (High Plains Associates, 1982) showed that at rates of ground water depletion and steady crop yield and price relations like those prevailing in the period 1975–1980, a transition to dryland farming over the next 40 years would decrease gross farm income in the region by 25 to 50% (Banks et al., 1984). These effects would be quite localized, on the southern margins of the region.

Throughout the western Great Plains, growers have demonstrated that they can adapt to conditions of increasing water scarcity by employing a wide range of technological and managerial strategies to conserve water. When these adaptations are employed, the transition from full irrigation can be prolonged, and surviving growers can use water more productively. Environmental problems and federal policies toward agriculture—particularly those related to crop support payments—also will influence the future of irrigated agriculture on the Plains. But despite the changing circumstances confronting irrigated agriculture, these growers have shown that they can adapt. Aside from the areas in which ground water will become economically exhausted, irrigated agriculture on the Plains should continue to prosper.

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6 The Future of Irrigated Agriculture

Irrigated agriculture in the western United States is confronted with change. For the past century, irrigated agriculture has been practiced in an environment characterized by plentiful water supplies, generous and supportive government policies, and reasonably favorable economic circumstances. This environment is undergoing profound change. Ground water overdraft and intensifying competition for scarce water supplies almost assuredly mean that water supplies available to western agriculture will be much smaller than historically, and significantly so in some regions. Neither agricultural nor water development policies are likely to be as favorable to irrigated agriculture as they have been in the past. Government policies will not be punitive, but the special treatment that policies historically have accorded agriculture will begin to disappear. The economic circumstances of western agriculture will become more demanding as the agricultural economy is driven increasingly by global markets for food and fiber. To survive, western growers will need to be innovative, aggressive, and as efficient and productive as possible (Figure 6.1).

These changes will not affect all regions equally. Ground water overdraft occurs to some extent throughout the West except in the Imperial Valley and the Upper Colorado/Great Basin regions. The effects of ground water overdraft are likely to be most severe in the southern Great Plains, where there are no alternative sources of supply. Important areas of irrigated acreage in this region are likely to be taken out of production during the next 20 years as ground water becomes too expensive to pump. The Central Valley of California and central and southern Arizona also will be affected by lowered ground water tables, although to a lesser extent. Nevertheless, some acreage likely will be lost to production in these regions as well.

Irrigated agriculture in all regions of the West will be confronted by increasing competition for supplies. In California, and to some extent in Arizona, rapid urban growth will compete with irrigated agriculture for fairly fixed supplies of developed water. Agricultural uses usually are lower valued than most municipal and industrial uses, and thus irrigated agriculture will be under pressure to reallocate some of its existing water entitlements to support population and economic growth in urban areas.

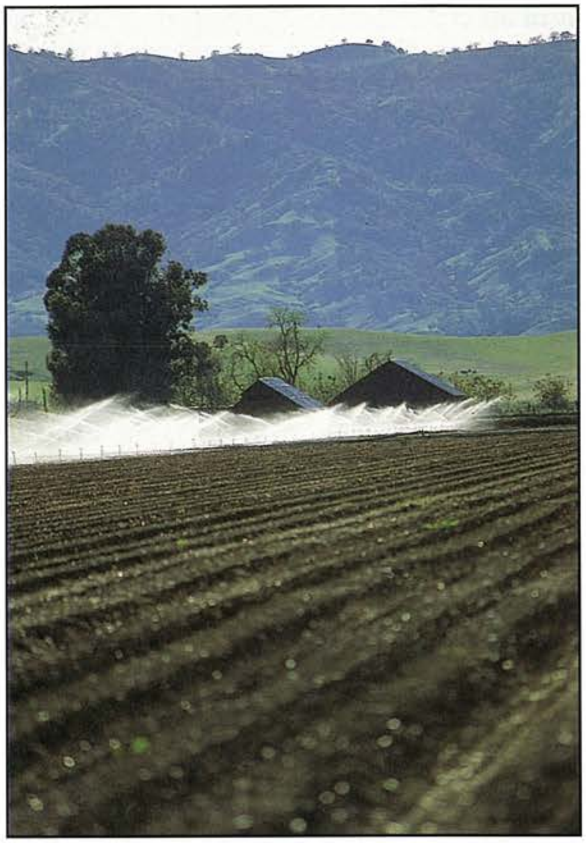

Figure 6.1. **Irrigated agriculture will remain profitable and vibrant despite the many changes to which it must adapt. Photo courtesy Jack Kelly Clark.**

Environmental and instream uses also will compete with agricultural uses. This competition is likely to be most intense in the Pacific Northwest, where, during times of less-than-average flows, instream flows will need to be augmented to support anadramous fish, hydroelectric power generation, and navigation. Considerably higher economic value attaches to these latter three uses than to agricultural use, with the likely consequence that some water will be reallocated from agriculture. California agriculture, especially in the Central Valley, also faces intense competition for water to support instream uses—primarily to maintain biodiversity, to protect endangered species, and to enhance recreational opportunities. In California, some water supplies historically devoted to agriculture very probably will be reallocated to support environmental uses.

Competition from environmental uses will be evident in all other regions of the West. In the Upper Colorado/Great Basin region, demands to maintain and to enhance instream flows to protect endangered species and water based recreational opportunities will intensify. The impact of such competition on irrigated agriculture will be relatively modest because the extent of agriculture likely will contract somewhat as a result of unfavorable climates and distances to markets. Some locales in Arizona and the western Great Plains also will become the focus of intense competition for available water between irrigated agriculture and environmental uses. On a regional basis, competition from environmental uses in Arizona and on the western Great Plains likely will have less of an effect on irrigated agriculture than in other regions of the West, however.

For many growers in virtually all regions, water costs likely will remain stable or will increase modestly. Sharply higher water costs are not anticipated unless there is a major disruption of world energy-markets. Certain groups of agricultural water users, however, can expect to pay more for their water. Those who contract with the Bureau of Reclamation will be under pressure to pay costs more nearly in line with the full cost than they have been paying. Growers who rely on ground water where overdraft prevails will be faced with steadily increasing water costs, and all growers who use water that must be pumped will be subject to the uncertainties surrounding world energy-markets. Growers who have had access to low-cost energy likely will be confronted with energy prices determined by the market and therefore higher than they have encountered. In short, many growers who have enjoyed low-cost water and power will face higher prices.

Public policies are unlikely to be as favorable to agriculture as they have been. The federal government will continue to devolve responsibility for development and management of water resources to the states, and state policies are likely to emphasize improved management practices rather than investment in the development of additional supplies. In all but a few exceptional instances, therefore, it is highly unlikely that the agricultural sector will be able to obtain additional water supplies. Federal agricultural policies will be less favorable in the future than they were in the past. Commodity payment policies, which have insulated growers from low commodity-prices, are slated to disappear altogether. These policies do not apply to most high-valued crops including fruits, nuts, and vegetables, and elimination of commodity support programs is unlikely to have a major impact on irrigated agriculture where these crops dominate. Western growers will, however, be subject increasingly to the competitive forces of the global marketplace without the protections once offered by government.

Simultaneously, federal agricultural policies will focus more on regulation and control of agricultural practices that have adverse impacts on the environment. Irrigated agriculture is unlikely to be exempted from future water-quality regulations. Congruent policies in which eligibility for benefits will depend on the adoption of environmentally benign practices are more likely to be the rule than the exception. Growers in all regions of the West will be under increasing pressure to farm in ways that minimize air and water pollution and erosion and that help protect endangered species. In many instances, these policies will increase the costs of production in irrigated agriculture, and growers will need to innovate in adopting technology and management schemes to offset or reduce increased costs.

Potential Native American water claims in the West amount to more than 44 million acre feet. Because the vast majority of these claims are likely to remain unresolved, substantial uncertainty about the security of some agricultural water rights will remain. In regions such as central and southern Arizona, where the magnitude of such potential claims is quite large, the consequence of settlements in favor of Native Americans may be a shifting of the locus of irrigated agriculture from currently irrigated to reservation lands. Settlement of claims involving enhanced instream flows in favor of Native Americans could affect agricultural water supplies adverse ly in specific locales, especially in the Pacific Northwest. Settlement of large-scale claims is not very likely, however, and thus the effect of Native American claims on western irrigated agriculture in the aggregate probably will be small.

Economic globalization also will affect irrigated agriculture. The NAFTA and the latest GATT round will affect commodities differently. Producers of grains, oilseeds, and livestock are expected to benefit. Thus, growers in the Upper Colorado/Great Basin region and those on the western Great Plains should be operating under more favorable economic circumstances. Producers of high-valued vegetable and fruit and other labor-intensive crops will face increased competition. Although the future effect of liberalized trade on fruit and nut producers is unclear, growers of produce that can be canned or frozen are likely to be affected adversely. In the citrus industry, adverse effects probably will fall mainly on growers in Florida and Brazil, and not on those in the Southwest. The effects of NAFTA and GATT on fresh fruit and vegetable markets are less predictable. Fruit and vegetable growing regions tend to have more opportunity to shift crop mix in response to changing circumstances than regions do in which only field crops are grown. Thus, the regions that may be affected most adversely by the globalizing agricultural economy also are the most adaptable.

Just as the forces of change will affect regions differently, regional capacities to adapt will differ. Where there are particularly favorable climates and soils, growers can alter crop mix in response to changing conditions. This fact suggests that growers in the Pacific Northwest, California, and Arizona are well equipped to respond to intensifying water scarcity and changing economic conditions. By contrast, those in the Upper Colorado/Great Basin region and those in the western Great Plains have limited opportunities to alter crop mix inasmuch as climate and soil are poorly suited to the production of high-valued fruit, nut, or vegetable crops.

The development of new technologies allowing water to be managed with improved precision and allowing irrigation systems to be automated fully also will provide growers a means of minimizing water use and lowering costs. Unless very inexpensive systems are developed for use on field crops, innovative technologies are likely to be most attractive and advantageous to growers of high-valued crops. The biological revolution also holds promise for the development of crops that can be grown more cheaply because they are pest and disease resistant or because they require less fertilizer or water. Similarly, innovations in the management of irrigated farming operations will allow growers to adapt. It is impossible to know whether biotechnology and managerial innovation will confer advantage broadly across the West or whether developments will benefit the producers of certain crops in certain regions.

Although future government policies will not be as favorable to irrigated agriculture, the evolution of policies and institutions should be guided to facilitate adaptation to change. Thus, for example, policies and institutions that create a consistent and certain regulatory environment will help agriculture adapt. Additionally, policies incorporating marketlike forces and marketlike incentives will facilitate adaptive processes at the farm level. The establishment of well-functioning water markets with appropriate protections for third parties also will help irrigated agriculture adjust to an era of diminished water supply. Creation of water markets will be particularly important in regions where competition for water is intense. The establishment of water markets in the Pacific Northwest, California, and Arizona will simplify the process of reallocating water from agriculture to urban and environmental uses. Growers electing to sell or to lease their water will be compensated fully through market mechanisms. There is no promise of compensation if needed reallocations must be left to the courts to implement.

This latter point underscores the fact that western growers would be well served by working to develop new policies and institutions that will help them adapt. Efforts to resist changes wrought by globalizing economic conditions and by an increasingly urbanized population are likely to be fruitless and to complicate adaptation. Increased investment in agricultural research and development will benefit all regions of the West, by helping growers adapt to such change and by enhancing their ability to compete in global food and fiber markets. Both private and public investment will be important.

There is little question that western growers must adapt to a confluence of changing circumstances, and there should be little doubt about their ability to do so. Growers have at hand numerous means of responding to change, and their willingness to invest in the development of new technology and new management regimes will enhance their adaptability. More important, perhaps, the survey of the various regions of the West indicates that growers have been adapting continually to new circumstances for at least the past two decades.

Experience in the Pacific Northwest and California illustrates how irrigated agriculture in these regions has become more productive despite decreased irrigated acreage. In both regions, the ability of growers to alter crop mix in the face of changing markets and diminishing water and land availability has resulted in increased income and productivity. In the Upper Colorado/Great Basin and the Great Plains, irrigated agriculture has become more productive over the past two decades even though the possibilities for altering crop mix have been quite constrained. This achievement, the result of innovative methods of managing water and other inputs, explains in large part why irrigated agriculture on the southern Great Plains has remained productive despite increasing water costs. The response of growers throughout the West to rapidly increasing energy prices during the 1970s and the early 1980s also illustrates their ability to adapt to substantive and unforeseen changes. Irrigated agriculture's history of adaptation to changing circumstances in the West is impressive, and there is no indication that rapid innovation and adaptation will slow or disappear in the future.

Irrigated agriculture itself will change as it responds to new circumstances. It will use fewer natural resources, especially less land and water. It will become more environmentally benign. The contributions of agriculture to air and water pollution will decline as reliance on chemicals declines and as new methods of managing soil and water are employed in the culture of irrigated crops. Although the irrigated agricultural sector in the western United States will be smaller in terms of land and water use and although irrigation will be practiced in more environmentally sensitive ways, western irrigated agriculture should continue to become increasingly productive. The past two decades have demonstrated that western growers can achieve significant increases in productivity without bringing substantial tracts of new land under irrigation. The next two decades should demonstrate that western growers can achieve substantial increases in productivity while using less land and water.

Appendix A: Abbreviations and Acronyms

a.f.	acre foot
AMA	Active Management Area
BMP	best management practice
c.f.s.	cubic feet per second
CPNRD	Central Platte Natural Resources District
CRP	Conservation Reserve Program
CVP	Central Valley Project
d	day
EPA	U.S. Environmental Protection Agency
GATT	General Agreement on Tariffs and Trade
in.	inch
INA	Irrigation Non-Expansion Area
km	kilometer
kwh	kilowatt hour
LEPA	low-energy precision application
NAFTA	North American Free Trade Agreement
ppm	parts per million
psi	pounds per square inch
SWP	State Water Project
USDA	U.S. Department of Agriculture

Appendix B: Glossary

Agriculturally dependent communities. Communities that depend on agriculture and related industries for more than 15% of total income and employment.

Anadromous fish. Fish, such as salmon, that ascend rivers from the sea at certain seasons for breeding.

Cultivars. A variety or strain of a plant that has originated and persisted under cultivation.

Ground water overdraft. The withdrawal of ground water through wells at rates exceeding those of ground water recharge. Overdraft results in a lowering of ground water tables.

Prescription farming. Farming in which nutrient and pesticide applications are tailored to plant requirements and/or soil types.

Saturated thickness. The depth of geological material in which the pore space is saturated with water.

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