2.1 Water Use and Pricing

Irrigated agriculture remains the dominant use of freshwater in the United States, although irrigation's share of total consumptive use is declining. National irrigated cropland area has expanded by a third since 1969, while field water application rates have declined about one fourth, leaving total irrigation water applied about the same in 1995 as in 1969. Nationally, variable irrigation water costs for ground water and off-farm surface water are roughly equivalent, averaging near $35 per acre. Neither reflects the full costs of water; onfarm well and equipment costs can be substantial for groundwater access, while infrastructure costs are often subsidized for publicly developed, off-farm surface water.

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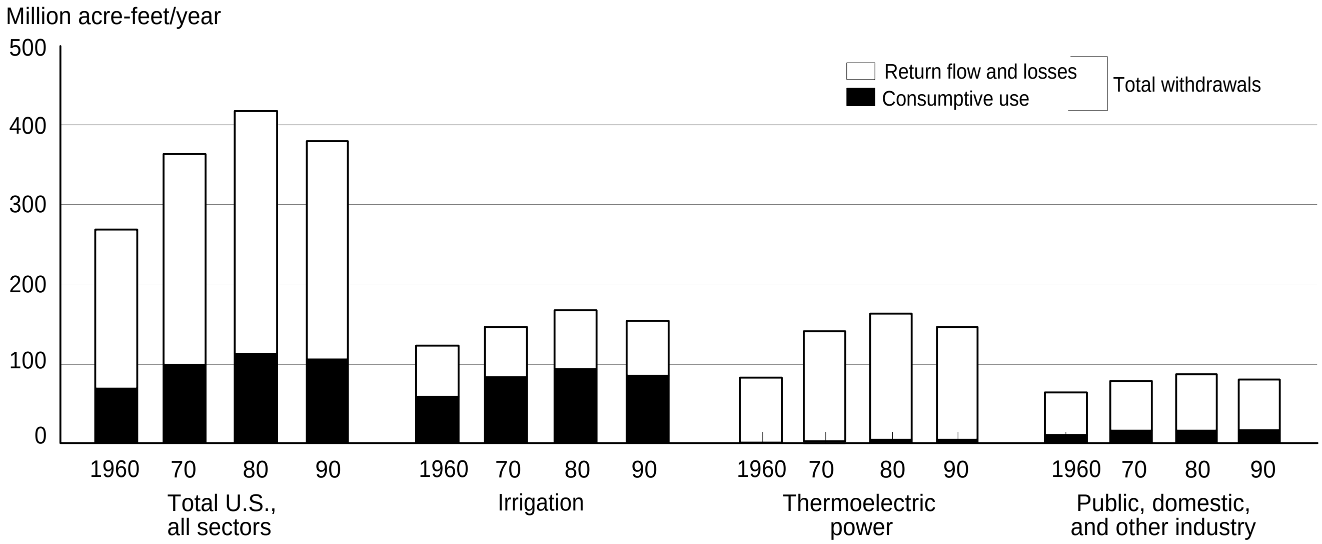
The United States, as a whole, has adequate water supplies. Annual renewable supplies in surface-water bodies and groundwater aquifers total roughly 1,500 million acre-feet per year (maf/yr). (See "Glossary of Water Use Terms" for definitions.) Of total renewable supplies, only one-quarter is withdrawn for use in homes, farms, and industry, and just 7 percent is consumptively used (Moody, 1993).[1] Renewable surface- and groundwater supplies account for roughly 90 percent of total water use nationwide. The remainder reflects depletion of stored ground water (Foxworthy and Moody, 1986).

An abundance of water in the aggregate belies increasingly limited supplies in many areas, reflecting uneven distribution of the Nation's water resources. In the arid West, consumptive use exceeds half of the renewable water supplies under normal precipitation conditions. In drought years, water use often exceeds renewable flow. While droughts exacerbate supply scarcity, water needs continue to expand in the aggregate and to shift among uses. Urban growth greatly expanded municipal water demands in arid areas of the Southwest and far West. At the same time, demand for high-priority instream (nonconsumptive) water flows for recreation, riparian habitat, and other environmental purposes has tightened competition for available water supplies in all but the wettest years. While future water needs for instream uses are difficult to quantify, the potential demands on existing water supplies are large and geographically diverse (see box, "Instream Water Flows," pp. 80-81).

[1] Consumptive uses considered here include those uses occurring after water is withdrawn from a river or aquifer. Other consumptive uses—riparian vegetation use and reservoir evaporation—require no water withdrawals and are not considered here. Instream water use for hydroelectric production, transportation, recreation, or aquatic and riparian habitat is also not included.

Figure 2.1.1--Water withdrawals and consumptive use, 1960-90



Source: USDA, ERS, based on Solley, Pierce, and Perlman, 1993.

Increased water demand in water-deficit areas was historically met by expanding available water supplies. Dam construction, groundwater pumping, and interbasin conveyance provided the water to meet growing urban and agricultural needs. However, future opportunities for large-scale expansion of supplies are limited due to lack of suitable project sites, reduced funding, and increased public concern for environmental consequences. Consequently, meeting future water demands will require some reallocation of existing supplies. And since agriculture is the largest water user, reallocation will likely result in reduced supplies for agriculture.

Irrigated cropland is an important part of the U.S. agricultural sector, contributing about 40 percent of the total value of crops on just 15 percent of total cropland harvested. In 1992, 279,000 farms irrigated 49.4 million acres of crop and pasture land. Irrigated acreage dominated the production of several major crops, including rice with 100 percent irrigated, orchards (76 percent), Irish potatoes (71 percent), and vegetables (65 percent). Irrigated acreages are substantial for several major field crops, including corn for grain with 9.6 million acres, all hay (8.6 million), wheat (4.1 million), and cotton (3.7 million) (USDC, 1994). Changes in agricultural water availability may have significant impacts on irrigated production and rural communities.

Irrigation Withdrawals

Freshwater withdrawals—a measure of the quantity of water diverted from surface- and groundwater sources—totaled 380 million acre-feet (maf) in 1990 (fig. 2.1.1). Major withdrawal categories include irrigation (153 maf), thermoelectric (146 maf), public and rural domestic supplies (52 maf), and other industries (28 maf) (Solley, Pierce, and Perlman, 1993).

Irrigation withdrawals as a share of total freshwater withdrawals declined from 46 percent in 1960 to 40 percent in 1990.[2] Public and rural domestic water withdrawals increased by almost 90 percent over the same period, corresponding with a U.S. population increase of 40 percent and a population shift to arid and warmer climates. Although thermoelectric withdrawals declined through the 1980's, the 1990 withdrawal was still 77 percent greater than 1960.

Most irrigation water withdrawals occur in the arid Western States where irrigated production is concentrated. Combined irrigation withdrawals in the four largest withdrawal States—California, Idaho, Colorado, and Montana—exceeded 75 maf, or nearly half of total U.S. irrigation withdrawals in 1990 (fig. 2.1.2). The top 20 irrigation States accounted for 97

[2] Irrigation withdrawal estimates by Solley, Pierce, and Perlman are primarily for agricultural purposes (cropland and pasture), but irrigation of recreational areas (parks and golf courses) is also included. Withdrawal estimates are done every 5 years, but data from 1995 are not yet available.

Table 2.1.1—Irrigation water withdrawals and consumptive use, 20 major irrigation States and total U.S., 1990

State[2]	Withdrawals[1]				Consumptive use[1]	
	Irrigation total	Surface water--Bureau of Reclamation	Surface water--Private	Ground water--All suppliers	Irrigation total	Irrigation's share of State consumptive use
	maf[3]	*Percent of irrigation water withdrawn*[4]			*maf*[3]	*Percent*
California	31.3	20	42	38	21.8	93
Texas	9.5	5	30	66	8.0	79
Idaho	20.9	44	21	35	6.8	99
Colorado	13.0	8	70	22	5.6	94
Kansas	4.7	2	3	95	4.5	92
Nebraska	6.8	13	15	71	4.4	93
Arkansas	5.9	0	18	82	4.4	94
Arizona	5.9	36	25	39	4.0	82
Oregon	7.7	25	67	8	3.4	95
Washington	6.8	70	17	12	2.9	92
Wyoming	8.0	18	79	3	2.9	95
Florida	4.2	0	48	52	2.8	79
Montana	10.1	11	88	1	2.2	93
Utah	4.0	9	77	14	2.2	87
New Mexico	3.4	21	33	46	2.0	86
Nevada	3.2	9	60	31	1.6	86
Mississippi	2.1	0	7	93	1.5	74
Louisiana	0.8	0	36	64	0.7	39
Georgia	0.5	0	40	60	0.5	54
Oklahoma	0.7	6	12	82	0.4	58
All other States	3.9	6	45	49	3.0	25
United States	153.0	20	43	37	85.4	81

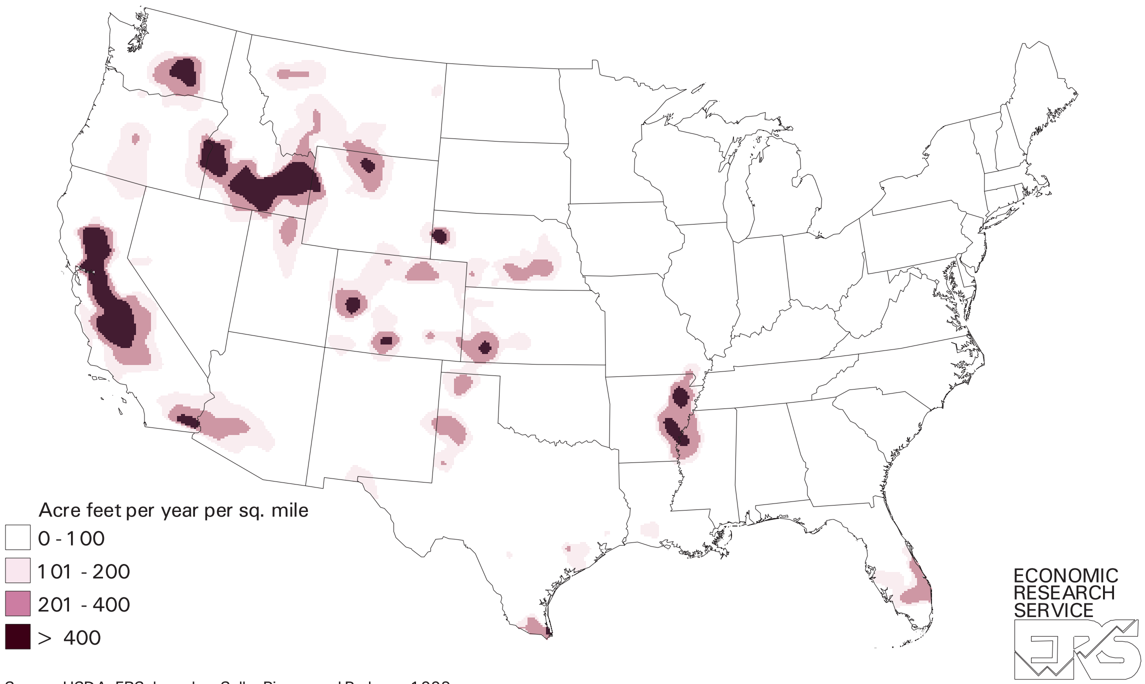
[1] Withdrawal and consumptive use estimates are from the U.S. Geological Survey. They include freshwater irrigation on cropland, parks, golf courses, and other recreational lands.
[2] States are ranked based on total irrigation consumptive use.
[3] maf represents 1 million acre-feet.
[4] May not add to 100 due to rounding.
Source: USDA, ERS, based on Solley, Pierce, and Perlman, 1993.

percent of U.S. freshwater irrigation withdrawals (table 2.1.1).[3] Most States rely on a combination of surface- and groundwater supplies for irrigation purposes.

Surface water accounted for 63 percent of total irrigation withdrawals in 1990, with ground water supplying the remaining 37 percent.[4] Approximately 32 percent of surface-water deliveries—or 20 percent of total irrigation withdrawals—was provided by the U.S. Department of Interior, Bureau of Reclamation (BOR). States with the largest total BOR deliveries include Idaho, California, and Washington; BOR's share of total irrigation withdrawals was greatest in Washington, Idaho, Arizona and Oregon. The share of irrigation withdrawals from surface-water sources varies from year to year depending on precipitation, surface runoff, and water stored in reservoirs.

[3] Irrigation States in table 2.1.1 are ranked according to consumptive use, and not irrigation withdrawals.
[4] Surface water availability was below normal over much of the West in 1990. In a normal or above-normal water supply year, the share of water supplied from surface sources is likely to increase.

Figure 2.1.2--Fresh water withdrawals for irrigation, 1990



Source: USDA, ERS, based on Solly, Pierce, and Perlman, 1993.

Ground water is the primary water source for irrigation in about half of the top 20 irrigation States (table 2.1.1). Ground water is pumped from wells drilled into underground, water-bearing strata. Total groundwater withdrawals were largest in the major irrigation States of California, Texas, and Idaho. Ground water as a share of irrigation withdrawals was highest in Kansas, Mississippi, Arkansas, Oklahoma, and Nebraska.

Groundwater overdrafting has been reported in many areas of the Great Plains, Southwest, Pacific Northwest, Mississippi Delta, and Southeast. Overdrafting occurs when withdrawals for irrigation and other uses exceed natural rates of aquifer recharge, which results in lowered water levels and reduced total water reserves. Consequences of overdrafting are slight in any year, but tend to be permanent and cumulative. Major impacts are increases in pumping costs and longrun adjustments in aquifer composition that can lead to land subsidence, saltwater intrusion along coastal areas, and loss of aquifer capacity.

Irrigation Consumptive Use

Consumptive use of freshwater—a measure of water used, not just withdrawn—totaled about 105 maf from all offstream uses in the United States in 1990 (fig. 2.1.1).[5] Irrigation, the dominant consumptive water use, accounted for 85 maf or 81 percent of the U.S. total. Consumptive use as a share of withdrawals was 56 percent for the irrigated sector, compared with 17 percent for public and rural supplies, 16 percent for industries other than thermoelectric, and just 3 percent for thermoelectric. Total irrigation consumptive use depends on crop acreage and evapotranspiration rates, with the latter dependent on climate, crop, yield, and management practices.

Consumptive water use for irrigation increased by about 60 percent between 1960 and 1980, reflecting the rapid expansion in irrigated area. By 1990, irrigation water use had declined from 1980 levels, due largely to reduced water use per irrigated acre. Reduced water consumption per irrigated acre in the 1980's primarily reflects regional cropping pattern shifts, including lower irrigation water needs in more

[5] Water use estimates are prepared every 5 years, but data for 1995 are not available at this time.

humid eastern States, and a reduction in irrigated cropland in some of the highest water-using areas of the Southwest.

Irrigation consumptive use in the 20 major irrigation States accounted for 96 percent of the national total. California has the greatest irrigation consumptive use, followed by Texas, Idaho, and Colorado. Combined, these four States accounted for nearly half of total irrigation consumptive use in the United States. Of the 20 major irrigation States, 5—Arkansas, Florida, Mississippi, Louisiana, and Georgia—are in humid areas where irrigation supplements usually adequate precipitation.

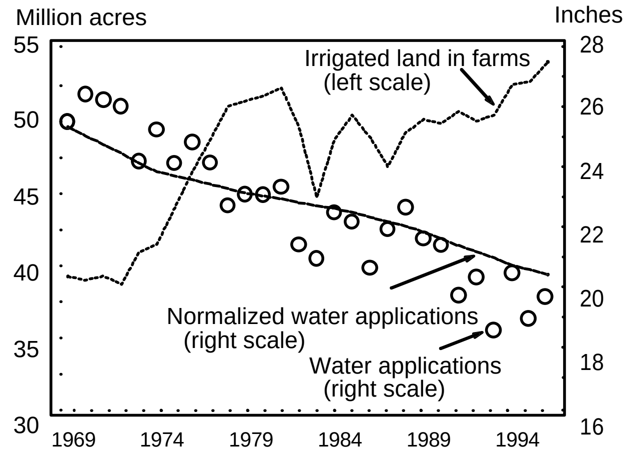
Irrigation's share of total consumptive water use fell by roughly 4 percent over 1960-90. A 4-percent share of the 1990 total water use represents more than 3 maf, or 17 percent of all nonirrigation water uses. This suggests that growth in nonagricultural water needs, particularly in areas with limited opportunities to increase supply, may be met by relatively small reductions in irrigation water use at the national level. However, small transfers from irrigation to other uses in the aggregate may mean substantial adjustments in some regional and local irrigated activity.

Nearly 20 million acres, or about 45 percent of total irrigated acres, were irrigated with surface water in 1994. All surface-water sources in 1990 accounted for 63 percent of total irrigation withdrawals (table 2.1.1). In general, land irrigated from surface-water sources had a higher average withdrawal rate per irrigated acre than groundwater-irrigated lands due to higher conveyance losses, more arid location, and seasonality of rainfall. Greater withdrawals, however, do not necessarily translate into greater consumptive use per acre. The difference between withdrawals and consumptive use highlights the importance of losses, runoff, and return flows. (For more on the relationship among withdrawals, consumptive use, and irrigation application efficiency, see chapter 4.6 on Irrigation Water Management.)

Irrigated Land in Farms

While national area of irrigated farmland is once again near peak levels reached in 1981 (fig. 2.1.3), varying regional trends reflect differences in water resource conditions. Western irrigation reached its peak with the agricultural export boom and high crop prices of the 1970's. The Southwest—the first region to fully utilize available water resources—became the first region to begin abandoning irrigated acreage in the face of growing water demand for urban and environmental uses. Farmers in 6 Southwest States

Figure 2.1.3--Irrigation trends, 1969-96



For detail on data and assumptions, see tables 2.1.3-2.1.4.
Estimated water applications with weather and crop choice effects removed
Source: USDA, ERS.

and in the Southern Plains irrigated 3 million acres less in 1995 than in 1981. In contrast, farmers in the Northern Plains and eastern regions continue to expand irrigation capacity, irrigating 3 million acres more in 1995 than in 1981.

The most reliable measure of irrigated farmland continues to be the census of agriculture, taken twice per decade. State summaries from the 1992 Census of Agriculture (table 2.1.2), when contrasted with 1982, highlight the East/West differences in recent trends (USDC, 1994 and 1984). Irrigated area in all but 4 States of the Northern Plains and East increased over 1982, with 8 States experiencing a 50-percent or greater increase in irrigated farmland. In the Pacific Coast and Mountain regions, 9 out of 11 States irrigated less farmland in 1992 than in 1982. The result is an increasing reliance on irrigation in the East, and a redistribution of acres in the West (fig. 2.1.4). Dense concentrations of irrigation are located in California's Central Valley, along the Snake and Columbia Rivers, and over the High Plains Aquifer from Texas to Nebraska. Significant concentrations of irrigation also occur in humid areas—Florida, Georgia, and in the Mississippi Delta, primarily Arkansas and Mississippi.

Changes in irrigated acreage are partially attributable to regional weather patterns. The major western drought of the late 1980's affected surface-water supplies across the region. In 6 southwestern States, the drought combined with competing urban and environmental demands to reduce irrigated area by a

Table 2.1.2—Irrigated area by State and region, 1982 and 1992 Census of Agriculture

State/region	1982	1992	Change
	1,000 acres		*Percent*
Maine	6	10	76
New Hampshire	1	2	34
Vermont	1	2	69
Massachusetts	17	20	15
Rhode Island	2	3	34
Connecticut	7	6	-12
New York	52	47	-11
New Jersey	83	80	-3
Pennsylvania	18	23	27
Delaware	44	62	40
Maryland	39	57	48
Northeast	**271**	**312**	**15**
Michigan	286	368	29
Wisconsin	259	331	28
Minnesota	315	370	17
Lake States	**861**	**1,070**	**24**
Ohio	28	29	6
Indiana	132	241	83
Illinois	166	328	98
Iowa	91	116	27
Missouri	403	709	76
Corn Belt	**820**	**1,423**	**74**
North Dakota	163	187	15
South Dakota	376	371	-1
Nebraska	6,039	6,312	5
Kansas	2,675	2,680	0
Northern Plains	**9,254**	**9,550**	**3**
Virginia	43	62	44
West Virginia	1	3	193
North Carolina	81	113	39
Kentucky	23	28	22
Tennessee	18	37	108
Appalachian	**165**	**242**	**46**
South Carolina	81	76	-7
Georgia	575	725	26
Florida	158	1,783	12
Alabama	66	82	24
Southeast	**2,308**	**2,665**	**15**
Mississippi	431	883	105
Arkansas	2,023	2,702	34
Louisiana	694	898	29
Delta	**3,147**	**4,482**	**42**
Oklahoma	492	512	4
Texas	5,576	4,912	-12
Southern Plains	**6,068**	**5,425**	**-11**
Montana	2,023	1,976	-2
Idaho	3,450	3,260	-6
Wyoming	1,565	1,465	-6
Colorado	3,201	3,170	-1
New Mexico	807	738	-9
Arizona	1,098	956	-13
Utah	1,082	1,143	6
Nevada	830	556	-33
Mountain	**14,056**	**13,264**	**-6**
Washington	1,638	1,641	0
Oregon	1,808	1,622	-10
California	8,461	7,571	-11
Pacific Coast	**11,907**	**10,835**	**-9**
48 States	**48,856**	**49,268**	**1**
Alaska	1	2	135
Hawaii	146	134	-8
U.S total	**49,002**	**49,404**	**0.8**

Source: USDA, ERS, based on USDC, 1994

million acres between 1989 and 1993. About half of this area has subsequently returned to irrigation. Winter precipitation in 1993 and 1995 refilled reservoirs, easing water supply constraints. Additionally, changes in Federal farm programs allowed planting of more program crop acreage. In the East, unusually wet seasons reduced irrigated acres in the Southern Plains, Delta, and Southeast regions in 1992 and across the Northern Plains, Corn Belt, and Lake States regions in 1993.

Based on assumptions of normal weather, over 53 million acres could be irrigated in 1996 (table 2.1.3). This would represent an increase of 1.3 million acres over 1995, with most of this increase projected for corn. The increase in 1996 acreage reflects, in part, changes in Federal commodity programs, which idled irrigable area in the past.

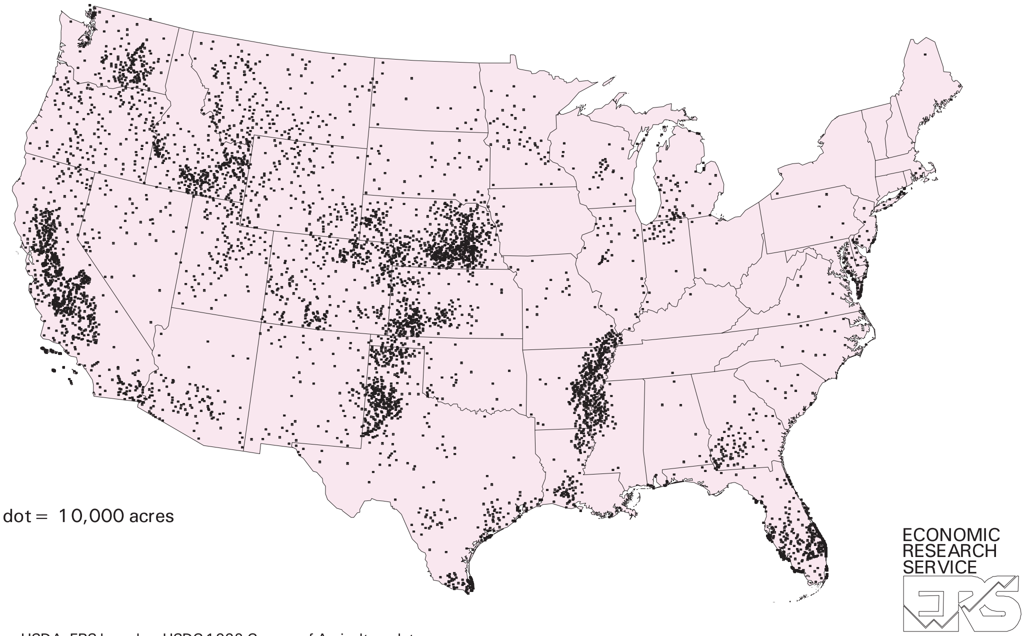
In addition to regional shifts in acreage, there has been a shift in the crop mix on irrigated cropland. Sorghum area irrigated has declined significantly due to improved dryland cultivars, limited water in primary growing areas, and lower returns relative to other irrigated crops. Irrigated areas of barley, oats, silage, and sugarbeets have also declined. Reduced acreage in these crops has been more than offset by increases in irrigated areas of corn, soybeans, alfalfa, fruits, and vegetables. Cotton and rice irrigated areas, while still below record levels of the 1970's, have also increased in recent years.

Irrigation Water Application Rates

Total depth of water applied through the irrigation season has averaged near 20 inches for the past 5 years (table 2.1.4). Since 1969, the national average application rate has declined by about 6 inches, or 25 percent, which is enough to offset the increase in irrigated acreage and maintain total water applied near the level of 25 years earlier. Application rates vary from less than 6 inches for soybeans in Atlantic States to as much as 5 feet for rice in the Southwest. Reductions in application rates have been widespread, with greatest declines in the Northern Plains and Mountain regions. (The higher rates for eastern regions during the 1970's reflects high crop prices and wide adoption of irrigation for water-intensive, specialty crops.)

Of the 6-inch decline in applied water, 2 to 3 inches are attributable to shifting shares of irrigated crop production between States and between crops within States. Recent growth in irrigated area has come in cooler northern States or humid eastern States with lower water application requirements. The remaining

Figure 2.1.4--Irrigated land in farms, 1992



Source: USDA, ERS based on USDC 1992 Census of Agriculture data.

3 to 4 inches of decline in application rates represent efficiency gains from changes in irrigation technologies and water management practices (see chapter 4.6, *Irrigation Water Management*).

Irrigation Water Prices and Costs

Prices paid for irrigation water supplies are of considerable policy interest due to their importance as a cost to irrigated agriculture, and their impact on regional water use. Increasingly, water pricing is viewed as a mechanism to improve the economic efficiency of water use. While the use of pricing to adjust input allocation over time and across sectors has appeal, problems emerge when applied to water.

Irrigation water prices are typically not set in a market, since market development has not been widespread. States generally administer water resources and grant (not auction) rights of use to individuals without charge, except for minor administrative fees. As a result, water expenses are typically based on the access and delivery costs of supplying water and generally do not convey signals about water's relative scarcity.[6]

Water prices could be set administratively, but this approach is not likely to achieve goals of economic efficiency. The localized nature of hydrologic systems and the externalities associated with water use and reuse would require precise adjustments in water prices—spatially and temporally—requiring high program costs. In addition, establishing a slightly higher price may not dramatically change input use in the current institutional environment. To prompt large changes in input use would require very large adjustments in price, all but prohibited by distributional concerns.

The price irrigators pay for water is usually associated with the expense of developing and providing the resource—including access, storage, conveyance, and in some cases, field distribution—and may not reflect the full social cost of its use. Irrigation water costs vary widely (table 2.1.5), reflecting different combinations of water sources, suppliers, distribution

[6] Irrigators, municipalities, environmental groups, and others seeking to increase water supplies where limits on development or use have been reached must purchase annual water allocations or permanent water rights from existing users. Prices of water purchased better reflect the scarcity of the resource.

Table 2.1.3—Irrigated land in farms, by region and crop, selected years 1969-96

Region	1969[1]	1974[1]	1978[1]	1981[2]	1982[1]	1987[1]	1992[1]	1993[2]	1994[2]	1995[3]	1996[4]
	Thousand acres										
USDA production region:											
Atlantic[5]	1,800	2,000	2,900	3,000	2,700	3,000	3,200	3,300	3,300	3,500	3,400
North Central[6]	500	600	1,400	1,600	1,700	2,000	2,500	2,300	2,600	2,500	2,700
Northern Plains	4,600	6,200	8,800	9,300	9,300	8,700	9,600	9,400	10,100	9,800	10,300
Delta States	1,900	1,800	2,700	3,300	3,100	3,700	4,500	4,500	5,000	4,700	4,900
Southern Plains	7,400	7,100	7,500	7,200	6,100	4,700	5,400	5,800	6,000	6,100	6,100
Mountain States	12,800	12,700	14,800	14,600	14,100	13,300	13,300	13,700	13,500	14,000	14,200
Pacific Coast	10,000	10,600	12,000	12,400	11,900	10,800	10,800	10,700	11,100	11,400	11,500
United States[7]	39,100	41,200	50,300	51,600	49,000	46,400	49,400	49,800	51,800	52,000	53,300
Crop:											
Corn for grain	3,300	5,600	8,700	8,500	8,500	8,000	9,700	9,600	10,600	9,800	10,900
Sorghum for grain	3,500	2,500	2,000	2,100	2,200	1,300	1,600	1,200	1,200	1,100	1,100
Barley	1,600	1,400	2,000	1,800	1,900	1,300	1,100	1,100	1,100	1,100	1,100
Wheat	2,000	3,300	3,000	4,800	4,600	3,700	4,100	4,100	4,100	4,300	4,500
Rice	2,200	2,600	3,000	3,800	3,200	2,400	3,100	2,900	3,400	3,200	3,300
Soybeans	700	500	1,300	1,800	2,300	2,600	2,500	2,600	2,900	2,800	2,700
Cotton	3,100	3,700	4,700	5,100	3,400	3,500	3,700	4,000	4,200	4,700	4,600
Alfalfa hay	5,000	5,200	5,900	5,700	5,500	5,500	5,700	6,000	6,100	6,400	6,400
Other hay	2,900	2,800	3,000	2,900	3,000	3,100	2,900	3,100	2,900	3,300	3,300
Vegetables	1,500	1,600	1,900	1,800	1,900	2,000	2,200	2,200	2,400	2,300	2,300
Land in orchards	2,400	2,600	3,000	3,300	3,300	3,400	3,600	3,700	3,800	3,700	3,700
Other land in farms	10,800	9,400	11,800	10,100	9,200	9,500	9,100	9,300	9,300	9,200	9,300

[1] Census of Agriculture.
[2] Revised estimates constructed from several unpublished USDA sources and the Census of Agriculture.
[3] Preliminary estimates.
[4] Forecast assumes normal weather and no ARP's.
[5] Northeast, Appalachian, and Southeast farm production regions.
[6] Lake States and Corn Belt production regions.
[7] Includes Alaska and Hawaii.
Source: USDA, ERS, based on USDC, Census of Agriculture, various years; and USDA, ERS data.

systems, and other factors.[7] Cost determinants are generalized below for ground- and surface-water sources.

Groundwater Costs

Ground water was the sole water source for 22.5 million acres and supplied some of the water for an additional 6.3 million acres in 1994. Ground water from an estimated 330,000 irrigation wells served approximately 105,000 farms nationwide (USDC, 1996). California had the most wells used for irrigation in 1994 with 63,000, followed by Texas, 55,000; Nebraska, 54,000; and Arkansas, 28,000. Ground water is usually supplied from onfarm wells, with each producer having one or more wells to supply the needs of a single farm. On average, a groundwater irrigated farm will have more than 3 wells, with about 6 percent of the farms reporting 10 or more wells.

Costs associated with groundwater pumping reflect both the variable cost of extraction and the fixed cost of access. Variable extraction costs primarily reflect the energy needed to power a pump.[8] Energy costs

[7] Other factors include farm (or field) proximity to water source, topography, underlying aquifer conditions, energy source, and structure of the water delivery organization.

[8] A limited number of artesian wells, in which natural aquifer pressure forces water to the ground's surface, are located primarily in Florida and Washington.

Table 2.1.4—Depth of irrigation water applied per season, by region and crop, selected years 1969-96

Item	1969[1]	1974[1]	1984[2]	1988[2]	1991[3]	1992[3]	1993[3]	1994[2]	1995[3]	1996[4]
					Inches[5]					
Region:										
Atlantic[6]	8.5	11.5	16.5	15.5	11.5	14.5	16.5	12.5	14.0	15.0
North Central[7]	7.5	8.0	9.5	10.5	8.0	8.0	5.0	7.5	7.0	7.5
Northern Plains	16.0	17.0	13.5	14.5	13.0	11.5	8.0	12.0	11.0	11.0
Delta States	15.5	17.5	17.5	18.0	12.0	15.0	15.0	13.5	14.5	14.0
Southern Plains	18.0	18.5	17.0	17.0	15.0	15.5	17.0	18.0	17.0	17.0
Mountain States	30.5	28.5	24.5	24.5	23.5	24.0	22.6	24.5	22.5	23.0
Pacific Coast	33.0	34.0	34.0	34.5	31.5	32.0	29.0	32.5	28.0	30.5
United States[8]	25.5	25.0	22.5	22.5	20.0	20.5	19.0	20.5	19.0	19.5
Crop:										
Corn for grain	18.5	19.5	16.0	16.0	14.0	13.0	11.0	13.5	12.5	12.5
Sorghum	19.0	19.0	14.5	14.0	13.5	12.5	11.5	13.5	12.0	12.5
Barley	30.0	26.5	18.5	18.0	17.5	18.5	17.5	19.0	17.5	18.0
Wheat	23.0	24.0	16.5	16.0	14.0	15.5	14.0	17.0	15.0	15.0
Rice	28.0	28.5	34.0	32.5	24.5	27.0	27.0	27.5	27.0	27.0
Soybeans	12.0	11.0	9.5	10.0	9.0	8.0	7.0	8.5	8.0	8.0
Cotton	23.0	25.5	25.0	24.5	21.0	23.0	21.5	21.0	20.5	21.0
Alfalfa hay	32.5	30.5	28.0	29.0	27.0	27.0	24.5	26.5	25.0	25.5
Other hays	22.0	21.0	21.0	19.5	19.5	20.0	19.5	20.5	20.0	20.0
Vegetables	25.0	25.5	27.0	26.5	24.5	24.5	23.5	24.0	23.0	24.0
Land in orchards	29.0	30.0	31.0	31.5	24.5	27.0	23.0	27.0	20.0	25.5

[1] Census of Agriculture, with imputations for individual crops.
[2] Estimates constructed by State, by crop from U.S. Dept. Commerce's Farm and Ranch Irrigation Surveys (FRIS) and ERS estimates of irrigated area.
[3] Aggregated from FRIS State/crop application rates adjusted to reflect annual changes in precipitation. Sensitivity to precipitation is estimated as a function of average precipitation and soil hydrologic group.
[4] Forecast using precipitation records through September 1995.
[5] Depths rounded to the nearest 0.5 inch.
[6] Northeast, Appalachian, and Southeast production regions.
[7] Lake States and Corn Belt farm production regions.
[8] Includes Alaska and Hawaii.
Source: USDA, ERS, based on USDC, Census of Agriculture, selected years; USDC, Farm and Ranch Irrigation Surveys.

vary widely depending on the depth to water, pumping system efficiency, the cost of energy, pressurization needs, and quantity of water applied. Total U.S. energy expenditures for irrigation water pumping were estimated at more than $1.2 billion in 1994 (USDC, 1996). Average energy expenditures were $34 per acre with a State range from $11 to $74 per acre (table 2.1.5). Capital costs of accessing ground water can be substantial, depending on local drilling costs, well depth, aquifer conditions, discharge capacity, power source, and pump type. Capital costs for a typical well and pumping plant are usually $20,000 to $120,000.

A limited amount of ground water is supplied to farms from off-farm sources. In this case, an irrigation district or mutual water-supply company will develop wells to serve irrigators during times of the year when surface-water supplies are unavailable or in short supply. While the quantities of water supplied are small—estimated at only 2 percent of irrigation withdrawals—the water is often critical for improved water management and drought protection. Availability of off-farm groundwater reserves provides irrigators a wider variety of crop alternatives without incurring the capital costs of individual well development. Pumping and access costs are probably similar to onfarm-supplied ground water, but producers pay a higher price because of overhead and water delivery losses.

Table 2.1.5—Supply sources and variable costs of irrigation water, 1994[1]

Water	Acres irrigated	Share of acres irrigated[2]	Average cost[2]	Cost range[2]	Comments
	Million	*Percent*	*$/acre*	*$/acre*	
Ground water			34[3]	11-744	Pumping cost varies with energy prices and depth to water.
Only source[5]	22.5	49			
Combined sources	6.3	14			
Onfarm surface water			n/a	0-15[6]	Costs are very low in most cases. Some water is pumped from surface sources at higher costs, since energy is required.
Only source	3.7	8			
Combined sources	2.2	5			
Off-farm surface water[7]			36[8]	13-78[9]	Most acres relying on off-farm sources are located in the West.
Only source	8.9	18			
Combined sources	5.0	11			
Total			n/a	n/a	The sum of acres is greater than the irrigated total in the Farm and Ranch Irrigation Survey due to double counting of combined water sources.
Only source	35.1	76			
Combined sources	13.5	29			

n/a indicates no data available.
[1] These values include only energy costs for pumping or purchased water costs. Management costs and labor costs associated with irrigation decisions, system maintenance, and water distribution are not included. [2] Available data are from the 1994 Farm and Ranch Irrigation Survey. [3] Reported national average energy expense for the onfarm pumping of irrigation water. [4] Range in State energy expenses for onfarm pumping of irrigation water. [5] Only source means that farms used no other irrigation water source. [6] Cost estimates based on engineering formulas with an efficient electric system. [7] Includes a minor amount of ground water supplied from off-farm suppliers. [8] Reported average cost for off-farm supplies. [9] Range is the average cost reported from off-farm suppliers for States irrigating 50,000 or more acres from off-farm sources. If all States are included, the range expands to $1 - $78 per acre.
Source: USDA, ERS, based on USDC, Farm and Ranch Irrigation Surveys.

Surface-Water Costs

Surface water from rivers, streams, and lakes supplied almost 20 million irrigated acres in 1994 (table 2.1.5). Onfarm surface water supplied about 6 million acres, including 3.7 million acres as the sole source. Off-farm water supplies provided all the water for about 9 million acres, and part of the supply for an additional 5 million acres. Water supplied by off-farm water suppliers is largely from surface-water sources (over 95 percent).

Onfarm surface-water sources provide all or part of the water needs for over 35,000 farms nationwide. Lands irrigated with onfarm surface water are concentrated in Montana, California, Oregon, Wyoming, and Colorado. Costs of onfarm surface water are likely the lowest on average, although little supporting data are available. In most cases, water is conveyed relatively short distances to the field by means of gravity, with costs limited to ditch establishment, maintenance, and repair. Where gravity conveyance is not possible due to topography or levees, water must be pumped. However, pumping costs are generally lower than groundwater pumping costs since the vertical lift is not as high.

Off-farm water suppliers provided water to about 85,000 farms nationwide. Seventy percent of the acres partially or totally supplied from off-farm sources are located in just six States—California, Idaho, Colorado, Montana, Washington, and Wyoming. These States account for more than two-thirds of the acres depending on off-farm water as the only water source.

Several types of organizations have been established to convey and deliver irrigation water from off-farm sources to irrigators.[9] Almost all are nonprofit

[9] See section 2.1, USDA, ERS, 1994 (AREI) for more information on types of irrigation organizations.

entities with a goal of dependable water service at low cost. In 1994, irrigators reported an average cost of water from off-farm sources of almost $36 per acre irrigated, or an estimated $16 per acre-foot (table 2.1.5). Pricing is often based on acreage served rather than water delivered, since administrative costs are lower with land-based charges. Under a land-based payment system, producers generally pay a fixed cost per acre and receive a specified water allotment. With this pricing system, producers have little financial incentive to conserve since charges are assessed regardless of the amount of the water allotment used.

Water Costs on Federal Projects

Since passage of the Reclamation Act of 1902, the Federal Government has had an important role in the development and distribution of agricultural water supplies in the West. Primary responsibility for construction and management of Federal water supply projects has resided with the U.S. Department of the Interior, Bureau of Reclamation (BOR). Today, the BOR serves as a water "wholesaler" for about 25 percent of the West's irrigated acres—collecting, storing, and conveying water to local irrigation districts and incorporated mutual water companies that, in turn, serve irrigators. Water delivery quantities and prices are usually specified under long-term (25-50 year) contracts between BOR and irrigation delivery organizations. New demands on water for urban growth and environmental restoration have focused attention on issues such as the recovery of irrigation subsidies and economic efficiency through water pricing.

The 1902 legislation emphasized Western settlement rather than a full market return for Federal water projects, and most water projects were subsidized. The subsidy stems primarily from Congressional actions authorizing the Reclamation program to (1) allow long-term repayment of construction loans to irrigators with no interest, and (2) shift irrigation-related costs that are above producers' "ability to pay" to other project beneficiaries. These subsidies have reduced the cost of irrigation water to both the delivery organization and irrigators. The degree to which subsidies have influenced water allocations and economic efficiency, both within agriculture and across sectors, varies across projects. Factors include magnitude of the subsidy, availability of water from alternative sources, profitability of cropping alternatives, and water demands from other sectors.

The Reclamation program has constructed 133 projects that provide irrigation water, spending $21.8 billion from 1902 through 1994. Of the total construction expenditures, $16.9 billion is considered reimbursable to the Federal Treasury. Reimbursable construction costs are those associated with hydroelectric power production and water-supply development for irrigation, municipal, and industrial use. Non-reimbursable construction costs are those allocated to flood control, recreation, dam safety, fish and wildlife purposes, and other uses that are national in scope. Irrigation has been allocated $7.1 billion of the reimbursable construction costs, with no interest costs considered. Of the $7.1 billion allocated to irrigation, $3.7 billion of the costs (53 percent) were determined to exceed irrigation's "ability to pay" and have been either shifted to other sectors ($3.4 billion) or relieved by congressional action ($0.3 billion) (GAO, 1996).

Considerable debate has focused on the issue of recovering some portion of the irrigation subsidy associated with past project construction. Critics contend that the current program seems inconsistent with Federal spending and equity goals because irrigators (1) continue to repay loans without interest and (2) shift costs to other sectors based on "ability-to-pay" provisions.[10] Additionally, some subsidies continue in the form of reduced electric power rates for irrigators in Federal projects and interest-free construction loans for the few projects still under construction. Proponents argue that subsidies associated with irrigation water delivery must be placed in an historic context that considers the goals of the Reclamation program established by Congress. They contend that the historic construction subsidy program reflected the intent of Congress and has effectively met program objectives. They also point to equity concerns in trying to recover subsidies from individuals who may not have directly benefited. In many cases, the value of the water subsidy has been capitalized into the value of the land; the original owner of the land received the subsidy, not subsequent owners who payed a higher price for the land because it had access to lower-cost water. Potential impacts on rural communities are also a major concern. While the discussion continues, the basic structure of the cost-repayment and cost-allocation system remains in effect after several congressional debates.

[10] Historically, the ability-to-pay calculations were made prior to construction based on projected profitability of a small-farm operation. The BOR is now requiring that all new, renewed, and amended contracts recompute ability-to-pay every 5 years.

Rising water demands for urban and environmental purposes have prompted discussions on how to more accurately reflect the opportunity costs of water in prices paid by irrigators. There are several options for States (and the BOR in some cases) to modify irrigation water price or quantity allocations to more accurately reflect scarcity value of water and to improve benefits derived from this important resource. Water-pricing reform, voluntary water transfers or markets, and water-quantity restrictions could all be used to achieve the same goals. One major limitation to both water-pricing reform and water-quantity restrictions is the need for intensive administrative control and oversight. Voluntary water markets require less administrative control and are allowed by most Western States; however, transactions costs are high in some locations, and institutional rigidities may limit water movement. The BOR can encourage the establishment of water markets by: (1) developing standard language on water marketing in all BOR contracts with water delivery organizations; (2) considering removal of restrictions on changes in location and type of water use, since most Western States already require this as a precondition to transfer; (3) clarifying who receives the increased income from the water sale or lease; and (4) reducing uncertainty regarding the effect of transfers on current contracts, contract water quantities, and procedures for assessing environmental benefits and costs (Mecham and Simon, 1995).

Recent legislation involving the Central Valley Project (CVP) in California—the BOR's largest project—establishes an important legislative precedent for the pricing, allocation, and transfer of Federal water supplies. Provisions of the law increase water prices for renewed contracts, implement tiered water-pricing schedules (higher per-unit rates for higher usage), and reallocate some water for environmental purposes. In addition, the legislation removed important barriers to water market transfers, thus allowing water to move both within and off the project areas to satisfy higher valued demands. CVP reforms may guide future BOR efforts in promoting water conservation and increasing economic returns from water use on other federally financed projects.

A recently completed study by the National Research Council (1996) concludes that irrigated agriculture is likely to remain an important sector, both in terms of the value of agricultural production and demand on land and water resources. However, changes in the irrigation sector are anticipated in response to increasing water demands for urban and environmental uses, and changing institutions governing farm programs and water allocations. Water dedicated to agricultural production will likely decline, with at least some portion shifted to satisfy environmental goals.

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Glossary of Water Use Terms

Acre-foot—A volume of water covering an acre of land to a depth of 1 foot, or 325,851 gallons.

Consumptive use—Amount of water lost to the immediate water environment through evaporation, plant transpiration, incorporation in products or crops, or consumption by humans and livestock.

Ground water—Generally all subsurface water as opposed to surface water. Specifically, water from the saturated subsurface zone (zone where all spaces between soil or rock particles are filled with water).

Industrial withdrawals/use (other than thermoelectric)—Includes the water withdrawn/consumptively used in facilities that manufacture products (including use for processing, washing, and cooling) and in mining (including use for dewatering and milling).

Irrigation withdrawals/use—Includes the water withdrawn/consumptively used in artificially applying water to farm and horticultural crops. Some data sources include water to irrigate recreational areas such as parks and golf courses.

Loss—Water that is lost to the supply, at the point of measurement, from a nonproductive use, including evaporation from surface-water bodies and nonrecoverable deep percolation.

Overdrafting—Withdrawing ground water at a rate greater than aquifer recharge, resulting in lowering of groundwater levels. Also referred to as aquifer mining.

Public and rural domestic withdrawals/use—Includes the water withdrawn/consumptively used by public and private water suppliers and by self-supplied domestic water users.

Recharge—The percolation of water from the surface into a groundwater aquifer. The water source can be precipitation, surface water, or irrigation.

Return flow—Water that reaches a surface-water source after release from the point of use, and thus becomes available for use again.

Surface water—An open body of water such as a stream, river, or lake.

Thermoelectric withdrawals/use—Includes the water withdrawn/consumptively used in the generation of electric power with fossil-fuel, nuclear, or geothermal energy.

Irrigation water application—The depth of water applied to the field. Irrigation application quantities differ from irrigation withdrawals by the quantity of conveyance losses.

Withdrawal—Amount of water diverted from a surface-water source or extracted from a groundwater source.

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Instream Water Flows

Increased demand for instream water flows have intensified competition for limited water supplies in many areas. Water historically withdrawn for consumptive use in irrigation and municipal sectors, or impounded for navigation and hydropower generation, is finding a new "use" as instream flows for recreational and environmental purposes. Instream flow requirements are increasingly guaranteed through legislatively mandated transfers, and in some cases, direct market purchases.

Recreation. Demand for water-based recreation has generally increased over time with expanding populations, leisure time, and disposable income. While water demanded for recreation is difficult to quantify due to the multi-use nature of recreational waters, the increase in participation provides an indicator of the increased demand for water-based recreation activities. The number of adults participating in boating activities nationally—including sailing, motor boating, water skiing, and canoeing—has expanded from 49.5 to 60.1 million (21 percent) since 1982 (Forest Service and others, 1995). Swimming in natural water bodies has increased from 56.5 to 78.1 million persons (38 percent) over the same period. Fishing activity has declined 3 percent, from 60.1 to 58.3 million persons.

Wildlife habitat. Wildlife, including but not limited to endangered species, often competes with out-of-stream uses for water resources. Many wildlife communities and their habitats—aquatic, riparian, wetland, and estuarine—depend on water. Efforts to protect wildlife and habitat may involve restrictions on water withdrawals, timing of deliveries, lake storage levels, and drainage flows. Instream flow restrictions to protect wildlife habitat has important implications for irrigated production and farm income. The responsibility of private water developments located on public lands to provide water for downstream fish and wildlife habitat is being "reexamined" through Section 389 of the 1996 Farm Act, which requires a Water Rights Task Force. The task force will study the issue of water rights for environmental protection on national forest land, the protection of minimum instream flows, and the protection of water rights that involve facilities on Forest Service lands.

Endangered species. Aquatic plant and animal species, and other predatory species that depend on healthy aquatic systems, may be highly sensitive to changes in instream water conditions. There are currently 663 species nationwide listed as "threatened" or "endangered" under the Federal Endangered Species Act (ESA). Current species listings specify various water flow-related reasons for species decline, potentially related to irrigation. These include water diversion/drawdown (141 species), water-level fluctuation (82 species), water-level stabilization (26 species), water temperature alteration (61 species), reservoirs (103 species), groundwater drawdown (71 species), and salinity alteration (14 species) (computed from data supplied by Biodata Inc., Golden, CO, 1995).

The restoration of aquatic and riverine ecosystems to protect and recover endangered species has emerged as one of the most critical agricultural water-supply issues of the 1990's. Many of the current conflicts involve allocation of surface-water flows in western river systems. This reflects various factors particular to the West—the unique biota of many western river systems; the scarcity of renewable water supplies in an arid environment; and the nature of water demands based on the concentration of irrigated production and rapid urban growth. However, conflicts involving wildlife and agriculture are not limited to surface water, and are no longer limited to the arid Western States.

Examples of instream flow competition. In the Pacific Northwest, a major Federal/State effort is underway to restore declining native salmon stocks of the Columbia-Snake River Basin, including three stocks listed under the ESA. Hydropower generation, irrigation diversions, land-use activities (logging, mining, and grazing), and fish harvesting have all contributed to the decline through extensive loss and degradation of salmon habitat. Increasing instream flow velocities to assist migrating salmon—through reservoir drawdown along the lower Snake River (Washington/Oregon) and reduced irrigation diversions in the upper Snake River (Idaho/Oregon)—represents a major element of recovery strategies under consideration (Aillery and others, 1996).

In California's San Francisco Bay/San Joaquin-Sacramento River Delta (Bay/Delta) area, efforts are underway to manage flows to restore endangered fish species and federally protected migratory waterfowl. The Bay/Delta region is important, both as a pumping/transfer point for agricultural and urban water supplies for much of central and southern California and as a natural site of ecological significance. Increased freshwater outflows from the Bay/Delta, linked to salinity standards, are being used to improve estuarine habitat. The higher water outflows translate into reduced water supplies for agriculture. Additionally, adjustments in river management to improve species protection are limiting the timing of withdrawals for agricultural purposes. Progress on solutions is being made through Federal, State and local cooperation (McClurg, 1996).

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Instream Water Flows (cont.)

The Edwards Aquifer region of south-central Texas illustrates the interaction between ground water and species protection. Extensive groundwater pumping for agricultural and urban uses contributes to annual declines in the aquifer water level, which reduces flows from aquifer-fed springs that support habitat for endangered aquatic species. The situation is compounded by the nature of the aquifer, which has high recharge from precipitation, and is therefore susceptible to the vagaries of weather and drought. Potential restrictions on groundwater use in the region to ensure minimum spring flows would impact irrigated agriculture (Baldwin and others, 1993 and Collinge and others, 1993).

In South Florida, extensive water-control infrastructure and management has severely altered the natural hydrologic cycle, contributing to the declining productivity of the natural ecosystem (Finkl, 1995). Wetland conversion for agricultural and urban uses has substantially reduced available wetlands for wildlife habitat and other environmental uses. Of the remaining wetlands, large areas are seriously degraded due to disruptions in the quantity, timing, and distribution of flows to meet water-supply and flood-control purposes. In addition, land-use activities have contributed to impaired water quality in some areas. A major effort is underway at the Federal and State level to restore natural hydrologic functions, to the extent practicable, while meeting water-supply and flood-control objectives for agriculture and an expanding urban sector (SFWMD, 1995).

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Recent ERS Research on Water Issues

Irrigation Water Use, 1994, AREI Update, 1996, No. 8 (Noel Gollehon and Marcel Aillery). This update presents State-level information on water sources (onfarm wells, onfarm surface, and off-farm surface) and irrigated acres by crop based on the 1994 Farm and Ranch Irrigation Survey.

Water Supplies, AREI Update, 1996, No. 3 (Noel Gollehon and Marcel Aillery). This look at the 1996 spring water supply forecasts and conditions highlights the drought area in the Southwest and Southern Plains, near- to above-normal irrigation supplies in the West, and adequate subsoil moisture conditions in the East.

Salmon Recovery in the Pacific Northwest: Agricultural and Other Economic Effects, AER-727, Feb. 1996 (Marcel Aillery, Paul Bertels, Joseph Cooper, Michael Moore, Steve Vogel, and Marca Weinberg). The agricultural effects of two proposed Snake River management measures—reservoir drawdown on the lower Snake and reductions in irrigation water supplies in the upper Snake—considered to recover three salmon runs are analyzed. For the Northwest region, adjustments in crop production could lower producer profit by $4-$35 million annually (less than 3 percent of the 1987 baseline), depending on specific alternatives.

Economic Analysis of Selected Water Policy Options for the Pacific Northwest, AER-720, June 1995 (Glenn Schaible, Noel Gollehon, Mark Kramer, Marcel Aillery, and Michael Moore). Irrigated agriculture in the Pacific Northwest could use significantly less water with minimal impact on agricultural economic returns. Net water savings for field crops of up to 18 percent of current use levels could be realized with less than a 2-percent decline in economic returns. Combining different approaches spreads the conservation burden among farmers, water suppliers, and production regions.

"**Multicrop Production Decisions in Western Irrigated Agriculture: The Role of Water Price**," ***American Journal of Agricultural Economics***, 76:859-874, Nov. 1994 (Michael Moore, Noel Gollehon, and Marc Carey). Econometric estimates of water demand and irrigated crop supply functions for four regions of the West provide the statistical base for this analysis. The analysis examined irrigator response to shortrun water price change, measured as increases in groundwater pumping cost. Findings suggest that irrigators respond primarily at the extensive margin—changing the acres devoted to specific crops—rather than at the intensive margin—changing the quantity of water applied during the irrigation season.

"**Alternative Models of Input Allocation in Multicrop Systems: Irrigation Water in the Central Plains**," ***Agricultural Economics***, 11:143-158, Dec. 1994 (Michael Moore, Noel Gollehon, and Marc Carey). This analysis compared different farm-level models of irrigation decisionmaking on farms with multiple crops in the Central Plains region. Water was modeled three ways: as a variable input, an input used without regard for price, and a fixed-allocatable input. The model considering water a fixed-allocatable input dominated the other models in both model specification tests and prediction accuracy measures.

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