2.1 Water Use and Pricing in Agriculture

Irrigated agriculture remains the dominant use of freshwater in the United States, although the share of water consumed by irrigation is declining. National irrigated cropland area has expanded by one-third since 1969, while irrigation water application rates have declined by about 15 percent. Water pricing policy as a mechanism for adjusting agricultural water demand must consider the unique linkages among water prices, water availability, and water suppliers.

The United States, as a whole, has adequate water supplies. Annual renewable supplies in surface streams and aquifers total roughly 1,500 million acre-feet per year (maf/yr).[1] Of total renewable supplies, only one-quarter is withdrawn for use in homes, farms, and industry, and just 7 percent is consumptively used (Moody, 1993).[2] Renewable surface and groundwater supplies account for roughly 90 percent of total water use nationwide. The remainder comes from depletion of stored ground water (Foxworthy and Moody, 1986).

Because the Nation's water resources and supply needs are not distributed evenly, an abundance in the aggregate belies the fact that water supplies are becoming increasingly limited in many areas. In the Colorado River Basin, 96 percent of the annual renewable supply is consumptively used before the river flows into Mexico. Comparatively high consumptive use rates of renewable supplies characterize the Rio Grande Basin (64 percent) and the Great Basin (49 percent) (Foxworthy and Moody, 1986). In contrast, the New England and Tennessee Water Resource Regions consumptively use less than 1 percent of renewable supplies, while the Pacific Northwest Region uses just 4 percent.

Water needs continue to evolve over time. Urban growth in arid areas of the Southwest and far West have greatly expanded municipal water needs. At the same time, competition for water supplies is increasing from instream (nonconsumptive) water uses for recreation, riparian habitat, and other environmental purposes. The impact of increased instream flow demands is just now being assessed. While water needs for instream uses are difficult to quantify, the potential demands on existing water supplies are large and geographically diverse. Instream demands include enhanced river flows for recovery of threatened salmon stocks in the Columbia-Snake river basin (see box, "Salmon Recovery in the Columbia-Snake River Basin"); groundwater pumping restrictions to protect natural springs in central Texas; mandatory allocations of Federal project water for fish and wildlife purposes in California's Central Valley Project; and the purchase of water rights by private and government organizations to ensure minimum flows in Nevada's Stillwater National Wildlife Refuge.[3]

Rising demands in water-deficit areas were historically met by expanding water supplies. Dam construction, interbasin conveyance facilities, and groundwater pumping have provided much of the water to meet growing urban and agricultural needs. However, new opportunities for large-scale supply enhancement are limited due to lack of suitable project sites, tightened fiscal constraints, and increased public concern for environmental consequences.[4] Depletion of groundwater stocks has further limited development in many areas. Consequently, expanding demands will require at least some reallocation of existing supplies. And since agriculture is the largest water user, emerging municipal and instream water demands will likely result in reduced supplies for agriculture.

Changes in agricultural water availability will affect irrigated production and rural communities. In 1987, 292,000 farms irrigated crop and pasture land. Irrigated agriculture is an important part of the U.S. cropland sector, contributing 38 percent of the total value of crops on just 15 percent of total cropland harvested. Irrigated acreage as a share of total acreage is most significant for rice (100 percent), orchards (81 percent), vegetables (64 percent), and

[1] An acre-foot is a volume of water covering an acre of land to a depth of 1 foot, or 325,851 gallons.

[2] Uses considered here include only consumptive uses occurring after water is withdrawn from a river or aquifer. Instream water use for hydroelectric production, recreation, or aquatic and riparian habitat is not included.

[3] Quantification of Federal reserved water rights—including treaty obligations on Native American lands—could substantially alter water allocations in the West, although the net effect on water use across sectors is uncertain.

[4] Research continues on practices and technologies to augment supplies, including cloud seeding, runoff management, groundwater recharge, water reuse, and desalination.

Salmon Recovery in the Columbia-Snake River Basin

The restoration of aquatic and riverine ecosystems in the West has emerged as one of the most critical water-supply issues of the 1990's. Perhaps nowhere is the debate over ecosystem impacts of traditional river allocations more pitched than in the Pacific Northwest, where native salmon stocks have decreased dramatically. Salmon and steelhead populations have fallen to less than 20 percent of the estimated 10-16 million spawning adults per year prior to basin development, with wild, naturally spawning salmon at just 2 percent of historical levels. Hydropower generation, irrigation diversions, and land-use activities, such as logging, mining, and grazing, have all contributed to the decline through loss and degradation of habitat. Extensive fish harvesting for commercial, recreational, and subsistence purposes has further reduced salmon stocks.

The Federal response to declining salmon resources in the Columbia River Basin is centered on two legislative mandates. The Pacific Northwest Electric Power Planning and Conservation Act (1980) requires that wildlife needs be treated equally with other river management objectives and called for a comprehensive regional restoration plan to protect the Columbia Basin fishery. More recently, the invoking of the Endangered Species Act (ESA) set in motion the development of a plan to recover species threatened with extinction. Since 1991, three Snake River salmon runs have been formally listed under the ESA as endangered, with additional runs currently under consideration.

Modifying traditional flow regimes to assist migrating juvenile salmon in the Columbia River Basin represents a major element of recovery strategies under discussion. Proposals call for higher river velocities during the spring and early summer via some combination of flow augmentation in the Upper Snake River Basin and reservoir drawdown along the Lower Snake. Upper Snake flow augmentation may be achieved through increased dam storage releases as well as reductions in river diversions for irrigation.

Modified flow regimes would affect regional agricultural output and producer income through adjustments in farm input costs and water availability. Reduced Snake River diversions may have significant impacts in southern Idaho and eastern Oregon, where crop production is heavily dependent on irrigation. Drawdown of Lower Snake reservoirs to below minimum operating levels for navigation would affect inland barging of wheat and barley in eastern Washington and northern Idaho. Pumpstation modifications may be required along the Lower Snake to maintain irrigated production during drawdown periods. Electrical energy costs for all uses, including irrigation pumping, would likely increase over much of the Northwest as flow regimes managed for hydropower production are modified to accommodate salmon.

Impacts of salmon recovery on the agricultural sector—and the larger regional economy—will depend on the specific measures implemented, the mitigating effects of input and output substitution, and the levels of compensation provided. For more information, see the USDA-ERS report by Aillery, et al., *Salmon Recovery in the Pacific Northwest: A Summary of Agricultural and Other Economic Effects* (AIB-699).

cotton (36 percent), with the largest total irrigated acreages in hay, corn for grain, wheat, and cotton (see box, "Irrigation and Water Data", p. 56).

Water Use

Water use is typically measured in terms of *withdrawals* or *consumptive use*. Withdrawals represent the amount of water diverted from a surface source or removed from the ground. Consumptive use is a measure of water lost to the immediate water environment through evaporation, plant transpiration, incorporation in products or crops, or consumption by humans and livestock. Consumptive use in agriculture is primarily crop evapotranspiration, which is heavily influenced by climate, crops irrigated, and yield. The difference between water withdrawals and consumptive use is water losses and return flow.

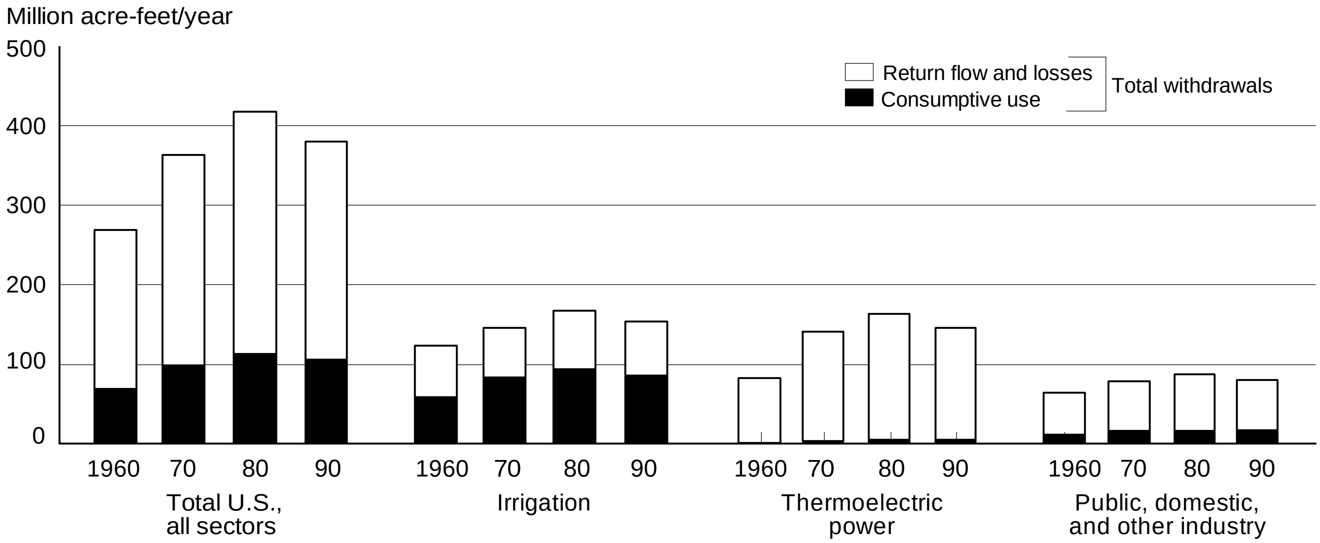
Withdrawals

Total freshwater withdrawals from surface and groundwater sources totaled 380 maf in 1990 (fig. 2.1.1). Major use categories include irrigation (153 maf), thermoelectric (146 maf), public and rural supplies (52 maf), and other industries (28 maf) (Solley, Pierce, and Perlman, 1993).

Irrigation withdrawals as a share of U.S. freshwater withdrawals declined from 46 percent in 1960 to 40 percent in 1990.[5] Public and rural domestic water withdrawals increased by almost 90 percent over the 1960-90 period, reflecting expanding urbanization and

[5] Irrigation in the estimates by Solley, Pierce, and Perlman is primarily agricultural irrigation (cropland and pastureland), but irrigation of recreational areas (parks and golf courses) is also included.

Figure 2.1.1
Water withdrawals and consumptive use, 1960-90



Source: Solley, Pierce, and Perlman, 1993.

a 40-percent increase in U.S. population. Thermoelectric energy withdrawals climbed by 77 percent over the same period, although levels declined through the 1980's.

Most of the 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. The top 20 irrigation States accounted for 97 percent of U.S. irrigation withdrawals (table 2.1.1). 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. States with the highest share of surface-water withdrawals include Montana, Wyoming, Oregon, Washington, and Utah. Approximately 32 percent of surface-water deliveries—or 20 percent of total irrigation withdrawals—is provided by the Federal Bureau of Reclamation (BoR). States with the largest total BoR deliveries were Idaho, California, and Washington. The BoR's share of total irrigation withdrawals was highest in Washington, Idaho, Arizona, and Oregon. Shares of irrigation withdrawals from surface-water sources vary from year to year depending on surface runoff and water stored in reservoirs. Surface-water availability in 1990 was below normal in much of the West.[6]

Ground water is the primary supply source for irrigation in about half of the States in table 2.1.1. Ground water is withdrawn with pumps 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. Irrigated agriculture has contributed to declining aquifers in many areas relying heavily on ground water (see box, "Groundwater Overdrafting", p. 54).

Consumptive Use

Consumptive use of fresh water in the United States totaled about 105 maf in 1990 (fig. 2.1.1). Irrigation, the dominant consumptive water use, accounted for 85 maf or 81 percent of the U.S. total. Consumptive use as a percentage of withdrawals was 56 percent for irrigation, compared with 17 percent for public and rural supplies, 16 percent for industries other than thermoelectric, and just 3 percent for thermoelectric power.

[6] Drought can also sharply focus the issue of adequate freshwater supplies in a region. For example, the California drought was in part responsible for legislation allowing sales of federally developed agricultural water to urban areas.

Table 2.1.1—Irrigation water withdrawals and consumptive use, major irrigation States, 1990

State[2]	Withdrawals[1]				Consumptive use[1]	
	Irrigation total	Surface water-- Bureau of Reclamation	Surface water-- Private suppliers	Ground water, all suppliers	Irrigation total	Irrigation's share of total consumptive use
	maf [3]	*-- Percent of irrigation water withdrawn --*			*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.

Source: Solley, Pierce, and Perlman, 1993.

Consumptive water use for irrigation increased by about 60 percent between 1960 and 1980, reflecting rapid expansion in western irrigated area. Irrigation water use has declined from 1975-80 levels, despite continued growth in irrigated acreage nationwide. Reduced water consumption per irrigated acre reflects lower irrigation water applications in humid irrigated areas, a shift to less water-intensive crops, and a reduction in irrigated cropland in some of the highest water-using areas.[7]

Irrigation's share of total consumptive water use fell by roughly 4 percent over the 1960-90 period. A 4-percent share of the 1990 total irrigation consumptive 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 supply-enhancement opportunities, may be met by relatively small shifts in national irrigation water use. However, small national shifts may mean large adjustments in regional and local irrigated activity.

Regionally, irrigation water consumption ranged from 0.2 maf in Appalachia to 21.8 maf in the Southern Pacific (fig. 2.1.2). Irrigation's share of total regional water use is highest in the Northern Mountain region (97 percent), followed by the Northern and Southern Pacific (93 percent) and the Northern Plains (91 percent).

[7] Reduced irrigation system losses from improved water conveyance and field application efficiency reduce withdrawals but not consumptive use.

Irrigation consumptive use in the 20 major irrigation States accounted for 96 percent of the national total of 85 maf. California had 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, five—Arkansas, Florida, Mississippi, Louisiana, and Georgia—are in humid areas where irrigation supplements usually adequate precipitation.

Irrigated Land in Farms

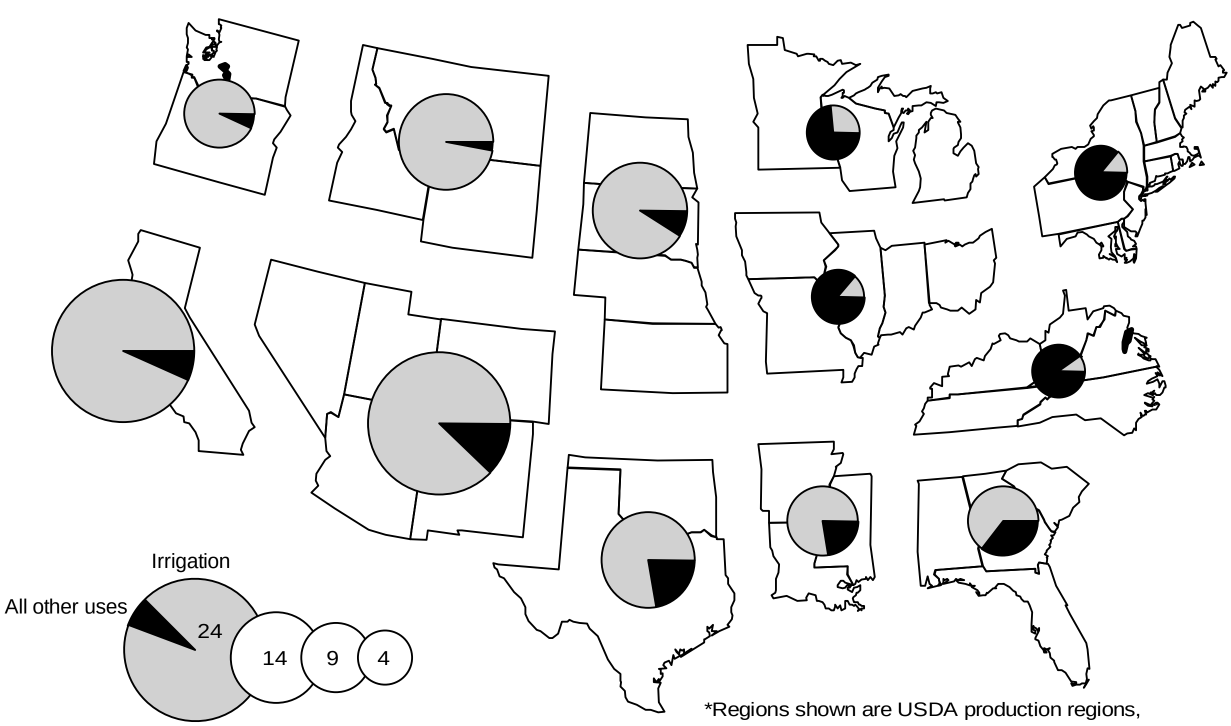
National irrigated cropland expanded rapidly from 38 million acres in 1972 to 52 million acres in 1981 (fig. 2.1.3). After sharp declines from 1981 to 1983 and from 1985 to 1987, irrigated area has resumed growth. A preliminary forecast based on normal summer precipitation suggests that 52 million acres have been irrigated in 1994 (table 2.1.2).

Western irrigation reached its peak with the agricultural export boom of the 1970's. Southwest irrigated area is now in a declining trend. In the Atlantic, North Central, Delta, and Northern Plains regions, irrigated acreage has increased from 9 to 22 million acres since 1969. Much of this development followed improvements in center-pivot technology (see box, "Irrigated Acreage: A Historical Perspective," p. 55).

As of June 1994, returns from the 1992 Census of Agriculture were available for 25 States (table 2.1.3). Irrigated area in 16 States increased over 1987, with 4 Corn Belt States experiencing gains of 25 percent or more. Significant drops in irrigated area occurred in the Northeastern States.

Irrigated area varies considerably from year to year. Annual estimates for 1969-94 (fig. 2.1.3) reflect the importance of the three most influential factors: crop prices, annual commodity program acreage restrictions, and weather. Relaxed program acreage restrictions and high crop prices in the 1970's accelerated irrigation development, increasing total irrigated area from 38 million acres in 1972 to 52 million acres in 1981. The effect of acreage restrictions under annual commodity programs was most pronounced when irrigated area dipped in 1983 and 1987.

Figure 2.1.2
Water consumption in irrigation and others uses, 1990, by region*



Value and corresponding circle size represent the upper range of consumptive use in million acre-feet.

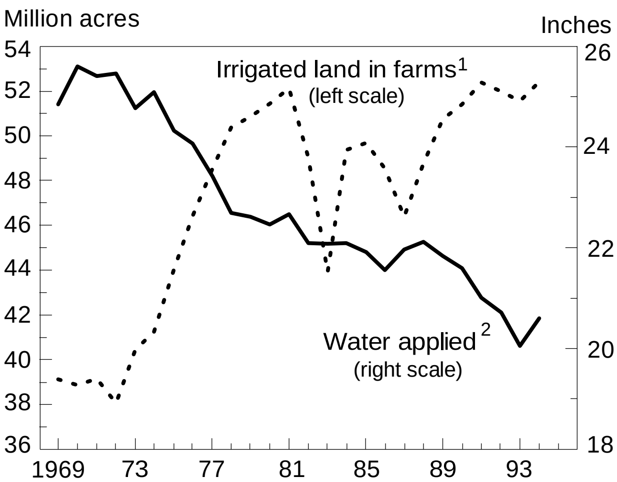
*Regions shown are USDA production regions, with the Pacific and Mountain regions divided into a northern and southern portion to highlight differences in water use.

Source: Solley, Pierce, and Perlman, 1993.

Irrigation in 1993-94

Weather is often an important factor in irrigation, but seldom has it had as much effect on regional irrigated area as in 1993. A drought in the Southeast was almost overlooked in a year that saw an important break in the Southwest drought and excessive rains in the Northern Plains and North Central States. Farmers reduced irrigation in the upper Mississippi and Missouri basins due to heavy spring and summer precipitation. Summer precipitation was twice the normal levels for much of the area, amounting to 25 inches or more in eastern Iowa. Both irrigated area and water use per acre were noticeably reduced.

Figure 2.1.3
Irrigation trends, 1969-94



[1] For detail on data and assumptions see table 2.1.2
[2] For detail on data and assumptions see table 2.1.4

Source: USDA, ERS data.

A perception that the Southwest drought was over in 1993 may have been premature. Critical winter precipitation has flipped from one of the wettest winters on record in 1993 to one of the driest in 1994. Irrigated area in the Southwest continued its decline into 1994 as available water supplies were used to replenish reservoir levels. Irrigation would normally have increased from 1989 to 1993, as mandatory acreage reductions for cotton, rice, and other crops were reduced. Instead, California irrigated acreage declined almost 1 million acres. High demand for urban uses and pressures to reallocate surface waters for environmental purposes may signal continued decline in irrigated area.

Table 2.1.2—Irrigated land in farms, 1889-1994, by region and crop

Region	1889[1,2]	1949[1]	1969[1]	1974[1]	1978[1]	1982[1]	1987[1]	1992[3]	1993[3]	1994[4]
					Thousand acres					
USDA production region:										
Atlantic[5]	-	500	1,800	2,000	2,900	2,700	3,000	3,500	3,600	3,700
North Central[6]	-	-	500	600	1,400	1,700	2,000	2,600	2,400	2,700
Northern Plains	-	1,100	4,600	6,200	8,800	9,300	8,700	10,200	9,800	10,300
Delta States	-	1,000	1,900	1,800	2,700	3,100	3,700	5,400	5,200	5,300
Southern Plains	-	3,200	7,400	7,100	7,500	6,100	4,700	5,300	5,500	5,300
Mountain States	2,300	11,600	12,800	12,700	14,800	14,100	13,300	13,600	13,900	14,300
Pacific Coast	1,200	8,300	10,000	10,600	12,000	11,900	10,800	10,500	10,100	10,300
United States[7]	3,600	25,800	39,100	41,200	50,400	49,000	46,400	51,300	50,600	52,000
Crop:										
Corn for grain	NA	NA	3,300	5,600	8,700	8,500	8,000	10,300	9,800	10,600
Wheat	NA	NA	2,000	3,300	3,000	4,600	3,700	4,100	3,900	3,900
Rice	NA	NA	2,200	2,600	3,000	3,200	2,400	3,500	3,100	3,400
Soybeans	NA	NA	700	500	1,300	2,300	2,600	3,100	3,200	3,200
Cotton	NA	NA	3,100	3,700	4,700	3,400	3,500	3,700	4,400	4,300
Hay	NA	NA	7,900	8,000	8,900	8,500	8,600	8,400	8,600	8,900

- indicates < 50,000 acres. NA = Not applicable.

[1] Census of Agriculture.

[2] Excludes rice, which was grown on 342,000 acres in South Atlantic and Gulf States in 1899.

[3] Preliminary estimates constructed from unpublished USDA sources and the Census. Partial returns from 1992 Census were incorporated.

[4] Forecast based on March Planting Intentions (NASS).

[5] Northeast, Appalachian, and Southeast farm production regions.

[6] Lake States and Corn Belt production regions. Remaining regions correspond to single farm production regions.

[7] Includes Alaska and Hawaii.

Source: USDA, ERS data.

Irrigation Water Applications

On average, irrigators apply almost 2 feet of water on each irrigated acre through the crop growing season (table 2.1.4). These rates vary from a half foot in some Eastern States to as much as 4 feet in the Southwest. There is no direct annual measure of irrigation water applications, but 5 years of census and post-census survey data suggest some trends. The east-west contrast in application rates has narrowed, with Atlantic States using almost twice as much water per acre in 1988 as in 1969. Despite increasing application rates in the East, national average application rates (fig. 2.1.3), as well as application rates for several major crops, have declined.

Table 2.1.3—Irrigated area, 1992 Census of Agriculture

State	1987	1992	Change
	1,000 acres		*Percent*
Colorado	3,014	3,170	5
Connecticut	7	6	-19
Delaware	61	62	2
Florida	1,623	1,783	10
Idaho	3,219	3,260	1
Illinois	208	328	58
Indiana	170	241	42
Iowa	92	116	25
Kansas	2,463	2,680	9
Maine	6	10	69
Maryland	51	57	12
Massachusetts	20	20	-1
Michigan	315	368	17
Missouri	535	709	33
New Hampshire	3	2	-41
New Jersey	91	80	-12
Ohio	32	29	-9
Oregon	1,648	1,622	-2
Rhode Island	3	3	-15
Vermont	2	2	16
Virginia	79	62	-22
Washington	1,519	1,641	8
West Virginia	3	3	-12
Wisconsin	285	331	16
Wyoming	1,518	1,465	-4
Total, 25 States	16,967	18,050	6

Note: The table includes 1992 data on States released by the Bureau of the Census by June 20, 1994.

Source: USDC, 1994.

Year-to-year variations in application rates are due to weather and other factors. In arid climates, precipitation changes are compensated for in water application rates and indirectly influence area irrigated as water supplies are affected. In humid climates, precipitation has a greater effect on irrigated area. Farmers respond to above-average rainfall in humid areas by cutting back on irrigated area of most crops.

Irrigation Water Prices and Costs

Prices of most agricultural inputs are established in markets, where prices indicate relative scarcity through supply and demand. An input in short supply is more costly, thus encouraging more efficient use and reduced consumption. In contrast, irrigation water prices are not set in a market. Water prices usually reflect only the cost of supplying water and generally do not convey market signals.

In general, water resources are publicly owned and administered at the State level. Water is typically "free" in the sense that most users do not compensate the State for its use. Water costs are usually limited to expenses associated with providing the resource—including access, storage, conveyance, and field distribution. Conveyance and distribution costs vary by supplier (onfarm or off-farm), water source (surface or ground water), and field distribution system. Irrigation water costs vary widely (table 2.1.5), reflecting different combinations of water sources, suppliers, distribution systems, and other factors.[8] While no one water cost is representative of all cases, cost determinants are generalized below by water source.

Onfarm Water Supplies

Ground water accounts for the major share of acres served by onfarm water sources, with 27 million acres in 1988. Onfarm surface-water sources (river, stream, or lake) supplied 6 million acres (table 2.1.5). Onfarm water sources totaled almost half of the water withdrawn for irrigation in 1990, with 35 percent from ground water and 14 percent from surface sources.

Major irrigation States relying on onfarm surface-water sources include California, Montana, Wyoming, and Oregon. Costs of onfarm surface water are perceived to be the lowest on average, although little

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

Table 2.1.4—Average depth of irrigation water applied per season, 1969-94, by region and crop

Item	1969[1]	1974[1]	1979[2]	1984[2]	1988[2]	1990[3]	1991[3]	1992[3]	1993[3]	1994[4]
					Inches[5]					
Region:										
Atlantic[6]	8.5	11.5	15.0	16.5	15.5	15.5	16.0	16.0	16.5	16.5
North Central[7]	7.5	8.0	9.5	9.5	10.5	9.0	9.5	10.0	8.0	10.0
Northern Plains	16.0	17.0	15.5	13.5	14.5	14.0	14.0	13.5	11.5	14.5
Delta States	15.5	17.5	26.0	17.5	18.0	16.5	15.5	16.5	15.5	15.5
Southern Plains	18.0	18.5	17.0	16.5	17.0	16.5	15.0	16.0	16.0	16.0
Mountain States	30.5	28.5	24.0	24.5	24.5	24.0	24.0	24.0	23.0	24.0
Pacific Coast	33.0	34.0	32.0	34.0	34.5	34.5	34.5	34.5	33.0	35.0
United States[8]	25.5	25.0	22.5	22.5	22.5	22.5	21.5	21.5	20.0	21.5
Crop:										
Corn for grain	18.5	19.5	17.0	16.0	16.0	15.5	15.0	15.0	13.5	15.5
Wheat	23.0	24.0	20.5	16.5	16.0	15.5	14.5	14.5	14.0	14.5
Rice	28.0	28.5	33.5	33.5	32.5	31.5	30.5	30.0	30.5	30.5
Soybeans	12.0	11.5	14.0	9.5	10.0	8.5	7.0	8.0	6.5	7.5
Cotton	23.0	25.5	24.0	25.0	24.5	23.0	21.0	23.0	20.0	21.5
Alfalfa hay	32.5	30.5	26.0	28.0	29.0	28.5	27.5	27.5	26.5	27.5

[1] Census of Agriculture.

[2] Estimates constructed by State, by crop, from Farm and Ranch Irrigation Surveys (FRIS) (USDC, 1990, 1986, and 1982a) 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 May 1994.

[5] Values rounded to nearest 0.5 inches.

[6] Northeast, Appalachian, and Southeast production regions.

[7] Lake States and Corn Belt farm production regions.

[8] Includes Alaska and Hawaii.

Source: USDA, ERS data.

supporting data are available. In most cases, water is conveyed relatively short distances from source to field by means of gravity. Costs are limited to ditch establishment, maintenance, and repair. Where gravity conveyance is not possible (due to topography or river levees), water must be pumped. Primary determinants of variable pumping costs are energy price and pumplift—the vertical distance that water is raised. Onfarm surface-water pumplifts are generally less than 20 feet, resulting in low energy costs of \$2-\$15 per acre-foot.[9] Initial expenditures for surface-water pumping plants can vary greatly depending on farm-specific conditions, but most systems cost \$3,000-\$10,000.

Ground water from 346,000 irrigation wells served approximately 112,000 farms nationwide in 1988. States with over 20,000 wells included California, Texas, Kansas, Nebraska, Arkansas, and Florida.

Production costs associated with groundwater pumping reflect both the variable cost of extraction and the fixed cost of access. Extraction costs are primarily associated with the energy needed to power a pump.[10] Energy costs vary widely depending on the pumplift, pumping system efficiency, the cost of energy, pressurization needs, and quantity of water applied. Total U.S. energy costs for pumping irrigation water were estimated at more than \$1 billion annually in 1988. Average energy expenditures by State range from \$11 to \$105 per acre (table 2.1.5).

Costs of accessing ground water include capital expenditures for well, pump, and power plant. These fixed costs may be substantial, depending on well depth, aquifer conditions, and discharge capacity. Costs for a typical well and pumping plant range from \$20,000-\$40,000 in the Southeast to \$30,000-\$50,000 in the Plains and \$70,000-\$120,000 in the Southwest.

[9] There are some significant exceptions, such as in areas of the Pacific Northwest where vertical lifts from river canyons to adjacent irrigated lands may exceed 400 feet.

[10] Natural aquifer pressure forces water to the ground's surface in about 1 percent of the wells. Irrigation using these systems requires no source of power to extract water.

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

Supplier and source	Acres irrigated[2]	Share of irrigation withdrawals[3]	Average cost[2]	Cost range[2]	Comments
	Million	*Percent*	*$/acre*	*$/acre*	
Onfarm supplies	NA	49	NA	NA	
Surface water	6	14	NA	0-15[4]	Costs are very low in most cases. Some water is pumped from surface sources at higher costs, since energy is required.
Ground water	27	35	31[5]	11-105[6]	Pumping cost varies with energy prices and depth to water.
Off-farm supplies	15	51	34[7]	10-90[8]	Most acres relying on off-farm supplies are located in the West.
Surface water	NA	49	34[9]	10-90[9]	
Ground water	NA	2	NA	NA	

NA indicates no data available.

[1] These values include only energy costs for pumping or purchased water costs. Labor costs associated with irrigation system maintenance and water distribution are not included. Also not included are charges for management time.

[2] Available data are from the 1988 Farm and Ranch Irrigation Survey, except where noted on individual items.

[3] Based on values in Solley, Pierce, and Perlman (1993).

[4] Cost estimates based on engineering formulas with an efficient electric system.

[5] Reported national average energy expense for the onfarm pumping of irrigation water.

[6] Range in State energy expenses for the onfarm pumping of irrigation water.

[7] Reported average cost for off-farm supplies.

[8] Range in reported State average cost of water 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-$90 per acre.

[9] Costs are those from total off-farm sources, since virtually all off-farm supplies come from surface sources.

Sources: Solley, Pierce, and Perlman, 1993; and USDC, 1990.

Off-Farm Water Supplies

Roughly 15 million acres on 94,000 farms nationwide were irrigated with water from off-farm sources in 1988. While this acreage represents about one-third of total irrigated acreage, the off-farm water supplying these acres accounted for roughly half of total withdrawals for irrigation. Surface water accounts for nearly all (95 percent) off-farm supplies.

Several types of organizations have been established to convey and deliver irrigation water. Most are nonprofit entities with a goal of dependable water service at low cost. In 1988, irrigators reported an average cost of water from off-farm sources of near $34 per acre irrigated, or $14 per acre-foot (table 2.1.5). Pricing is often based on acreage served rather than water delivered, since administrative costs are lower for a land-based charge. Producers generally pay a fixed cost per acre and receive a specified water allotment. With this pricing structure, producers have little financial incentive to conserve water, given that charges are incurred regardless of the amount of the water allotment used.

About 7,400 organizations, mostly in the West, supplied irrigation water to farmers in the late 1970's (U.S. Department of Commerce, 1982b).[11] Two types of organizations—mutual supply systems and irrigation districts—supplied over 90 percent of the off-farm supplied acres. Mutual supply systems, owned by water users, accounted for over 80 percent of the organizations and over 40 percent of total acres served. Mutual systems are often informal entities with minimal expenses, relying largely on labor and material supplied by water users. On average, water prices charged by mutual systems were about one-third the average price charged by all off-farm suppliers. Irrigation districts are legal entities, generally with operational staffs, boards of directors, and associated overhead expenses. Irrigation districts supplied about 50 percent of the acres served by off-farm suppliers in 1978. On average, irrigation district water prices were one-third greater than the average price for all off-farm suppliers.

[11] Data collection for the *Census of Irrigation Organizations* was discontinued after 1978. Although numbers of organizations have changed since 1978, percentage changes occur slowly, especially when long-term contracts are involved.

Groundwater Overdrafting

Groundwater overdrafting occurs when withdrawals for irrigation and other uses exceed natural rates of aquifer recharge. Overdrafting results in a lowering of aquifer water levels and a reduction in total reserves.

Groundwater overdrafting has been recorded in the Great Plains (Nebraska, Kansas, Colorado, Oklahoma, New Mexico, and Texas); Southwest (California and Arizona); Pacific Northwest (Idaho); Delta (Arkansas); and Southeast (Florida and Georgia). Significant areas of Idaho, Texas, and Kansas have reported water table declines exceeding 4 feet annually. States containing over 2 million irrigated acres in areas reporting annual declines of at least 6 inches include Texas, Kansas, California, and Nebraska. Affected irrigated acres as a share of total irrigated acres statewide exceed 60 percent in Oklahoma, New Mexico, Texas, Arizona, and Kansas (Sloggett and Dickason, 1986).

Overdrafting of groundwater reserves has several potential consequences, most of which are long-run. The most widespread impact involves an increase in pumping costs. Declining water tables cause greater pumplifts and reduced pump efficiencies, and thus result in higher groundwater extraction costs. While annual cost increases may be small ($2 per acre or less), they tend to be permanent and cumulative.

Land subsidence from groundwater overdrafting is caused by compaction of the aquifer structure, which lowers surface elevation. The land's susceptibility depends on the geologic structure of the aquifer; groundwater subsidence problem areas are concentrated in Texas, California, Arizona, and Nevada. Nationwide, annual losses from lowered surface elevations due to underground fluid withdrawal, mainly ground water, are estimated at $35 million (National Research Council, 1991). In addition to monetary losses, compaction causes a permanent loss in the aquifer's capacity to store water, thus reducing the potential for natural and artificial recharge.

Other impacts of overdrafting include saltwater intrusion into underground freshwater supplies in coastal States (California, Texas, and Florida) and reduced streamflows in interconnected ground- and surface-water systems. Sustained overdrafting will eventually result in exhaustion of the groundwater reserves that can be economically tapped.

Progress in curtailing overdrafts has varied widely across States. A number of programs—authorized and perhaps mandated at the State level but implemented locally—have slowed aquifer declines in many areas. Program measures may include: restrictions on new well development, limits on groundwater withdrawals, promotion of artificial recharge, substitution of alternative surface-water sources (including reclaimed wastewater), and incentives for adoption of water-conserving irrigation technologies.

The Federal Government supplies irrigation water through projects constructed by the U.S. Department of the Interior, Bureau of Reclamation (BoR). Federal involvement in irrigation project development is rooted in 1902 legislation designed to promote Western settlement. Most BoR projects collect, store, and convey water to local irrigation districts and incorporated mutual water companies that, in turn, serve irrigators. The BoR serves as a water "wholesaler" for about 25 percent of the West's irrigated acres. Water delivery quantities and prices are specified under long-term (25- or 40-year) contracts between BoR and irrigation delivery organizations.

Federal policies affect BoR water prices in two important ways. First, because the original legislation focused on Western settlement rather than financial solvency, most projects were, and continue to be, subsidized. Subsidy rates are as high as $150 per acre served, with an average of $54 per acre. BoR subsidies reduce the cost of irrigation water to both the delivery organization and to irrigators. Second, since most water delivery organizations contract with a Federal agency, changes in Federal policy can directly affect prices paid for irrigation water, but only after expiration of the current contract.[12] Existing contracts (some with 20-30 years remaining) would not immediately be affected by legislation to remove Federal subsidies, although incentives or penalties could be offered to encourage early

[12] Values reported here reflect "subsidies" as defined by the Reclamation Reform Act of 1982, even though there is no universally accepted definition of "irrigation subsidy." Much of the subsidy stems from policy decisions at the time of project construction to allow long-term repayment by irrigators at low, or no, interest. In many cases, the "value of the subsidy" has been capitalized into the value of the land. Current adjustments in Federal water policy should consider these past actions. See Moore and McGuckin (1988).

Irrigated Acreage: A Historical Perspective

Development of irrigation in the United States has been shaped by the climatological split between the arid western half of the country and the humid eastern half. The lower precipitation levels in the West sharply limit the productive capacity of rainfed agriculture. In the more arid areas of the West, large-scale cropped agriculture relies completely on irrigation.

Population settlements in the West exploded in the late 19th century, with many Western States seeing tenfold increases in population within one generation. To feed these populations, farmers cooperated to bring water from where it was abundant to where it was most useful for crops. The Census of Agriculture reported that irrigation was already an established practice by 1889 on almost 4 million acres (table 2.1.2). By 1910, irrigation enterprises had developed the capability to irrigate almost 20 million acres, and the area irrigated had increased to 14 million acres, with the Pacific and Mountain States accounting for more than 90 percent.

With the exception of rice production in the Mississippi Delta and Gulf Coast areas, irrigation remained a western activity through 1949, when Pacific and Mountain States still accounted for 77 percent of irrigated area. Total cropland area had peaked two decades before and further increases in crop production would come from yield gains. In areas of marginally adequate rainfall, this required supplemental irrigation. Improvements in irrigation technologies brought more ground water within reach and reduced labor requirements. By 1969, the Plains States, sitting on huge underground reservoirs of water, had almost a third of all irrigated area. Eastern States (primarily Florida, Louisiana, and Arkansas) accounted for over 10 percent of irrigated area, with substantial areas of crops other than rice beginning to be irrigated.

renegotiation. Recent legislation involving the Central Valley Project (CVP) in California—the BoR's largest project—requires that (1) water prices be increased as contracts are renewed, and (2) charges for water delivered be levied on a per-acre-foot basis. The legislation also encourages early contract renewal by assessing a fee for each year the current contract remains in force after a specified date.[13]

With rising water needs for urban and environmental purposes, water pricing reform has been viewed as a potential means of reducing water demand in agriculture, the largest current water user. However, significant barriers may have to be overcome in developing a comprehensive pricing policy. These involve:

- the nonmarket nature of existing water costs;
- the diversity of State laws governing withdrawals and instream uses;
- the diversity of water management institutions and delivery organizations across water source and supplier combinations; and
- various institutional and administrative impediments to water market development.

[13] The fee, set at about 12 percent of the State average off-farm water price, is payable in a lump sum before a new contract can be issued.

BoR pricing reform establishes an important precedent for water pricing and allocation. Under the recent CVP legislation, pricing reforms were enacted as part of a comprehensive package to provide water for environmental purposes and to encourage water market transfers. The CVP is unique, given the size of the project (almost 25 percent of all BoR lands) and the combined effects of sustained drought, rising urban water demands, and environmental needs. The legislation has implications, however, for other basins where competition for limited water supplies is increasing. The CVP reforms could serve as a model for future BoR pricing adjustments to promote water conservation throughout the West.

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Irrigation and Water Data

Interested in learning more on water use and irrigated agriculture but don't know where to begin? Major contributions of selected reference materials are classified below. Complete citations for the materials are found in the references.

Irrigation Data

- State-level summaries of water use are found in **Agricultural Irrigation and Water Use** by Rajinder S. Bajwa, William M. Crosswhite, John E. Hostetler, and Olivia W. Wright.

- State-level summaries of irrigated acres and water applications by crop are found in **Farm and Ranch Irrigation Survey (1988)** published by the Bureau of the Census.

- County-level summaries of irrigated acres by crop are found in the **1987 Census of Agriculture** and the **1992 Census of Agriculture** published by the Bureau of the Census.

Water Use Data

- State-level water withdrawal and consumptive use estimates are reported in **Estimated Use of Water in the United States in 1990** by Wayne B. Solley, Robert R. Pierce, and Howard A. Perlman.

- Trends in agricultural water use are discussed in "Agricultural Water Use in the United States, 1950-85," by Michael R. Moore, William M. Crosswhite, and John E. Hostetler.

Water Price and Water Supplying Organization Data

- Information about water supplying organizations is contained in **Irrigation: Chapter 2. 1978 Census of Irrigation Organizations** by the Bureau of the Census.

- Water delivery activities of the Bureau of Reclamation are detailed in the annual **Summary Statistics** published by the Bureau of Reclamation.

- Information on the Bureau of Reclamation irrigation water subsidies may be found in "Program Crop Production and Federal Irrigation Water," by Michael R. Moore and Catherine A. McGuckin.

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