2.1 Water Use and Pricing in Agriculture

Irrigated agriculture remains the dominant use of fresh water in the United States, although irrigation's share of total consumptive use is declining. National irrigated cropland area has expanded over 40 percent since 1969, while field water application rates have declined about 20 percent. The total quantity of irrigation water applied increased about 15 percent since 1969. Nationally, variable irrigation water costs for groundwater averaged $32 per acre and off-farm surface water about $41 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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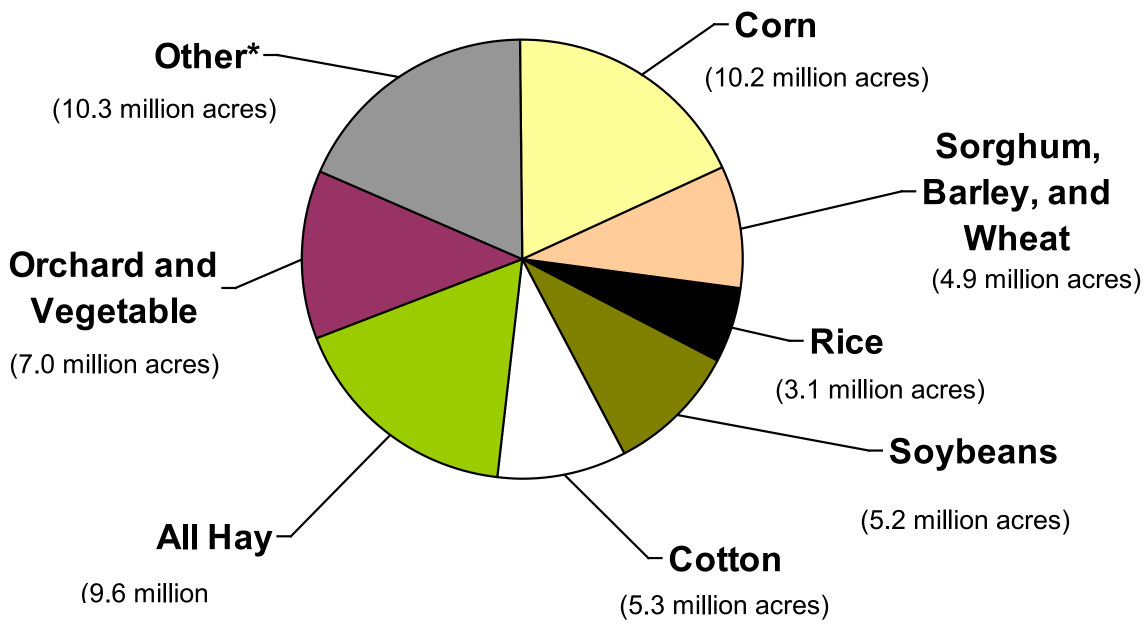
The United States, as a whole, has abundant freshwater supplies. Annual renewable supplies in surface streams and aquifers total roughly 1,500 million acre-feet per year (maf/yr). (See box "Glossary of Water Use Terms" for definitions.) Of total renewable supplies, only one-quarter is withdrawn for use in homes, farms, and industry, and just 7 percent is actually used (Moody, 1993). Consumptive uses considered here include only those uses occurring after water is withdrawn from a river or aquifer.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. Renewable surface and groundwater supplies account for roughly 90 percent of total water use nationwide. The remainder comes from depletion of stored groundwater (Foxworthy and Moody, 1986).

An abundance of water in the aggregate belies increasingly limited water supplies in many areas, reflecting uneven distribution of the Nation's water resources. In the arid West, consumptive use exceeds one-half of the renewable water supplies under normal precipitation conditions. In drought years, water use often exceeds renewable flow through the increased use of aquifers and stored surface water. While droughts exacerbate supply scarcity, water demands 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 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.

Increased water demand in water-deficit areas historically was 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 seasonally reliable water supplies are limited due to lack of suitable project sites, reduced funding, and increased public concern for environmental consequences. Future water demands will increasingly be met by reallocation of existing supplies. Since agriculture is the largest water user, reallocation will likely result in reduced supplies for agriculture. Changes in agricultural water availability may have significant impacts on irrigated production and rural communities.

Irrigated agriculture is an important part of the U.S. cropland sector, contributing almost half the total value of crop sales on just 16 percent of total cropland harvested. In 1997, 279,000 farms irrigated 55.1 million acres of crop and pasture land. Irrigated acreage as a share of total acreage (irrigated plus non-irrigated) was most significant for rice (100 percent), orchards (80 percent), Irish potatoes (79 percent), vegetables (70 percent), and cotton (37 percent) (USDA, 1999a). Projected irrigated acreages in 2000 were substantial for several crops, including corn for grain (10.2 million acres), all hay (9.6 million), orchards and vegetables (7 million), cotton (5.3 million), and soybeans (5.2 million) (fig. 2.1.1).

Figure 2.1.1 -- Area irrigated by crop, 2000



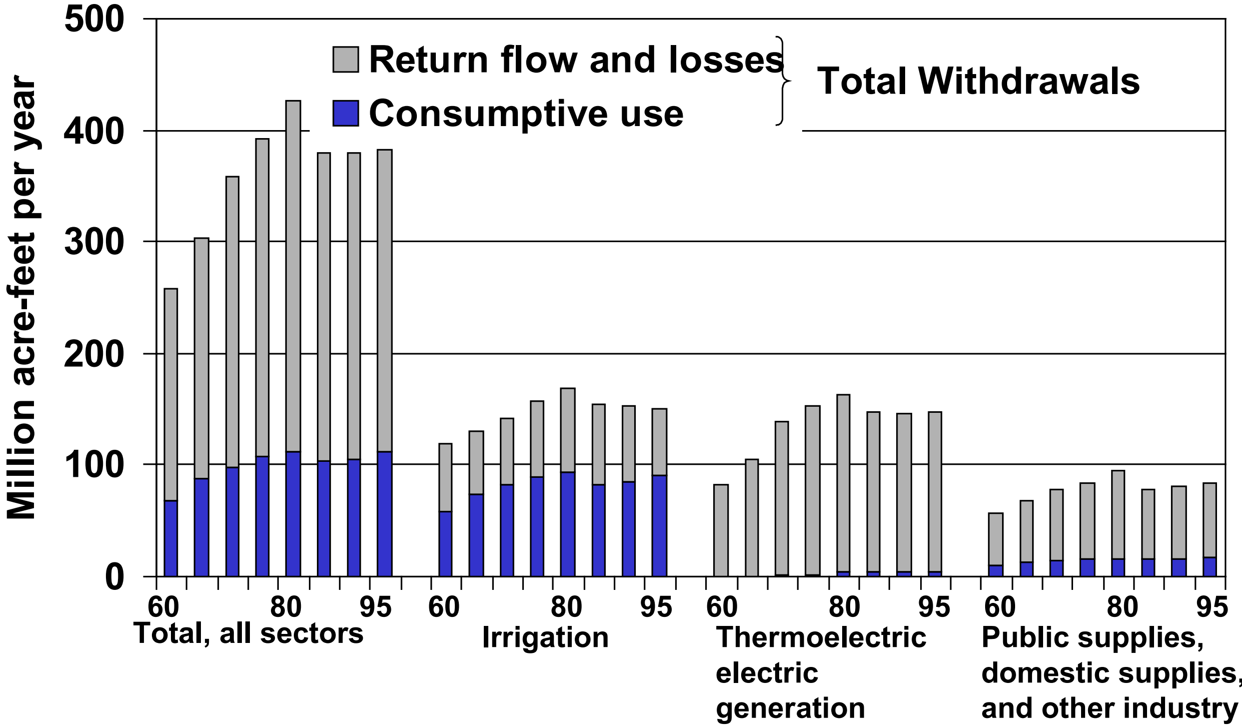
Source: USDA/ERS estimates based on 1997 Census of Agriculture and other USDA/NASS estimates.

Irrigation Withdrawals

Freshwater withdrawals—a measure of the quantity of water diverted from surface- and groundwater sources—totaled 382 million acre-feet (maf) in 1995 (fig. 2.1.2). Major use categories include irrigation (150 maf), thermoelectric (148 maf), domestic and commercial water supplies (40 maf), and other industries (38 maf) (Solley et al., 1998).

Although irrigation withdrawals increased in absolute terms, irrigation withdrawals as a share of U.S. freshwater withdrawals declined from 46 percent in 1960 to 40 percent in 1995 (fig. 2.1.2). Irrigation withdrawal estimates by Solley, Pierce, and Perlman are primarily for agricultural purposes (cropland and pastureland), but irrigation of recreational areas (parks and golf courses) is also included. Withdrawal estimates are done every 5 years, but the data for 2000 are not yet available.

Figure 2.1.2--Water withdrawals and consumptive use, 1960-95



Source: USDA, ERS, based on Solley et al., 1998

Water withdrawals for public distribution systems (mainly domestic and commercial use) increased by 48 percent over the same period, corresponding with a U.S. population increase of 50 percent and a population shift to arid and warmer climates. Although thermoelectric withdrawals have declined relative to their peak in 1980, the 1995 withdrawals were still 90 percent greater than the 1960 volume.

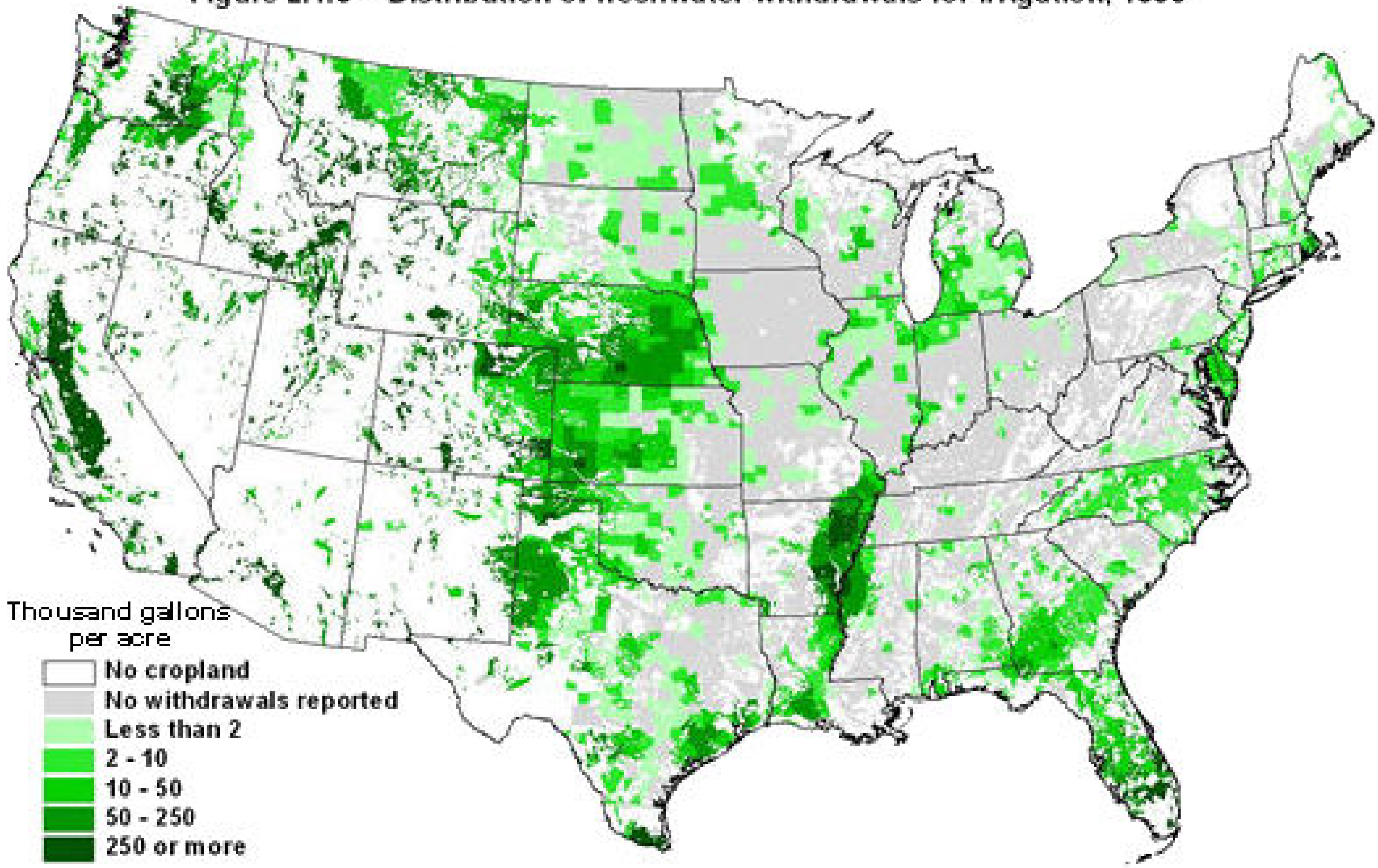
Most irrigation water withdrawals occur in the arid Western States, where irrigated production is concentrated. Combined irrigation withdrawals in the four largest withdrawal States—California, Idaho, Colorado, and Texas—approached 72 maf, or nearly half of total U.S. irrigation withdrawals in 1995 (table 2.1.1; fig. 2.1.3). The top 20 irrigation States accounted for 97 percent of U.S. freshwater irrigation withdrawals (table 2.1.1). Irrigation States in table 2.1.1 are ranked according to consumptive use, not irrigation withdrawals. Most States rely on a combination of surface- and groundwater supplies for irrigation purposes.

Table 2.1.1—Irrigation water withdrawals and consumptive use, 20 major irrigation States and total U.S., 1995

	Withdrawals[1]			Consumptive use[1]	
		Water source			
State[2]	Total	Ground water	Surface water	Total	Irrigation's share of State consumptive use
	Maf[3]	Percent[4]		Maf[3]	Percent[4]
California	32.39	37	63	26.37	92
Texas	10.59	69	31	9.13	77
Nebraska	8.46	77	23	7.56	96
Colorado	14.28	16	84	5.51	94
Arkansas	6.65	83	17	4.92	92
Idaho	14.63	19	81	4.83	99
Kansas	3.79	93	7	3.62	89
Arizona	6.36	38	62	3.56	83
Oregon	6.91	14	86	3.44	96
Washington	7.25	13	87	3.14	91
Wyoming	7.39	3	97	2.98	95
Florida	3.89	48	52	2.43	78
Utah	3.96	11	89	2.16	88
Montana	9.58	1	99	2.04	93
New Mexico	3.36	43	57	1.88	85
Mississippi	1.95	94	6	1.24	71
Nevada	1.84	39	61	1.19	79
Georgia	0.81	66	34	0.81	62
Louisiana	0.86	62	38	0.67	31
Missouri	0.64	94	6	0.47	61
Subtotal	145.60	36	64	87.95	88
All other States	4.19	57	46	3.11	27
United States	149.79	37	63	91.06	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 on total irrigation consumptive use.
[3] Maf = 1 million acre-feet.
[4] May not add to 100 due to rounding
Source: USDA, ERS , based on Solley et al., 1998

Figure 2.1.3 -- Distribution of freshwater withdrawals for irrigation, 1995



Source: USDA, ERS based on Solley et al, 1998. Total county volumes of withdrawal are averaged over the mapped area segments of each county. Mapped segments are those identified as having significant cropland.

Surface water accounted for 63 percent of total irrigation withdrawals in 1990, with groundwater supplying the remaining 37 percent. Surface water was the dominant source of water in 29 States, including 12 of the top 20 States. States with the greatest volume of surface-water withdrawals include California, Colorado, Idaho, Montana, and Wyoming. States with the largest share of irrigation withdrawals supplied by surface sources in 1995 include West Virginia (100 percent), Montana (99 percent), Wyoming (97 percent), Kentucky (96 percent), and New Hampshire (96 percent). In States dependent on surface water, reduced runoff and stream flow can limit irrigators' ability to withdraw water and water stored in reservoirs can serve as a buffer for year-to-year variation in precipitation.

Groundwater is the primary supply source for irrigation in 8 of the 20 States in table 2.1.1. Groundwater 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, Nebraska, Arkansas, and Kansas. Groundwater as a share of irrigation withdrawals was highest in Illinois (100 percent), Wisconsin (99 percent), Missouri (94 percent), and Mississippi (94 percent). States, where groundwater was a dominant supply source, include Kansas (93 percent), Oklahoma (89 percent), and Nebraska (77 percent).

Groundwater 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. Overdrafting has been reported in the Great Plains, Southwest, Pacific Northwest, Mississippi Delta, and Southeast. Areas of Texas, New Mexico, Oklahoma, and Kansas over the High Plains aquifer have experienced declines in water levels of more than 100 feet and reductions in saturated thickness of more than 50 percent, when compared to predevelopment levels (Alley et al., 1999). Consequences of overdrafting are slight in any year, but tend to be permanent and cumulative. Major impacts are increases in pumping costs (from increased depth and reduced well yield) and longrun adjustments in aquifer composition that can lead to land subsidence, saltwater intrusion along coastal areas, and loss of aquifer capacity. Land subsidence in the United States directly affects more than 17,000 square miles in 45 States with conservative annual costs in excess of $100 million, most attributable to groundwater overdrafting (Galloway et al., 1999).

Irrigation Consumptive Use

Consumptive use of fresh water—a measure of water used, not just withdrawn—totaled about 112 maf from all offstream uses in the United States in 1995 (fig. 2.1.2). Irrigation, the dominant consumptive water use, accounted for 91 maf (81 percent) of total U.S. water use. Consumptive use as a percentage of withdrawals was 61 percent for the irrigated sector, compared with 22 percent for domestic and commercial use, 22 percent for industries other than thermoelectric, and just 3 percent for thermoelectric. Total irrigation consumptive use depends on crop acreage and evapotranspiration rates, which depend on climate, crop, yield, and management practices.

Consumptive water use for irrigation increased by about 60 percent between 1960 and 1980 (from 58 maf to 93 maf), reflecting rapid expansion in irrigated area. Despite continued growth in irrigated acreage, irrigation water use in 1995 (91 maf) remained slightly below the 1980 level because of reduced water use per irrigated acre. Reduced water consumption per irrigated acre reflects regional cropping pattern shifts, including lower irrigation water needs in more humid Eastern States, and a reduction in irrigated cropland in some of the highest water-use areas of the Southwest.

Irrigation consumptive use in the 20 major irrigation States accounted for 97 percent of the national total. California had the greatest irrigation consumptive use, followed by Texas, Nebraska, Colorado, and Arkansas. Combined, these five States accounted for almost 60 percent of total irrigation consumptive use in the United States. Of the 20 major irrigation States, six (Arkansas, Florida, Mississippi, Georgia, Louisiana, and Missouri) are in humid areas where irrigation supplements growing season precipitation.

Surface-water sources in 1998 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 2.2, Irrigation Water Management.)

Irrigated Land in Farms

The national area of irrigated farmland, now more than 55 million acres (table 2.1.2), has increased at an average rate of a half million acres per year over the last three decades, continuing a century-long trend (fig. 2.1.4). However, annual estimates available for the last three decades (fig. 2.1.5) show substantial variation about the trend. Most of this variation can be explained by year-to-year changes in three factors: farm program requirements, crop prices, and weather effects on both water supplies in the West and on the need for supplementary irrigation in humid areas (Quinby et al., 1990). High prices for export commodities and elimination of annual crop program restrictions contributed to the unusually fast pace of irrigation expansion in the 1974-78 period, with irrigation reaching 52 million acres in 1981. A period of generally lower prices and sharp year-to-year changes in crop area restrictions for farm program payments followed. Sharp drops in irrigated area in 1983 and 1987 reflected the irrigated share of cropland taken out of production (78 and 61 million acres, respectively) in those years.

From 1988 to 1995, the national area irrigated was affected by continuing program requirements plus a combination of wet seasons in regions of supplementary irrigation and water supply problems in the Southwest. A major drought in the West, which began in the late 1980s, reduced surface-water supplies across the region for several years. In six Southwestern States, the drought combined with competing water demands to reduce water deliveries for some irrigation districts to less than one-half normal volume. Winter precipitation in 1993 and 1995 refilled reservoirs, easing water supply constraints. 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. In 1996, the remaining farm program restrictions were eliminated and irrigated area exceeded the 1981 mark. In recent years, national irrigated area has plateaued at about 55 million acres.

While national acreage has trended up, regional patterns have varied widely. In general, there is an increasing reliance on irrigation in the humid East, a northward redistribution of acres in the West, and declines, relative to peak levels, in the arid Southwest (figs. 2.1.6, 2.1.7). At mid-century, the highest concentrations of irrigation were located in California's Central Valley and over the High Plains Aquifer in the Texas panhandle, with smaller concentrations scattered along rivers throughout the West. More recently, large concentrations of irrigation developed in humid areas—Florida, Georgia, and especially in the Mississippi Delta, primarily Arkansas and Mississippi. A northward redistribution of irrigation in the West is highlighted by the development of irrigation in the Columbia Basin and over the Ogallala Aquifer in Nebraska, Kansas, and Colorado.

In addition to the geographic shift, the mix of irrigated crops has changed. From 1969 to 1982, irrigated area increased for almost all crops, with the biggest gains in the major export grains (corn, soybeans, and wheat). Since 1982, there has been a general trend towards crops with higher value per acre irrigated. Acreage of irrigated horticulture, soybean, corn for popping, and mint has doubled, while declines occurred in irrigated areas of sorghum, wheat, oats, barley, dry beans, pasture, and unharvested cropland. Farmers have also increased their irrigated area of corn (2.2 million acres), cotton (1.2 million), orchards (0.9 million), and vegetables (0.6 million). By 1997, production of nursery, orchard, and vegetable crops was almost entirely irrigated, with sales of these crops accounting for 60 percent of sales from all irrigated cropland and about 30 percent of total crop sales.

Table 2.1.2--Irrigated land in farms, by region and crop, 1900-2000

Region	1900[1]	1949[1]	1969[1]	1978[1]	1982[1]	1987[1]	1992[1]	1997[1]	1998[2]	1999[2]	2000[2]
USDA production region:						*1,000 acres*					
Atlantic Regions [3]	-	500	1,800	2,900	2,700	3,000	3,200	3,600	3,600	3,500	3,500
North Central [4]	-	-	500	1,400	1,700	2,000	2,500	2,800	2,800	2,900	3,000
Northern Plains	200	1,100	4,600	8,800	9,300	8,700	9,600	10,200	10,100	10,200	10,500
Delta States	200	1,000	1,900	2,700	3,100	3,700	4,500	5,700	6,300	6,000	5,900
Southern Plains	100	3,200	7,400	7,500	6,100	4,700	5,400	6,000	5,900	5,900	5,800
Mountain States	5,300	11,600	12,800	14,800	14,100	13,300	13,300	14,400	14,300	14,400	14,200
Pacific Coast	2,000	8,300	10,000	12,000	11,900	10,800	10,800	12,400	12,200	12,300	12,400
United States [5]	7,800	25,800	39,100	50,300	49,000	46,400	49,400	55,100	55,200	55,300	55,300
Irrigated Crop:											
Corn for Grain			3,200	8,700	8,500	8,000	9,700	10,600	10,700	9,900	10,200
Sorghum for grain			3,500	2,000	2,200	1,300	1,600	900	600	800	600
Barley			1,600	2,000	1,900	1,300	1,100	1,100	1,000	1,000	1,000
Wheat			1,900	3,000	4,600	3,700	4,100	4,000	3,700	3,400	3,300
Rice			2,200	3,000	3,200	2,400	3,100	3,100	3,400	3,500	3,100
Soybeans			700	1,300	2,300	2,600	2,500	4,200	4,400	4,800	5,200
Cotton			3,100	4,700	3,400	3,500	3,700	4,900	4,600	4,800	5,300
Alfalfa hay			5,000	5,900	5,500	5,500	5,700	6,000	6,300	6,400	6,300
Other hay			2,900	3,000	3,000	3,100	2,900	3,600	3,400	3,500	3,300
Vegetables			1,500	1,900	1,900	2,000	2,200	2,400	2,500	2,600	2,700
Land in orchards			2,400	3,000	3,300	3,400	3,600	4,100	4,100	4,200	4,300
Other irrigated land in farms			11,100	11,800	9,200	9,500	9,100	10,300	10,500	10,400	10,300

- Indicates none or fewer than 5,000 acres.

[1] Census of Agriculture.

[2] Estimates constructed from the Census of Agriculture and other USDA sources.

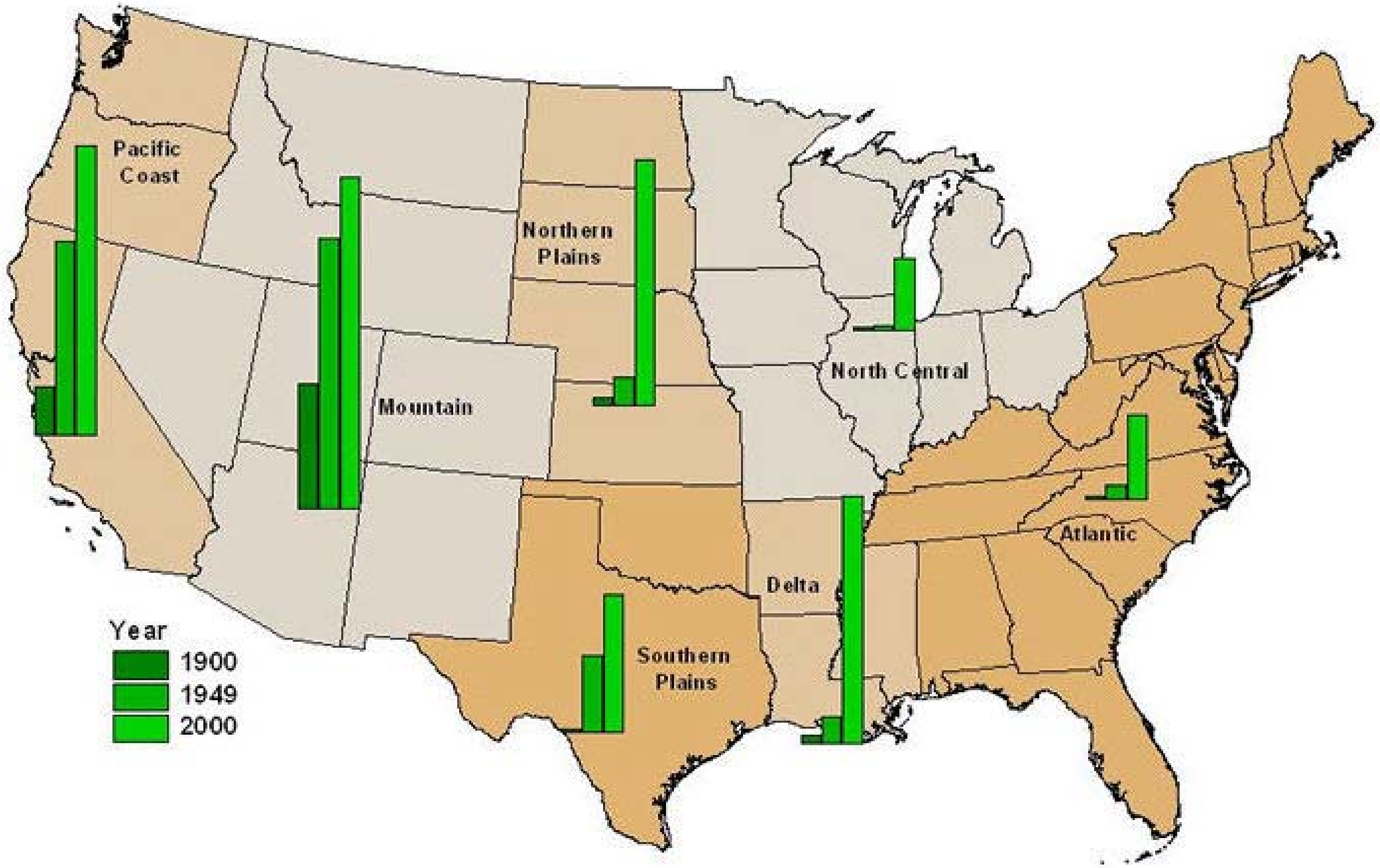
[3] Northeast, Appalachian, and Southeast farm production regions.

[4] Lake States and Corn Belt production regions.

[5] Includes Alaska and Hawaii.

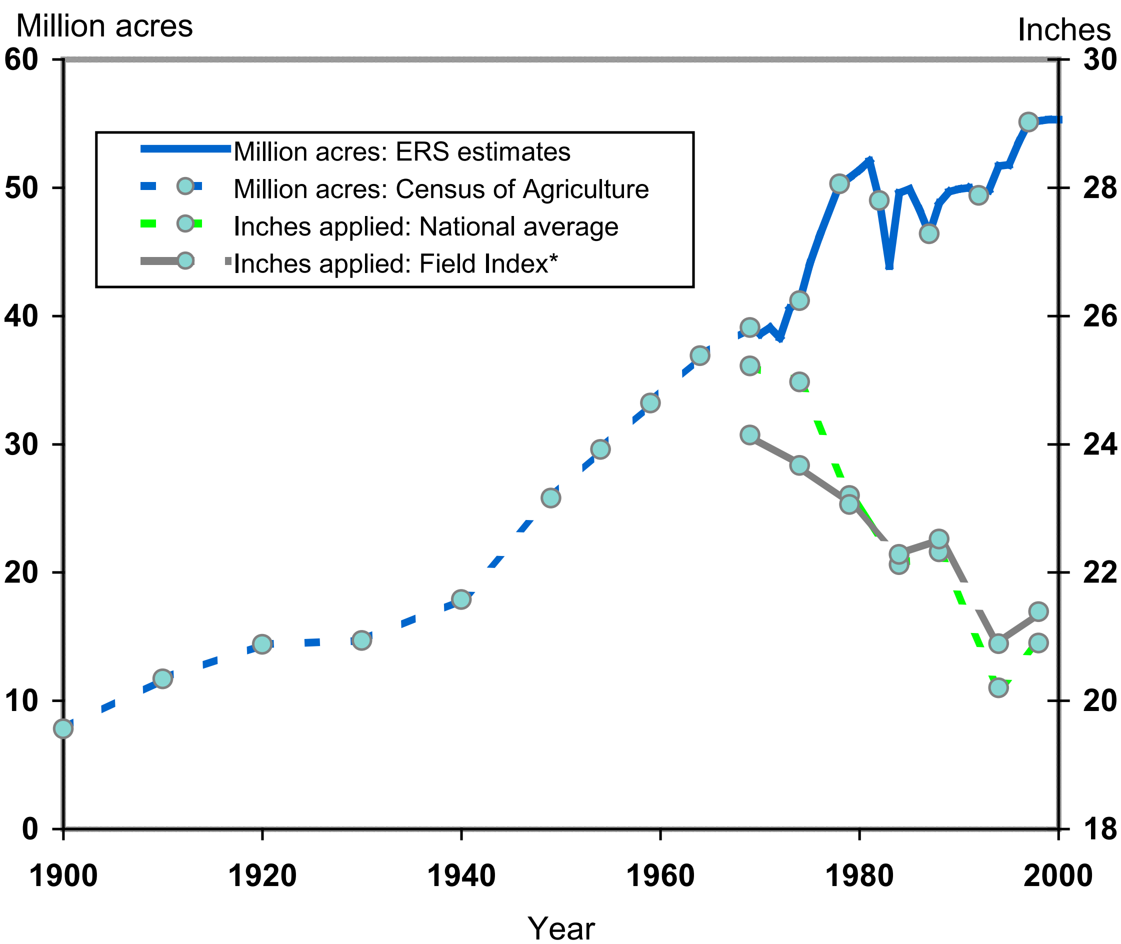
Source: USDA, ERS, based on Census of Agriculture, various years (USDA, 1999a; USDC, 1994; and previous versions); and USDA, ERS data.

Figure 2.1.4 -- Irrigated area by region for 1899, 1949, and 2000



Source: Census of Agriculture: USDOI/U.S.Census Office (1902); USDOC/Bureau of the Census (1952); USDA/ERS estimates, Table 2.1.2

Figure 2.1.5 -- Irrigation trends, 1900-2000



Source: see notes for tables 2.1.2 and 2.1.3 .
* Field index shows the average field-level trend in application rates, abstracted from changes in the mix of crops irrigated, the geographic location of irrigation, or known weather effects. The index is approximated by removing the part of application rates that is correlated with precipitation and averaging the remainder over fixed, 30-year State averages of crop areas and weather.

Irrigation Water Application Rates

Total depth of water applied through the irrigation season declined 4.3 inches, from a national average of 25.2 inches in 1969 to 20.9 inches in 1998, or 17 percent (table 2.1.3). Regional application rates vary from less than 6 inches for sorghum in North Central States to more than 4.5 feet for orchards in Mountain States. Reductions in application rates have been widespread, with the greatest declines in the Northern Plains and Mountain regions. Application rates for major crops range from 29 inches per acre for alfalfa hay to 10 inches per acre for soybeans (fig. 2.1.8).

The bulk of the decline in average application rates is due to efficiency gains from on-field improvements in water management and irrigation system technology (2.7 inches). On-field gains in water use efficiency are estimated by an index created from observed State/crop application rates, adjusted for weather effects, and from 30-year averages of estimated irrigated area by State/crop (fig. 2.1.5, and see Chapter 2.2, Irrigation Water Management). Much of this on-field decline is attributable to improvements in sprinkler technology and increased sprinkler use.

Table 2.1.3--Depth of irrigation water applied, by region and crop, 1969-98

	1969 [1]	1974 [1]	1979 [2]	1984 [2]	1988 [2]	1994 [2]	1998 [2]
				Inches [5]			
Region:							
Atlantic [3]	8.0	11.0	13.0	14.0	12.5	10.5	13.0
North Central [4]	7.5	8.0	8.5	9.0	10.0	7.5	8.0
Northern Plains	16.0	17.5	15.0	13.5	14.5	12.0	12.0
Delta States	15.5	17.0	17.5	17.5	18.0	13.0	16.5
Southern Plains	18.0	18.5	17.5	16.5	17.0	17.0	17.0
Mountain States	30.5	28.5	26.5	24.5	24.5	24.0	24.5
Pacific Coast	32.5	33.5	33.5	33.5	34.5	32.5	33.0
United States [5]	25.2	25.0	23.2	22.1	22.3	20.2	20.9
Crop:							
Corn for grain	18.5	19.5	16.5	16.0	16.0	13.5	14.5
Sorghum for grain	19.0	19.0	16.5	14.5	14.5	13.5	12.5
Barley	30.0	26.5	23.0	18.5	18.0	19.0	19.5
Wheat	23.5	24.0	21.0	16.5	16.0	17.0	17.0
Rice	28.0	28.5	30.0	33.5	32.5	27.0	28.5
Soybeans	12.0	11.0	10.5	9.5	10.0	8.5	10.0
Cotton	23.0	25.5	26.0	24.5	24.0	20.0	19.0
Alfalfa	32.5	30.5	28.0	28.0	29.0	26.5	29.0
Other hays	22.0	21.0	20.0	21.0	19.5	20.5	24.5
Vegetables	25.0	25.5	25.5	27.0	26.5	24.0	24.0
Land in orchards	29.0	30.0	30.0	31.0	31.5	27.0	28.0

[1] Census of Agriculture.

[2] Estimates constructed by State/crop from the Farm and Ranch Irrigation Survey and ERS estimates of irrigated area.

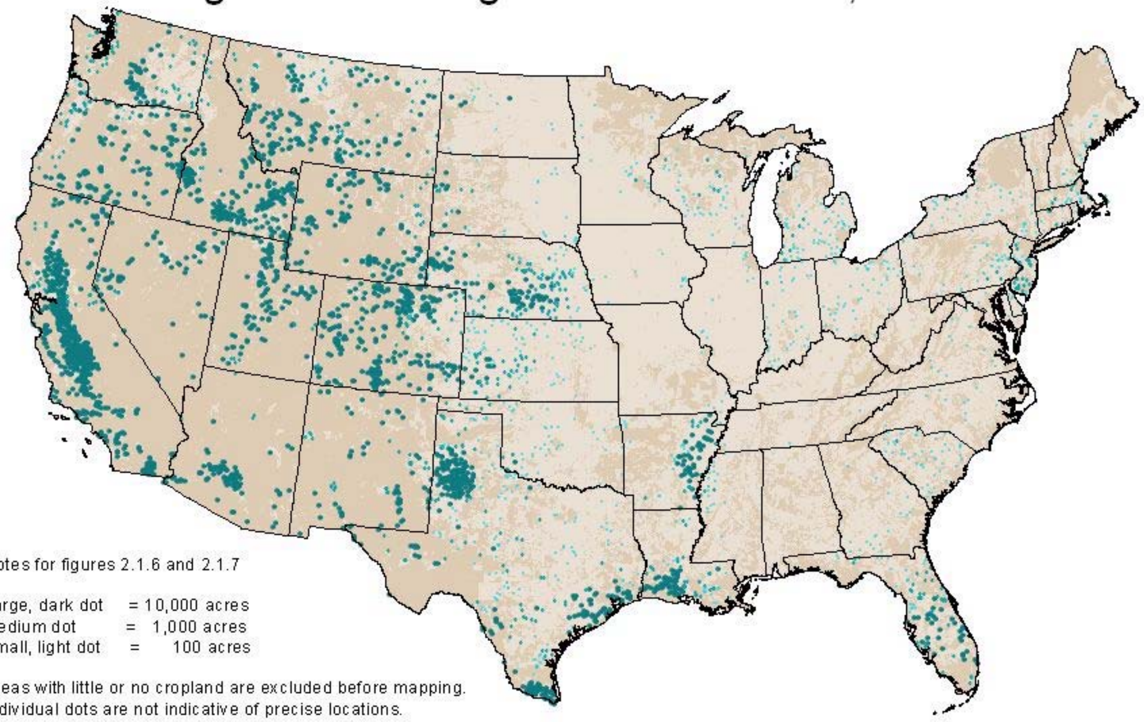
[3] Northeast, Appalachian, and Southeast production regions.

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

[5] Includes Alaska and Hawaii.

Source: USDA, ERS, based on USDC Census of Agriculture, various years; Farm and Ranch Irrigation Surveys (USDA, 1999b; USDC, 1996; USDC, 1990, and previous versions).

Figure 2.1.6--Irrigated land in farms, 1949



Notes for figures 2.1.6 and 2.1.7

Large, dark dot = 10,000 acres
Medium dot = 1,000 acres
Small, light dot = 100 acres

Areas with little or no cropland are excluded before mapping.
Individual dots are not indicative of precise locations.

Source: USDA, ERS based on Census of Agriculture:
USDoC, Bureau of the Census, 1949 and USDA, NASS, 1997

Figure 2.1.7--Irrigated land in farms, 1997

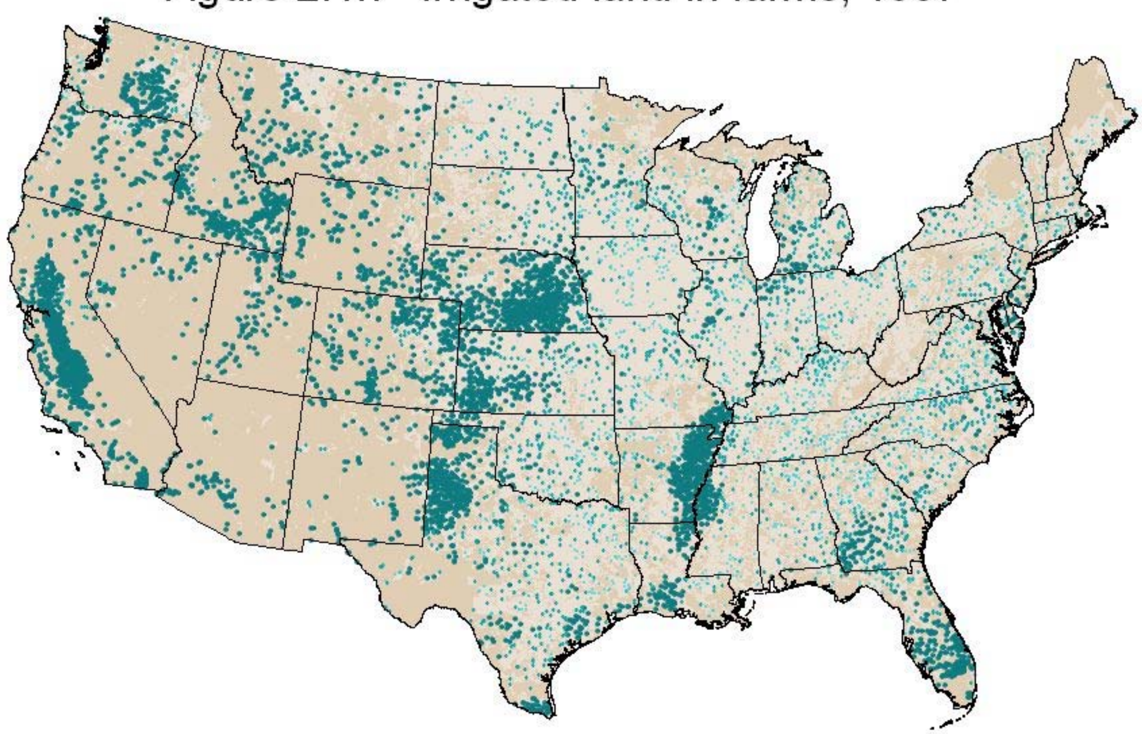
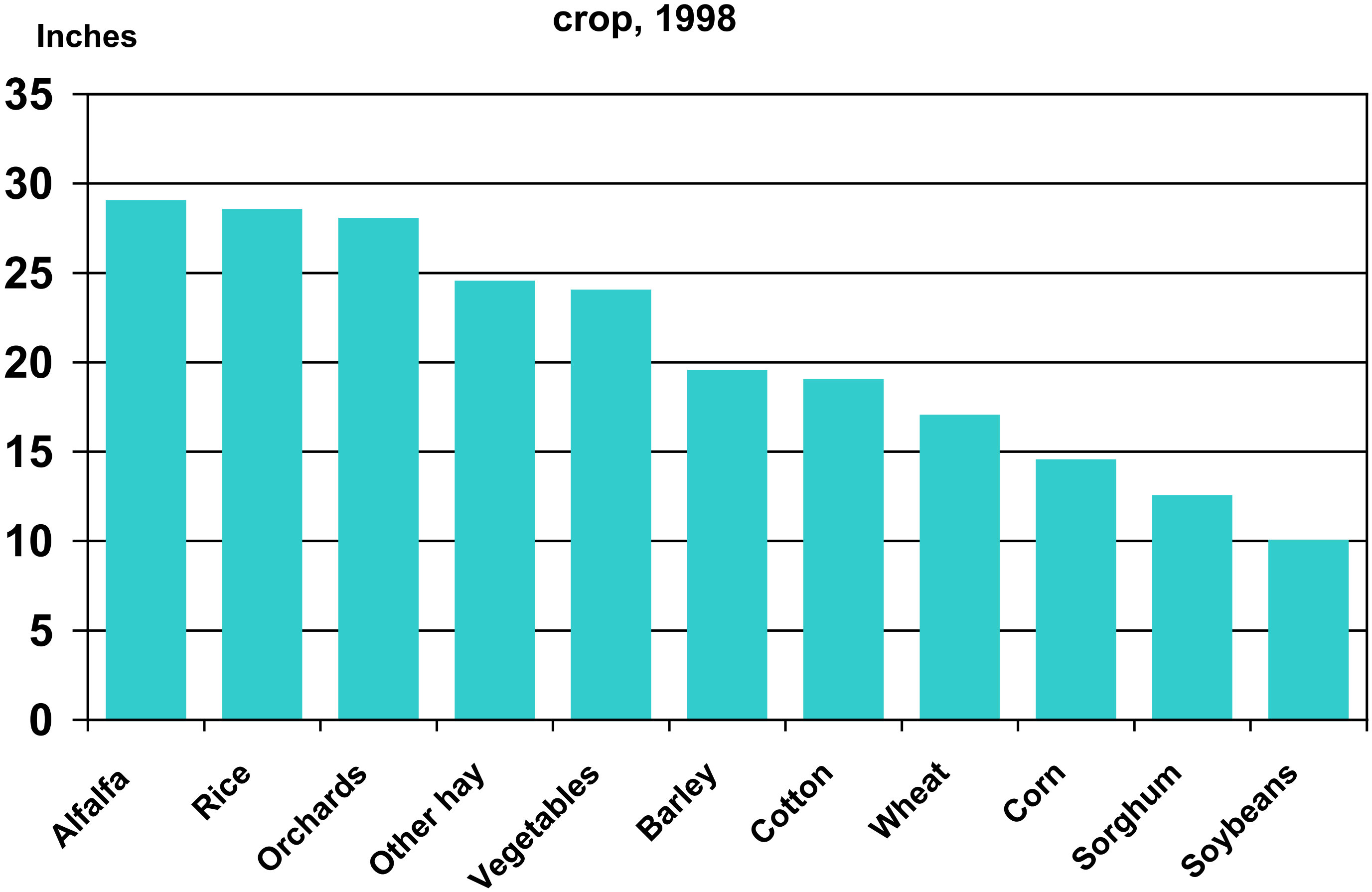


Figure 2.1.8 -- Average depth of irrigation water applied by crop, 1998



Source: USDA/NASS, 1998 Farm and Ranch Irrigation Survey

Most of the remaining decline in average application levels (1.6 inches) is attributable to increasing irrigated area in cooler Northern States or humid Eastern States with lower water application requirements. The general perception that cropping patterns have changed, thus using less water per acre, is not supported by the data. Among Western States, only four (Montana, Nebraska, North Dakota, and South Dakota) have reduced water use by changing the crop mix. Nationally, 28 States have actually increased average application rates by changes in the crop mix, with the biggest increases in Missouri and the arid Southwest. Significant declines in State average application rates from changes in crop mix occurred in the Delta and Northern Plains regions, from growth in irrigated soybeans.

Average application rates in 1974 and 1994 merit further mention. The 1974 application rates are "above trend" because of incentives from high crop prices to maximize production and the inability to rapidly adjust capital stock of irrigation equipment and wells. The 1969-74 gains in on-field efficiency were largely offset in most of the major irrigation States by within-State changes in the crop mix towards crops for export, which tend to use more water than the crops they replaced. More corn, wheat, cotton, and rice were irrigated at the expense of pasture, sorghum, and other low-value field crops. As irrigated area expanded in the subsequent 1974-79 period, the geographic center of irrigation shifted eastward in favor of States with lower average application rates. The national average rate of water use in 1994 was affected by water supply constraints in the Southwest and a relatively moist crop year across the Eastern States.

The net adjustment in total water applied to irrigated lands reflects the effect of efficiency gains on a per acre basis, shifts in crop locations, and changes in acres irrigated. Per acre declines in application rates have been enough to partially offset the increase in irrigated acreage since 1969. In this period, irrigated acreage increased by 40 percent while total water applied increased by only 16 percent, to the 1998 level of more than 95 million acre-feet.

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 widespread markets have not developed. 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, which are typically based on the access and delivery costs of supplying water, generally do not convey signals about water's relative scarcity. 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.

Water prices could be set administratively, but this approach is not likely to achieve the 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 administrative 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 generally require very large adjustments in price, all but prohibited by equity 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 2.1.4), reflecting different combinations of water sources, suppliers, distribution systems, and other factors, including farm (or field) proximity to water source, topography, underlying aquifer conditions, energy source, and structure of the water delivery organization.

We use the Farm and Ranch Irrigation Survey (USDA, 1999b) to examine the cost determinants for ground- and surface water sources.

Groundwater Costs

Groundwater was the sole water source for 23.5 million acres and supplied some of the water for an additional 6.3 million acres in 1998. Groundwater from an estimated 336,000 irrigation wells served approximately 85,000 farms nationwide (USDA, 1999b). Texas had the most wells used for irrigation in 1998 with 65,000, followed by California (49,000), Nebraska (48,000) and Arkansas (37,000).

Table 2.1.4—Supply sources and variable costs of irrigation water, 1998[1]

Water source	Acres irrigated	Share of acres irrigated[2]	Average cost[2]	Cost Range[2]	Comments
	Million	*Percent*	*$/acre*	*$/acre*	
Groundwater:			32[3]	7-69[4]	Pumping cost varies with energy prices, depth to water, and efficiency of pumping system.
Only source[5]	23.5	47			
Combined sources	6.3	13			
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	4.2	8			
Combined sources	2.7	5			
Off-farm surface water[7]**:**			41[8]	10-85[9]	Most acres relying on off-farm sources are located in West.
Only source	10.3	21			
Combined sources	4.8	10			
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	37.9	76			
Combined sources	13.8	27			

n/a indicates data not available

[1] These values include only energy costs for pumping or purchased water costs. Management and labor costs associated with irrigation decisions, system maintenance, and water distribution are not included.

[2] Available data are from the 1998 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 the 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] Included a minor amount of groundwater supplied from off-farm suppliers.

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

[9] 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 $2 - $175 per acre.

Source: USDA, ERS based on USDA (1999), 1998 Farm and Ranch Irrigation Survey

Groundwater 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 over 9 percent of the farms reporting 10 or more wells. Irrigated acres by water source are reported from the Farm and Ranch Irrigation Survey (FRIS), which excluded certain irrigated farms with about 5 million (10 percent) of the irrigated acres estimated from the Census of Agriculture. FRIS is the sole data source for acres irrigated by source of water that also collects additional information, such as costs.

Costs associated with groundwater pumping reflect both the variable cost of extraction and the investment cost of access. Variable extraction costs primarily reflect the energy needed to power a pump. A limited number of artesian wells (less than 2 percent), in which natural aquifer pressure forces water to the surface, are located primarily in California, Arkansas, Kansas, and Colorado. Energy costs 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 all onfarm irrigation water pumping were estimated at more than $1.2 billion in 1998, mostly associated with pumping groundwater (USDA, 1999b). Average energy expenditures were $32 per acre with a State range from $7 to $69 per acre (table 2.1.4). Capital costs of accessing groundwater 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 widely variable, but usually lie in the range of $20,000 to $200,000.

Research at ERS has examined the effect of short-term variability in energy on a series of producer decisions, including land area irrigated, crops selected, and water application rate (Moore et al., 1994). The research focused on the farm's input and resource allocation decisions and not farm profitability. The research found that small-to-moderate increases in pumping costs encouraged irrigators to apply less water in total, but the reduction was accomplished by changing irrigated area and its allocation to crops. Once the crop was selected, the water application rate was relatively insensitive to the price increase.

A limited amount of groundwater is supplied to farms from off-farm sources, when an irrigation district or mutual water-supply company develops wells to serve irrigators during times of the year when surface water supplies are unavailable or in short supply. While the quantities of groundwater 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 investment costs of individual well development. Pumping and access costs are probably similar to onfarm-supplied groundwater. Producers, however, pay a higher price because overhead costs and water delivery losses must be paid in addition to pumping and a share of the access costs.

Surface-Water Costs

Surface water from rivers, streams, and lakes supplied about 22 million irrigated acres in 1998 (table 2.1.4). Onfarm surface water supplied almost 7 million acres, including 4.2 million acres as the sole source (USDA, 1999b). Off-farm water supplies provided all the water for over 10 million acres, and part of the supply for an additional 4.8 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 almost 37,000 farms nationwide. Lands irrigated with onfarm surface water are concentrated in California, Montana, 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 great.

Off-farm water was supplied to more than 83,000 farms nationwide. Two-thirds of the acres supplied from off-farm sources are located in six States—California, Idaho, Colorado, Montana, and Washington, and Wyoming. Several types of organizations have been established to convey and deliver irrigation water from off-farm sources to irrigators (for more information on types of irrigation organizations, see chapter 2.1, USDA, ERS, 1994 (AREI)). Almost all are nonprofit entities with a goal of dependable water service at low cost. In 1998, irrigators reported an average cost of water from off-farm sources of over $41 per acre irrigated, or an estimated $16 per acre-foot delivered (table 2.1.4). Pricing is often based on acreage served, rather than water delivered, since administrative costs are lower with acreage-based charges where 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 independently 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 (for more information on instream flow components of environmental restoration, see pages 80-81 of chapter 2.1, USDA, ERS, AREI, 1997).

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. The influence of the subsidy depends on its magnitude, the availability of water from alternative sources, the profitability of cropping alternatives, and other sectors' water needs and willingness to pay for water supplies.

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. 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.

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 a historical context that considers the goals of the Reclamation program established by Congress. They contend that the historical 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 paid 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.

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 prices 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, but transaction 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).

A 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 of 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, as well as to 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 environment through evaporation, plant transpiration, incorporation in products or crops, or consumption by humans and livestock.

Groundwater—Generally 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 surfacewater and nonrecoverable deep percolation.

Overdrafting—Withdrawing groundwater 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—Generally, an open body of water such as a stream, river, or lake, as opposed to water located below the ground's surface.

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.

Recent ERS Research on Water Issues

"Agriculture and Ecosystem Restoration in South Florida: Assessing Trade-Offs from Water-Retention Development in the Everglades Agricultural Area," *American Journal of Agricultural Economic*s, 83(1):183-195, Feb. 2001 (Marcel Aillery, Robbin Shoemaker, and Margriet Caswell). Irrigated agricultural production—an important economic activity in South Florida—has contributed to some loss of environmental amenities and ecosystem function in the Everglades watershed. Restoration of the Everglades ecosystem has implications for the future extent and profitability of agricultural production in the region. This study applies a model of crop production, soil loss, and water retention in the Everglades Agricultural Area to assess agricultural impacts under alternative water policy and land acquisition scenarios.

"Estimating Producer's Surplus with the Censored Regression Model: An Application to Producers Affected by Columbia River Basin Salmon Recovery," *Journal of Agricultural and Resource Economics.* 25:325-346, Dec. 2000 (Michael R. Moore, Noel R. Gollehon, and Daniel M. Hellerstein). In this study, crop supply functions are estimated for multi-output irrigators in the Pacific Northwest, with expected producer's surplus (profits) and confidence intervals computed based on the supply functions. An experiment predicts decreases in the expected producer's surplus given increases in water prices (measured as water pumping costs). The experiment replicates the numerical range and geographic pattern of possible increases in hydroelectric prices attributable to the salmon recovery program in the Columbia-Snake River Basin. Output substitution explains producers' ability to mitigate the effect of the price increases on producer's surplus.

"Irrigation in the American West: Area, Water, and Economic Activity," *International Journal of Water Resource Development*. 16(2):187-195, June, 2000 (Noel Gollehon and William Quinby). Irrigation in the American West is examined based on consistent data sources using three measures: irrigated area, water use in irrigation, and the sales value of crops produced. We find that irrigation accounts for about three-fourths of the value of crops sold from about one-fourth the harvested cropland in the West. In accomplishing the higher sales, irrigated agriculture accounts for three-quarters of the water withdrawn and most of the water use in the West.

"Economic and Conservation Tradeoffs of Regulatory vs. Incentive-based Water Policy in the Pacific Northwest," *International Journal of Water Resource Development*. 16(2):221-238, June, 2000 (Glenn Schaible). Onfarm water conservation and economic tradeoffs between selected regulatory- and incentive-based water policy perspectives are analyzed using a total of 37 alternative policy scenarios. Results demonstrate that incentive-based water policy, when integrated within balanced policy reform, can produce upwards of 1.7 million acre-feet of onfarm conserved water for the region, while also significantly increasing economic returns to farmers. Producer willingness to accept water policy change is lowest for regulatory policy ($4-$18 per acre-foot of conserved water), but highest for conservation incentive policy that increases both irrigation efficiency and crop productivity ($67-$208 per acre-foot of conserved water).

(continued)

Recent ERS Research on Water Issues (continued)

"The Edwards Aquifer Water Resource Conflict: USDA Farm Program Resource-Use Incentives?" *Water Resources Research*, 35(10):3171-3183, October 1999 (Glenn D. Schaible, Bruce A. McCarl, and Ronald D. Lacewell). This paper summarizes economic and hydrological analyses of the impacts of the 1990 and 1996 USDA farm programs on irrigation water withdrawals from the Edwards Aquifer in south central Texas, and on aquifer-dependent spring flows that support threatened and endangered species. Economic modeling, a regional producer behavioral survey, as well as institutional and farm characteristic analyses are used to examine likely irrigation water-use impacts. Hydrologic modeling is used to examine spring-flow effects. Study results show that USDA commodity programs caused producers to require less irrigation water, in turn increasing rather than decreasing aquifer spring flows. Market economic factors are the dominant criteria influencing producer irrigation decisions.

An Economic Assessment of the 1999 Drought, AIB No. 755, USDA/ERS, September 1999 (Mitchell Morehart, Noel Gollehon, Robert Dismukes, Vince Breneman, and Ralph Heimlich). While the 1999 drought has had severe financial impacts on agricultural producers in the drought regions, its impact on U.S. agricultural production has been limited. The drought will reduce commodity receipts relative to 1998 by an estimated $1.29 billion. Estimated net farm income losses, including expected yield losses, increases in expenses, and insurance indemnities, will total $1.35 billion, about 3 percent of expected 1999 U.S. net farm income. The crops grown in affected regions, the increased use of irrigation, and crop insurance coverage limited the drought's impacts on agriculture nationally. Drought also affects the rural population by reducing water supplies available for human and livestock consumption

"Water Markets: Implications for Rural Areas of the West," *Rural Development Perspectives*, Vol 14, No. 2. USDA/ERS, August 1999 (Noel Gollehon). Market transfers of water from irrigated agriculture are viewed as one of the most likely ways to accommodate new demands for water supplies. Market transfers generally improve statewide economic efficiency by shifting water to higher valued uses. However, case studies find the impact of these transfers on agriculturally dependent rural communities to be significant because the costs accrue to the area of origin and the benefits to the area of new water use.

"Salmon Recovery in the Columbia River Basin: Analysis of Measures Affecting Agriculture," *Marine Resource Economics*, 14:15-40, Spring 1999 (Marcel Aillery, Michael Moore, Marca Weinberg Robbin, Glenn Schaible, and Noel Gollehon). Recovery measures such as modified timing for dam releases, reservoir drawdown, and flow augmentation in the Columbia River Basin, if combined, would increase power rates, grain transportation costs, and irrigation water costs and reduce the supply of water to irrigators. The authors quantify these input cost and quantity changes and combine them into seven recovery scenarios for analysis. Results suggest that drawdown and/or minor reductions in irrigation water diversions would reduce producers' profits by less than 1 percent of baseline levels. However, the most extreme scenario—a long drawdown period combined with a large reduction in irrigation diversions—would reduce producers' profits by $35 million (2.5 percent) annually.
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