2.1 Water Use and Pricing

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

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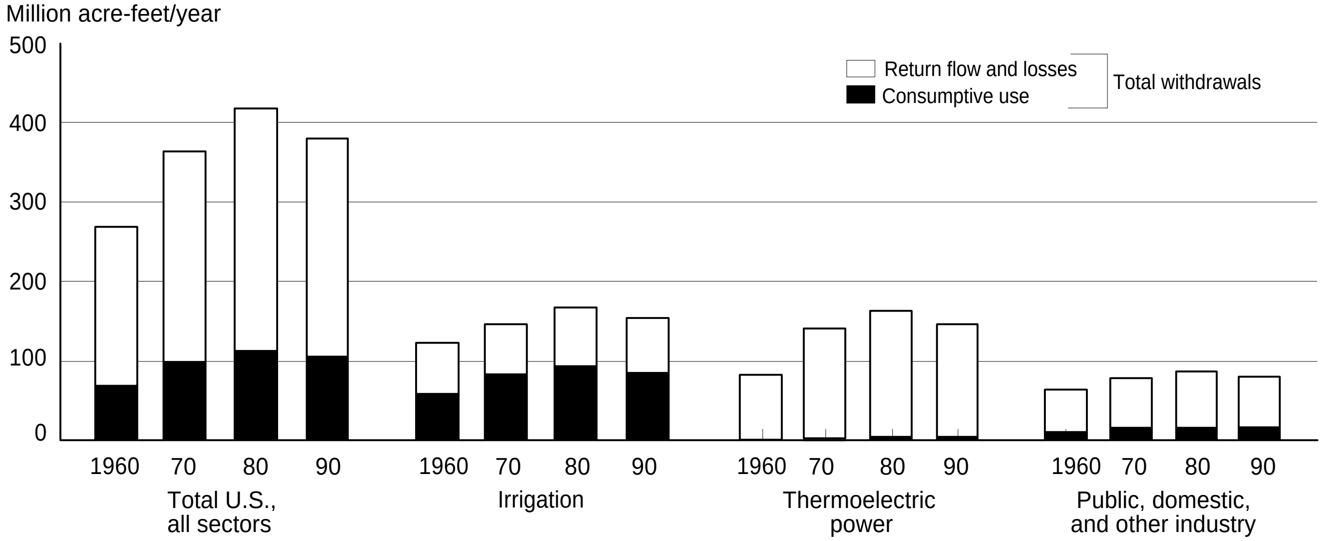
The United States, as a whole, has adequate water supplies. Annual renewable supplies in surface-water bodies and groundwater aquifers total roughly 1,500 million acre-feet per year (maf/yr). (See "Glossary of Water Use Terms" for definitions.) Of total renewable supplies, only one-quarter is withdrawn for use in homes, farms, and industry, and just 7 percent is consumptively used (Moody, 1993).[1] Renewable surface- and groundwater supplies account for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

[1] Consumptive uses considered here include those uses occurring after water is withdrawn from a river or aquifer.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

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

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



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

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

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

Irrigation Withdrawals

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

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

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

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

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

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

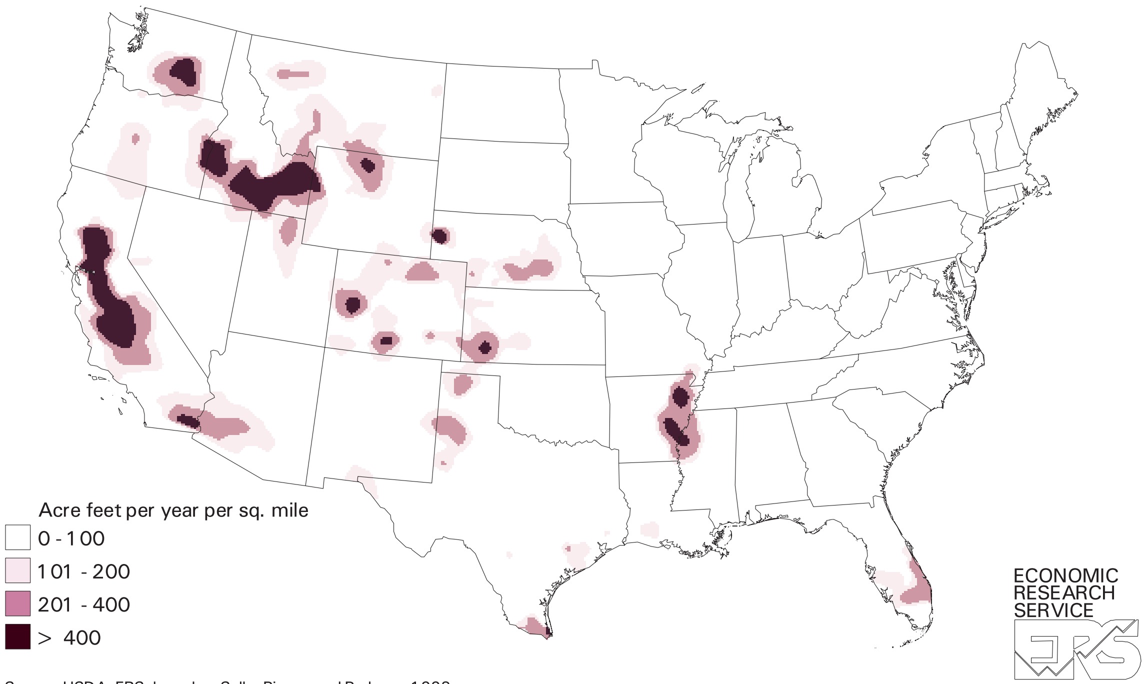
[1] Withdrawal and consumptive use estimates are from the U.S. Geological Survey. They include freshwater irrigation on cropland, parks, golf courses, and other recreational lands.
[2] States are ranked based on total irrigation consumptive use.
[3] maf represents 1 million acre-feet.
[4] May not add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

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

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

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

Figure 2.1.2--Fresh water withdrawals for irrigation, 1990



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

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

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

Irrigation Consumptive Use

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

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

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

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

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

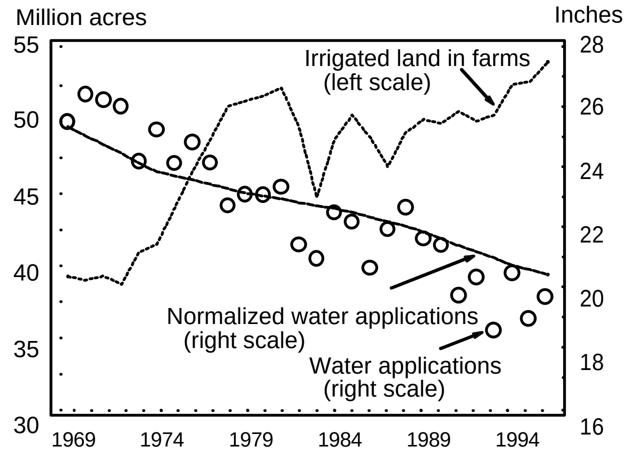
Irrigation's share of total consumptive water use fell by roughly 4 percent over 1960-90. A 4-percent share of the 1990 total water use represents more than 3 maf, or 17 percent of all nonirrigation water uses. This suggests that growth in nonagricultural water needs, particularly in areas with limited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

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

Irrigated Land in Farms

While national area of irrigated farmland is once again near peak levels reached in 1981 (fig. 2.1.3), varying regional trends reflect differences in water resource conditions. Western irrigation reached its peak with the agricultural export boom and high crop prices of the 1970's. The Southwest—the first region to fully utilize available water resources—became the first region to begin abandoning irrigated acreage in the face of growing water demand for urban and environmental uses. Farmers in 6 Southwest States and in the Southern Plains irrigated 3 million acres less in 1995 than in 1981. In contrast, farmers in the Northern Plains and eastern regions continue to expand irrigation capacity, irrigating 3 million acres more in 1995 than in 1981.

Figure 2.1.3--Irrigation trends, 1969-96



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

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

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

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

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

Source: USDA, ERS, based on USDC, 1994

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

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

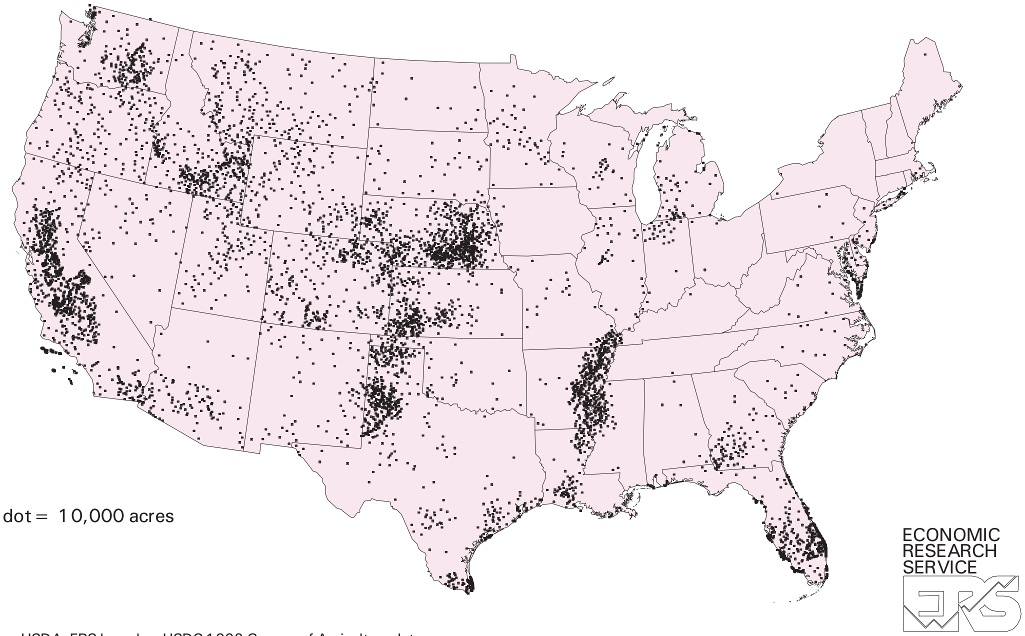
In addition to regional shifts in acreage, there has been a shift in the crop mix on irrigated cropland. Sorghum area irrigated has declined significantly due to improved dryland cultivars, limited water in primary growing areas, and lower returns relative to other irrigated crops. Irrigated areas of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

Irrigation Water Application Rates

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

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

Figure 2.1.4--Irrigated land in farms, 1992



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

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

Irrigation Water Prices and Costs

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

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

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

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

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

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

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

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

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

Groundwater Costs

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

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

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

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

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

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

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

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

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

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

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

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

Surface-Water Costs

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

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

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

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

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

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

Water Costs on Federal Projects

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

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

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

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

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

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

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

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

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References

Aillery, M.P., P. Bertels, J.C. Cooper, M.R. Moore, S.J. Vogel, and M. Weinberg (1996). *Salmon Recovery in the Pacific Northwest: Agricultural and Other Economic Effects*. U.S. Department of Agriculture, Economic Research Service, AER-727.

Baldwin, P., E.H. Buck, B.A. Cody, and M.L. Corn (1993). *The Edwards Aquifer and Vulnerable Species*. The Library of Congress, Congressional Research Service, No. 93-484 ENR.

Collinge, R.A., P.M. Emerson, R.C. Griffin, B.A. McCarl, and J.D. Merrifield (1993). *The Edwards Aquifer: An Economic Perspective*. Texas A&M University, Texas Water Resources Institute, TR-159.

Finkl, C.W. (1995). "Water Resource Management in the Florida Everglades: Are 'Lessons from Experience' a Prognosis for Conservation in the Future?" *The Journal of Soil and Water Conservation.* 50(6):592-600, Nov./Dec.

Forest Service, Bureau of Land Management, U.S. Army Corps of Engineers, and National Park Service (1995). "National Survey on Recreation and the Environment: 1994-1995 Key Findings" presentation during the Congressional Reception and Exhibition sponsored by the Sporting Goods Manufacturers Association, October 25, 1995. Washington, DC.

Foxworthy, B.L., and D.W. Moody (1986). "Water-Availability Issues: National Perspective on Surface-Water Resources." *National Water Summary 1985--Hydrologic Events and Surface-Water Resources*. U.S. Geological Survey, U.S. Department of the Interior. Water Supply Paper 2300, pp. 51-68.

McClurg, S. (1996). "Delta Developments," *Western Water*. Water Education Foundation, Sacramento, CA. Jan/Feb: 4-13.

Mecham, D., and B.M. Simon (1995). "Forging a New Federal Reclamation Water Pricing Policy: Legal and Policy Considerations," *Arizona State Law Journal* 27 (2), Summer, pp. 509-557.

Glossary of Water Use Terms

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Moody, D.W. (1993). "Water: Fresh-Water Resources of the United States," *Research & Exploration*. Water Issue, National Geographic Society, Washington DC, pp. 80-85.

National Research Council Water Science and Technology Board (1996). *A New Era for Irrigation.* Washington, DC.

Solley, W.B., R.R. Pierce, and H.A. Perlman (1993). *Estimated Use of Water in the United States in 1990*. U.S. Geological Survey, U.S. Department of the Interior. Circular 1081.

South Florida Water Management District (1995). *South Florida Ecosystem Restoration Plan*. West Palm Beach, FL, Nov.

U.S. Department of Agriculture, Economic Research Service (1994). *Agricultural Resources and Environmental Indicators*. AH-705.

U.S. Department of Commerce, Bureau of the Census (1996). *Farm and Ranch Irrigation Survey (1994)*. Volume 3, Part 1 Related Surveys of *1992 Census of Agriculture*, AC92-RS-1. U.S. Government Printing Office, Washington, DC.

Instream Water Flows

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

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

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

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

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

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

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

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Instream Water Flows (cont.)

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

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

_____ (1994). *1992 Census of Agriculture*. Volume 1, Parts 1-51. U.S. Government Printing Office, Washington, DC.

_____ (1990). *Farm and Ranch Irrigation Survey (1988)*. Volume 3, Part 1 Related Surveys of *1987 Census of Agriculture*, AC87-RS-1. U.S. Government Printing Office, Washington, DC.

_____ (1989). *1987 Census of Agriculture*. Volume 1, Parts 1-51. U.S. Government Printing Office, Washington, DC.

_____ (1986). *1984 Farm and Ranch Irrigation Survey*. Special Report Series, AG84-SR-1. U.S. Government Printing Office, Washington, DC.

_____ (1984). *1982 Census of Agriculture*. Volume 1, Parts 1-51. U.S. Government Printing Office, Washington, DC.

_____ (1982). *1979 Farm and Ranch Irrigation Survey*. Volume 5, Part 8 Special Reports of *1978 Census of Agriculture*, AC78-SR-8. U.S. Government Printing Office, Washington, DC.

U.S. Department of the Interior, Bureau of Reclamation (no date). *1995 Irrigation Water Rates, Central Valley California*. Bureau of Reclamation; Mid-Pacific Region, Sacramento, CA.

_____ (no date). *1991 Summary Statistics*. Bureau of Reclamation; Analysis, Contracts, and Lands Division; Denver, CO.

U.S. General Accounting Office (1996). "Bureau of Reclamation: Information on Allocation and Repayment of Costs of Constructing Water Projects." GAO/RCED-96-109. Washington, DC.

Recent ERS Research on Water Issues

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

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

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

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

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

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

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2.2 Water Quality

Agricultural production often emits pollutants that affect the quality of the Nation's water resources and impose costs on water users. The extent and magnitude of agricultural pollution is difficult to assess because of its nonpoint nature. However, agriculture is the leading source of impairment in the Nation's rivers and lakes, and a major source of impairment to estuaries.

Contents

Producing food and fiber involves many activities and practices that can affect the quality of water resources under and near the field. For example, tilling the soil and leaving it without plant cover for extended periods of time results in accelerated soil erosion. The use of chemical inputs increases the probability that some of these materials will wash off or leach through the field to enter water resources. Irrigation can move salt and other dissolved minerals to surface water. Livestock operations produce large amounts of waste which, if not properly disposed of, can threaten human health as well as contribute to excess nutrient problems in streams, rivers, and lakes.

Quality of the Nation's Water

The Clean Water Act (passed in 1972 as the Federal Water Pollution Control Act) defines water quality in terms of designated beneficial uses with numeric and narrative criteria that support each use. Designated beneficial uses are the desirable uses that water resources should support. Examples are drinking water supply, primary contact recreations, and aquatic life support. Numeric water quality criteria establish the minimum physical, chemical, and biological parameters required for water to support a beneficial use. Physical and chemical criteria may set maximum concentrations of pollutants, acceptable ranges of physical parameters, and minimum concentrations of desirable parameters, such as dissolved oxygen. Biological criteria describe the expected attainable community attributes and establish values based on measures such as species richness, presence or absence of indicator taxa, and distribution of classes of organisms (EPA, 1994). Narrative water quality criteria define conditions and attainable goals that must be maintained to support a designated use. Narrative biological criteria describe aquatic community characteristics expected to occur within a water body.

Surface-Water Quality

The Nation's surface-water quality has improved since 1972, primarily through reductions in pollution from point sources. However, many water quality problems remain. Water Quality Inventories, published by the U.S. Environmental Protection Agency (EPA), show no major improvement in the quality of the Nation's rivers, lakes, ponds, and estuaries since 1990 (EPA, 1995). Agriculture is cited by States as a leading source of water quality impairment. A little over one-third of river miles, lake acres (excluding the Great Lakes), and estuarine waters assessed by the States were found to not fully support their designated uses in 1994 (table 2.2.1).

The Great Lakes continue to suffer serious pollution, even though some progress has been made in reducing the worst cases of nutrient enrichment

Table 2.2.1—Status of the Nation's surface-water quality, 1988-94

Item	Rivers				Lakes[1]				Estuaries			
	1988	1990	1992	1994	1988	1990	1992	1994	1988	1990	1992	1994
	Percent of total water											
Water systems assessed	29	36	18	17	41	47	46	42	72	75	74	78
	Percent of assessed waters											
Meeting designated uses:												
Supporting	70	69	62	64	74	60	56	63	89	67	68	63
Partially supporting	20	21	25	22	17	19	35	28	8	25	23	27
Not supporting	10	10	13	14	10	21	9	9	3	8	9	9
Clean Water Act goal of fishable:												
Meeting	86	80	66	69	95	70	69	69	97	77	78	70
Not meeting	11	19	34	31	5	30	31	31	3	23	22	30
Not attainable	3	1	-	-	-	0	-	-	0	-	0	0
Clean Water Act goal of swimmable:												
Meeting	85	75	71	77	96	82	77	81	92	88	83	85
Not meeting	11	15	20	23	4	18	22	19	1	12	17	15
Not attainable	4	10	9	-	-	-	-	-	7	-	0	-

- = less than 1 percent of assessed waters.
[1] Excluding Great Lakes.
Source: USDA, ERS, based on Environmental Protection Agency National Water Quality Inventories, 1988, 1990, 1992, 1994.

(particularly in Lake Erie). Only 3 percent of the assessed shoreline miles (with 96 percent assessed) fully support designated uses (EPA, 1995). Sixty-three percent of the assessed shoreline does not support designated uses at all. Most of the Great Lakes shoreline is polluted with toxic organic chemicals, primarily PCB's and DDT that are often found in fish samples. Atmospheric deposition of toxics, including pesticides, and contaminated sediments are the leading sources of impairment.

The Chesapeake Bay, the largest estuary in the world, has seen water quality degrade over time because of agricultural development, population growth, and sewage treatment plant emissions. While an aggressive program has reduced phosphorus, nitrogen concentrations remain high, leaving the bay overenriched. Shellfish harvests have declined dramatically in recent years, and poor water quality is believed to be an important contributing factor.

Contaminated seafood and fishkills are also indicators of surface water quality. States issue fish consumption advisories to protect the public from ingesting harmful quantities of toxic pollutants. All States but Alaska, South Dakota, and Wyoming issued fish consumption advisories in 1994, for a total of 1,531. This was up from 1,279 fish consumption advisories in 46 States in 1993 (EPA, 1994). Mercury, PCB's, chlordane, dioxin, and DDT caused more than 93 percent of the fish consumption advisories in 1994. These contaminants have been linked with human birth defects, cancer, neurological disorders, and kidney ailments. In addition, bacterial and viral contamination closed over 6,000 square miles of shellfish beds in 15 States during 1992-94. Most of the problems are from improperly treated sewage and urban runoff, but animal waste also contributes.

The number of fishkills provides some idea of pollutant impacts on aquatic life. These are most often sporadic events, rather than a chronic problem. Thirty-two States, tribes, and other jurisdictions reported 1,454 fishkill incidents during 1992-93 (EPA, 1995). Pesticides and manure/silage were identified by States as major contributors to fishkill incidents.

Groundwater Quality

Some States report on the general quality of their groundwater resources in Section 305(b) reports. Of 38 States that reported overall groundwater quality in 1992, 29 judged their goundwater quality to be good or excellent (EPA, 1994). Generally, States report that degradation of groundwater resources is a local occurrence. Agriculture was cited as a source in 44 of the 49 States that reported major sources of groundwater contamination.

An indication of agriculture's impact on groundwater quality comes from the EPA's National Survey of Pesticides in Drinking Water Wells, conducted in 1988-90. The survey provided the first national estimates of the frequency and concentrations of pesticides and nitrate in community water system wells and rural domestic drinking water wells. (Results of this survey are reported in following sections.) In summary, the proportion of wells found to contain any particular pesticide or pesticide degradate was low. However, many wells were affected by the presence of nitrate at levels exceeding EPA health guidelines.

Agricultural Pollutants

Agricultural production produces a wide variety of pollutants. These include sediment, nutrients, pesticides, salts, and pathogens. While farmers do not intend for these materials to move from the field to water resources, they often do. For example, as much as 15 percent of the nitrogen fertilizer and up to 3 percent of pesticides applied to cropland in the Mississippi River Basin makes its way into the Gulf of Mexico (Goolsby and Battaglin, 1993). States reported that agriculture is the leading remaining source of impairment in the Nation's rivers and lakes, and a major source of impairment in estuaries (EPA, 1995). An estimated 71 percent of U.S. cropland (nearly 300 million acres) is located in watersheds where the concentration of at least one of four common surface-water contaminants (nitrate, phosphorus, fecal coliform bacteria, and suspended sediment) exceeded generally accepted criteria in 1989 (Smith, Schwarz, and Alexander, 1994).

Sediment

Disturbing the soil through tillage and cultivation and leaving it without vegetative cover increases the rate of soil erosion. Dislocated soil particles can be carried in runoff water and eventually reach surface water resources, including streams, rivers, lakes, reservoirs, and wetlands. Sediment causes various damage to water resources and to water users.

Table 2.2.2—Trends in concentrations of agricultural water pollutants in surface waters, 1980-90

Water resources region	Nitrate	Phos-phorus	Suspended sediment
	Average percentage change per year		
North Atlantic	*	-1.4	-0.4
South Atlantic-Gulf	*	0.1	0.2
Great Lakes	*	-3.3	0.5
Ohio-Tennessee	*	-1.0	-1.3
Upper Mississippi	-0.4	-1.2	-1.3
Lower Mississippi	-1.6	-3.8	-1.2
Souris-Red-Rainy	*	-0.8	1.2
Missouri	*	-1.7	-0.2
Arkansas-White-Red	*	-3.1	-0.7
Texas-Gulf-Rio Grande	*	-0.9	-0.6
Colorado	*	-2.4	-0.8
Great Basin	*	-2.7	-0.2
Pacific Northwest	*	-1.7	-0.1
California	*	-1.4	-0.6

* Between -0.1 and 0.1.
Source: USDA, ERS, based on Smith, Alexander, and Lanfear, 1993.

Accelerated reservoir siltation reduces the useful life of reservoirs. Sediment can clog roadside ditches and irrigation canals, block navigation channels, and increase dredging costs. By raising stream beds and burying streamside wetlands, sediment can increase the probability and severity of floods. Suspended sediment can increase the cost of water treatment for municipal and industrial water uses. Sediment can also destroy or degrade aquatic wildlife habitat, reducing diversity and damaging commercial and recreational fisheries.

Siltation is one of the leading pollution problems in U.S. rivers and streams and among the top four problems in lakes and estuaries (EPA, 1995). Sediment damages from erosion have been estimated to be between $2 billion and $8 billion per year (Ribaudo, 1989). These include damages or costs to navigation, reservoirs, recreational fishing, water treatment, water conveyance systems, and industrial and municipal water use.

Soil conservation efforts over the past 10 years, particularly the Conservation Reserve Program and Conservation Compliance, are starting to pay off (see chapters 6.2 and 6.3). The National Resources Inventory reports that the average rate of sheet and rill erosion on cropland declined by about one-third between 1982 and 1992. In most regions of the country, the U.S. Geological Survey (USGS) found that suspended sediment concentrations trended slightly downward over the 1980's, particularly in the Ohio-Tennessee, and Upper and Lower Mississippi regions (table 2.2.2) (Smith, Alexander, and Lanfear, 1993). Areas characterized by corn and soybean production and mixed crops had the greatest downward trends.

Nutrients

Nutrients can enter water resources three ways. *Runoff* transports pollutants over the soil surface by rainwater or irrigation water that does not soak into the soil. Nutrients move from fields to surface water while dissolved in runoff water or adsorbed to eroded soil particles. *Run-in* transports chemicals directly to groundwater through sinkholes or porous or fractured bedrock. *Leaching* is the movement of pollutants through the soil by percolating rain or irrigation water. Soil organic matter content, clay content, and permeability all affect the potential for nutrients in soils to leach through the root zone.

Important nutrients from a water quality standpoint are nitrogen and phosphorus. Nitrogen, primarily found in the soil as nitrate, is easily soluble and is transported in surface runoff, in tile drainage, or with leachate. Phosphorus, primarily in the form of phosphate, is only moderately soluble and, relative to nitrate, is not very mobile in soils and ground water. However, erosion can transport considerable amounts of suspended phosphorus to surface waters.

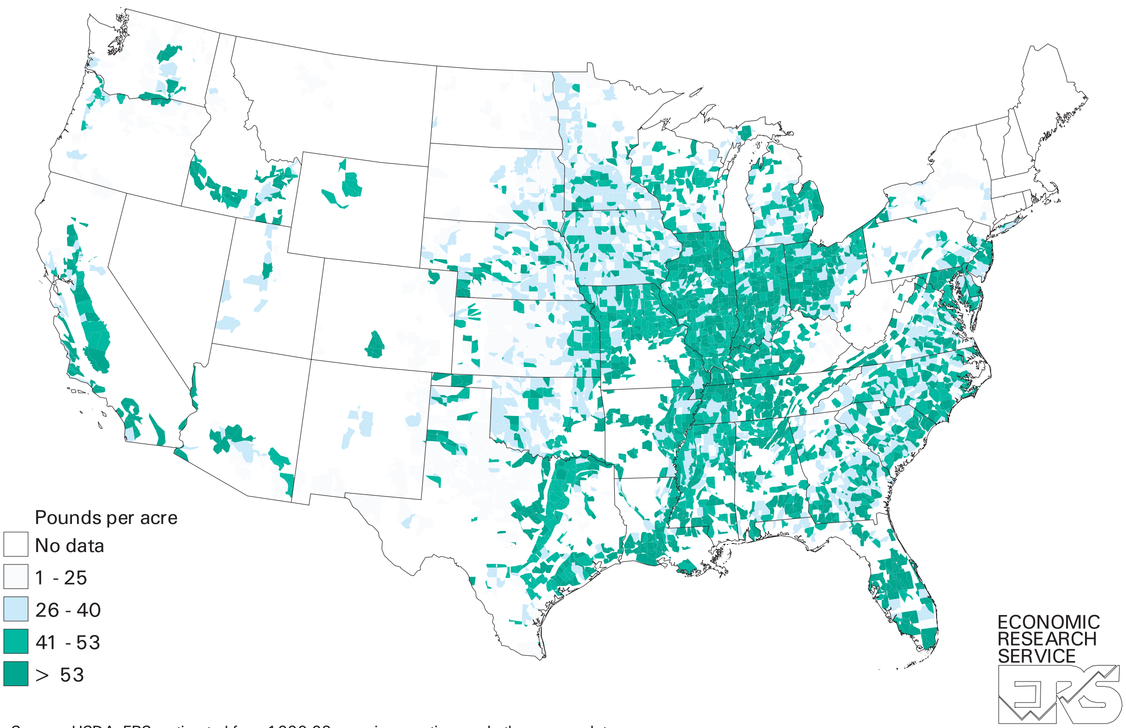
Nutrients from agriculture can accelerate algal production in receiving surface water, resulting in a variety of water-quality problems, including clogged pipelines, fishkills, and reduced recreation opportunities. Nitrate is the only nutrient for which the EPA has established a maximum contaminant level (MCL, a legal maximum long-term exposure) in drinking water (10 mg/L). Nitrate can be converted to nitrite in the gastrointestinal tract. In infants under 6 months of age, this nitrite could cause methemoglobinemia, otherwise known as "blue-baby syndrome," which prevents the transport of sufficient oxygen in the bloodstream. The presence of nitrate in concentrations above 10 mg/L in sources of public drinking water systems requires additional treatment, with associated treatment costs.

EPA reports that nutrient pollution is the leading cause of water quality impairment in lakes and estuaries, and is the third leading cause in rivers (1995). Agriculture is the primary source of nutrients in impaired surface waters.

From its 1988-90 national survey of drinking water wells, the EPA found nitrate in more than half of the 94,600 community water system (CWS) wells and almost 60 percent of the 10.5 million rural domestic wells, making nitrate the most frequently detected chemical in well water. However, only 1.2 percent of the CWS's and 2.4 percent of the rural domestic wells were estimated to contain levels above the MCL. About 3 million people (including 43,500 infants) using water from CWS's and about 1.5 million people (including 22,500 infants) using rural wells are exposed to nitrate at levels above the MCL (EPA, 1992). Higher findings for rural domestic wells are expected since they are closer to farmland and are generally shallower than wells used by CWS's, making them more susceptible to contamination. More recently, the USGS found that the MCL was exceeded in about 1 percent of CWS's, but 9 percent of rural domestic wells (Mueller and others, 1995). The difference with EPA's findings is probably due to different sampling strategies. The USGS found that about 21 percent of wells under agricultural land exceeded the MCL in selected watersheds, with particularly high proportions exceeding the MCL in the Northern Plains (35 percent) and the Pacific (27 percent) regions.

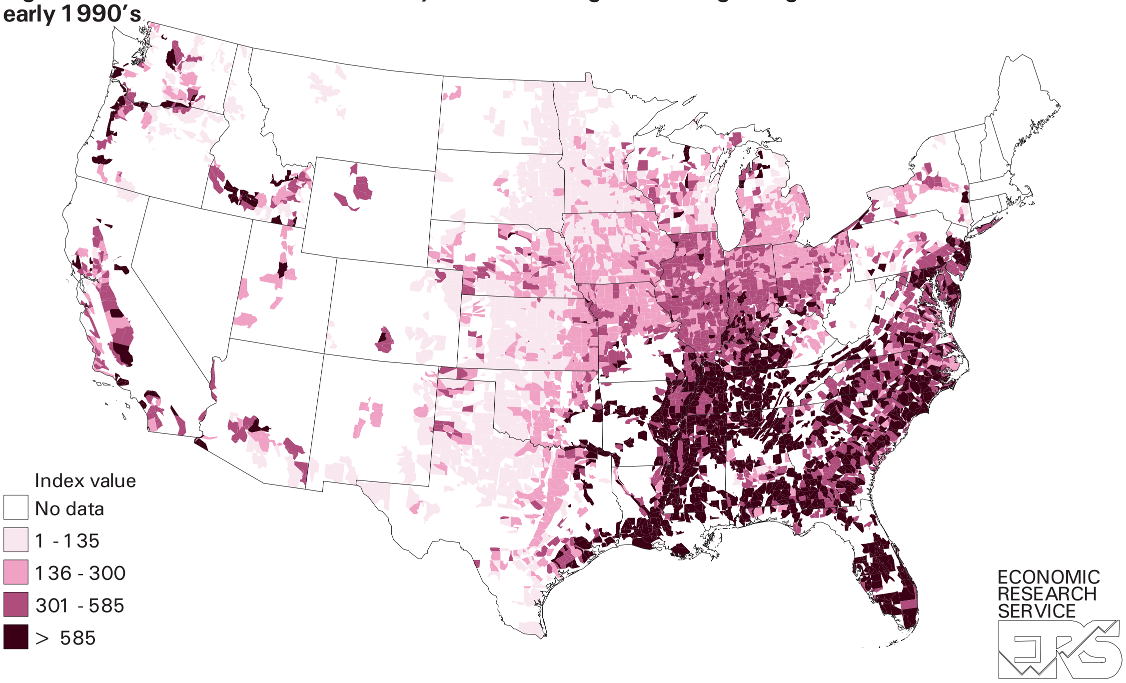
Residual nitrogen is that portion of nitrogen available from natural and manmade sources that is not taken up by crops. Residual nitrogen on cropland (nitrogen from both commercial and manure sources in excess of plant needs) is an indicator of potential nitrate availability for runoff to surface water or leaching to ground water. Regions with relatively high residual nitrogen include the Corn Belt, parts of the Southeast, and the intensively irrigated areas of the West (fig. 2.2.1). However, residual nitrogen by itself does not necessarily result in water quality problems. For example, warm, moist soil conditions in the Southeast tend to volatilize residual nitrogen to the atmosphere, and vegetative buffers capture excess nitrogen before it reaches water systems (Mueller and others, 1995). Therefore, nitrate levels in surface and ground water in the Southeast tend to be low, even though the vulnerability index and residual applications may be high. Regions with the greatest potential for nitrate contamination of groundwater include parts of the Lower Mississippi River, Southeast, and intensively irrigated areas of the West, reflecting areas of heavy

Figure 2.2.1--Residual soil nitrogen including nitrogen from manure, early 1990's



Source: USDA, ERS, estimated from 1990-93 cropping practices and other survey data.

Figure 2.2.2--Groundwater vulnerability index for nitrogen including nitrogen from manure, early 1990's



Source: USDA, ERS, estimated from NRCS National Resources Inventory and 1990-93 Cropping Practices Survey and other data.

use and/or areas with soils prone to leaching (fig. 2.2.2). A similar index is not available for surface water. However, areas with high residual nitrogen and low groundwater vulnerability are more likely to have a high surface-water vulnerability.

Agricultural activities are not the only cause of nutrient pollution. Other sources of nitrogen and phosphorus include point sources such as wastewater treatment plants, industrial plants, and septic tanks. Atmospheric deposition is another nonpoint source of nitrogen. Indeed, more than half the nitrogen emitted into the atmosphere from fossil fuel-burning plants, vehicles, and other sources is deposited on U.S. watersheds (Puckett, 1994). The relative shares of point and nonpoint sources vary by region, with commercial agricultural fertilizers the dominant source in some areas of the West, and in the central and southeastern United States (Puckett, 1994). Nitrogen discharges from point sources, based on National Pollution Discharge Elimination System permits, are concentrated in the Northeast, Lake States, and Appalachian regions, areas with major population centers and large concentrations of industry (fig. 2.2.3). Areas that may have to deal with both point and nonpoint sources include the eastern Corn Belt, the agricultural areas of California, parts of the Southeast, and the Mid-Atlantic region (including Chesapeake Bay).

USGS analysis of nutrients in surface waters over the 1980's shows different trends for nitrate and phosphorus in surface water (table 2.2.2) (Smith, Alexander, and Lanfear, 1993). Nitrate, in general, showed no statistically significant trend, which differs from the rise noted during 1974-81. This follows the pattern of agricultural nitrogen use, which rose sharply during the 1970's, peaked in 1981, and then stabilized. Phosphorus in water during the 1980's continued a decline noted in the 1970's, likely due to improved wastewater treatment, decreased phosphorus content of detergents, reduced phosphorus fertilizer use, and reduced soil erosion. Indeed, the rate of phosphorus decline in water in cropland areas was more than twice that in urban areas.

Pesticides

A wide variety of pesticides, with different levels of toxicity, solubility, and persistence, are applied to agricultural crops to control pests, fungus, and disease (see chapter 3.2, *Pesticides*). Pesticides are extremely important to production, but their use and/or misuse may lead to water quality problems. Pesticides move to water resources much as nutrients do. In addition, some pesticides can be carried into the air attached to dust or as an aerosol, and deposited into water bodies with rainfall.

Pesticide residues reaching surface-water systems may harm freshwater and marine organisms, damaging recreational and commercial fisheries. Pesticides in drinking water supplies pose risks to human health. Some commonly used pesticides have been identified as probable or possible human carcinogens. The presence of regulated pesticides above specified levels in water supplies requires additional treatment, placing added costs on water utilities and their customers. Enforceable drinking water standards have been established for 15 currently used pesticides, and more are pending (see box, "Maximum Contaminant Levels").

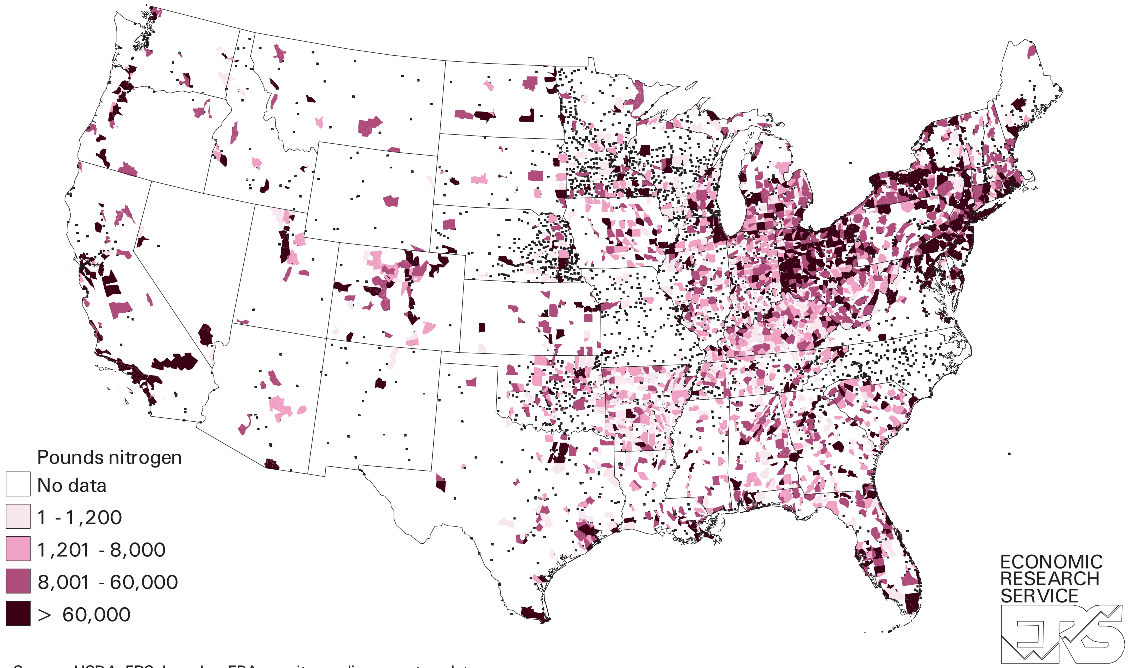
Well over 500 million pounds (active ingredient) of pesticides are applied annually on farmland (see chapter 3.2, *Pesticides*), and certain chemicals can travel far from where they are applied (Smith, Alexander, and Lanfear, 1993; Goolsby and others, 1993). Their presence in food and water has been highlighted and made an issue by environmental and consumer safety groups.

Maximum Contaminant Levels (MCL's)

Public Water Systems are required to make sure that the water they supply does not exceed the MCL for each chemical. These are enforceable standards, set by EPA, that are considered feasible and safe. MCL's have been set for 15 agricultural chemicals.

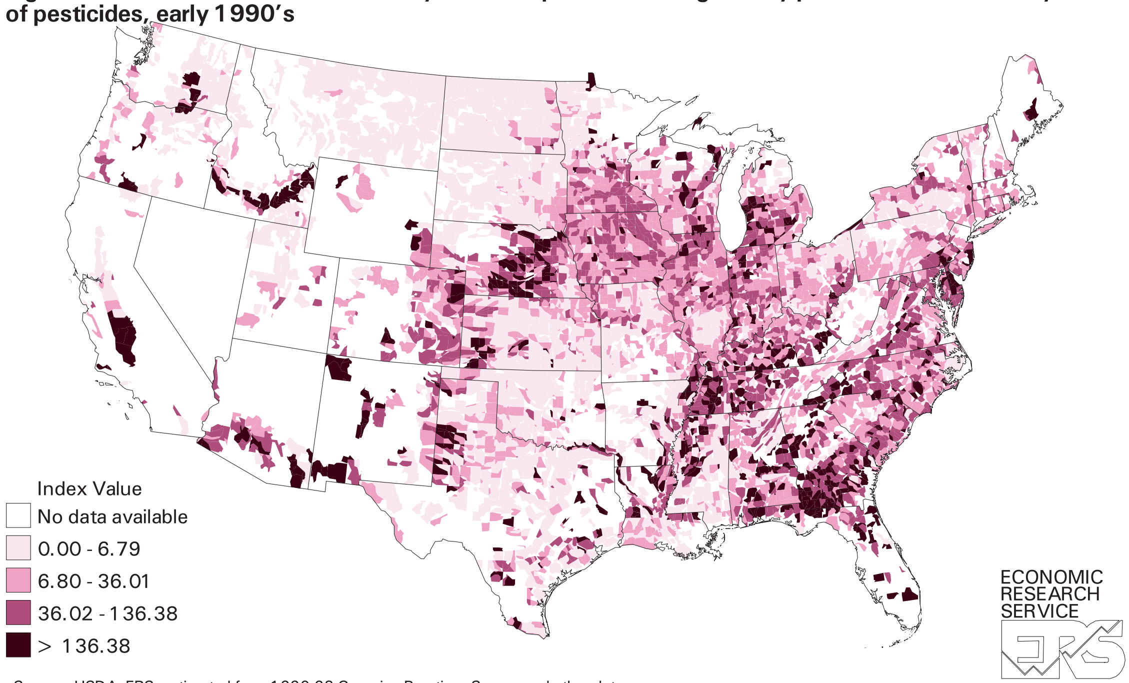
Chemical	MCL (mg/l)	Type chemical
Nitrate	10.0	fertilizer
Alachlor	.002	herbicide
Atrazine	.003	herbicide
Carbofuran	.04	insecticide
2,4-D	.07	herbicide
Dalapon	.2	herbicide
Dinoseb	.007	herbicide
Diquat	.02	herbicide
Endothall	.1	other
Glyphosate	.7	herbicide
Lindane	.0002	insecticide
Methoxychlor	.04	insecticide
Oxamyl	.2	insecticide
Picloram	.5	herbicide
Simazine	.004	herbicide

Figure 2.2.3--Nitrogen from point sources (excluding confined animal operations), 1993



Source: USDA, ERS, based on EPA permit compliance system data.

Figure 2.2.4--Groundwater vulnerability index for pesticides weighted by persistence and toxicity of pesticides, early 1990's



Source: USDA, ERS, estimated from 1990-93 Cropping Practices Survey and other data.

Areas with low pesticide use usually have low detection frequencies (Barbash and Resek, 1995). Conversely, areas where a pesticide is detected frequently are often those of high use. However, low frequencies of pesticide detection are often encountered in areas of high use, indicating that other factors influence pesticide movement.

Most studies of pesticides in surface water focus on the midcontinent region where large amounts of pesticides are used. Goolsby and others (1993) found that herbicides are detected at low levels throughout the year in the rivers of the Midwest, including the Mississippi River. The amounts transported by streams and rivers in the Midwest are generally less than 3 percent of the amount applied, but can still result in concentrations above the MCL. Atrazine (and its metabolites), alachlor, cyanazine, and metolachlor, used principally for weed control in corn and soybeans, were the principal contaminants detected, and are also the most widely used pesticides in the region. Such chemicals, once in drinking water supplies, are not controlled by conventional treatment technologies (Miltner and others, 1989). About 21 million people in the Midwest rely on drinking water from surface sources, about 42 percent of the population.

High concentrations of atrazine in some water supplies in the Midwest have prompted concerns that public water utilities will have to install expensive water treatment systems in order to meet Safe Drinking Water Act requirements. In 1990, about 29 percent of public utilities dumped powdered activated carbon into their systems to spot-treat for organic chemicals, primarily pesticides (American Water Works Association, 1992). If all the treatment plants withdrawing from surface sources upgrade their treatment systems to remove pesticides, annual treatment costs would increase by $400 million per year (Ribaudo and Bouzaher, 1994). Because of these concerns, EPA has placed the triazine herbicides (atrazine, cyanazine, and simazine) under special review due to potential health and ecological concerns. DuPont has already announced that it will phase out its cyanazine production.

Some pesticides leach into underlying aquifers. EPA's survey of drinking water wells found that 10 percent of the CWS's and 4 percent of rural domestic wells contained at least one pesticide (1990). Pesticides or their transformation products have been detected in the ground waters of 43 States (Barbash and Resek, 1995). However, the EPA estimated that less than 1 percent of the CWS's and rural domestic wells had concentrations above MCL's or Lifetime Health Advisory Levels (the maximum concentration of a water contaminant that may be consumed safely over an average lifetime). Problems were found more frequently in shallow wells in agricultural areas. A sampling of wells in corn- and soybean-growing areas in the Midwest found 28 percent of wells had detectable levels of selected pesticides and metabolites, but none exceeded the MCL (Kolpin, Burkart, and Thurman, 1993). Atrazine was the most frequently detected compound.

Groundwater vulnerability to pesticides varies geographically, depending on soil characteristics, pesticide application rates, and the persistence and toxicity of the pesticides used (fig. 2.2.4) (see chapter 3.2, *Pesticides*, for more discussion of persistence and toxicity). Areas with sandy, highly leachable soils, such as central Nebraska and the blueberry barrens of Maine, have high vulnerability ratings. Highly vulnerable areas characterized by heavy applications of generally toxic materials on fruit and vegetable crops include the San Joaquin Valley in California, Florida, and southern Arizona. In contrast, the Corn Belt, despite the widespread use of chemicals, particularly herbicides, has a lower rating than other areas because the predominant soils are not prone to leaching.

Animal Waste

Animal operations can generate large amounts of waste which, if improperly handled or disposed of, can affect the quality of surface- and groundwater resources. Improperly constructed storage pits or lagoons at confined facilities can break or leak, releasing large amounts of concentrated waste directly into surface water. Dissolved material can leach into groundwater if lagoons or pits are improperly lined. Pastured animals allowed to graze near or to water in streams can contaminate water. Improper application of animal waste on fields, such as spreading on frozen ground, can result in large amounts being flushed into water bodies after rain or a thaw.

An issue of increasing importance to water quality is the management of manure from confined animal operations. This stems from increasing concentration in the animal industry, a number of incidents where manure has contaminated local water bodies (see box "Animal Waste Storage Failures"), and a greater awareness of the potential for contamination of drinking water supplies by waste-borne parasites. Larger operations, particularly for hogs and dairy cows, now characterize the industry. As animal production units grow increasingly large and

Animal Waste Storage Failures

The growing concerns over concentrated animal operations were highlighted when a dike around a large hog-waste lagoon in North Carolina failed, releasing an estimated 25 million gallons of hog waste (twice the volume of the oil spilled by the Exxon Valdez) into nearby fields, streams, and the New River. The 8-acre earthen lagoon was built to allow microbes to digest the waste, and is a common form of management for confined operations. The spill killed virtually all aquatic life in the 17-mile stretch between Richlands and Jacksonville, NC.

There are approximately 6,000 confined animal operations with at least 1,000 animal units in the United States. (One animal unit equals 1 beef animal, 0.7 dairy cow, 2.5 hogs, 18 turkeys, or 100 chickens.) Under the Clean Water Act, these facilities cannot discharge to waters except in the event of a 25-year/24-hour storm. This requirement necessitates the construction of onsite storage facilities for holding manure and runoff. In addition to these large operations, facilities with more than 300 animal units that discharge directly to waters are required to take the same measures. Regions with large numbers of animal operations containing more than 1,000 animal units include the Northern Plains (for beef), Pacific (dairy), Corn Belt (swine), Appalachian (swine), and Southeast (broilers).

Most States are responsible for carrying out Clean Water Act regulations. A survey of livestock waste control programs in 10 Midwest and Western States indicated that few States actively inspect facilities for problems, including the integrity of storage structures (Iowa Dept. Nat. Res., 1990). National estimates of broken or leaking storage facilities do not exist. However, a North Carolina State University study estimated that wastes were leaking from half of North Carolina's lagoons built before 1993 (Satchell, 1996), so the problem may be widespread.

specialized, they tend to lack sufficient cropland on which manure can be spread. Without adequate cropland, larger and more sophisticated manure handling and storage systems are required. Improper management, equipment failure, or unusual rainstorms can cause serious water quality problems.

Animal waste contains a number of pollutants. Waste can contain significant amounts of nitrogen and phosphorus. These nutrients pose the same concerns about eutrophication and methemoglobinemia as inorganic sources. In addition, fish and other aquatic organisms may die from ammonia produced as manure decays, or they may suffocate due to insufficient oxygen levels caused by the oxygen-demanding decomposition of organic matter in the manure.

Nitrogen from animal waste is an important source of total nitrogen loads in some parts of the country. Many areas have high ratios of nitrogen from manure on confined animal operations to the operations' land available for spreading (see chapter 4.5, *Nutrient Management*). The highest ratios of nitrogen to land are found in parts of the Southeast, Delta, and Southwest. Studies in 16 watersheds found that manure was the largest nitrogen source in 6, primarily in the Southeast and Mid-Atlantic States (Puckett, 1994).

Animal waste also contains pathogens that pose a threat to human health. Up to 150 diseases from the microorganisms in livestock waste can be contracted through direct contact with contaminated water, consumption of contaminated drinking water, or consumption of contaminated shellfish. Some illnesses that can be contracted from animal waste include cholera, tuberculosis, typhoid fever, salmonella, and polio. Parasites of concern include cryptosporidium and giardia.

Outbreaks of cryptosporidia, a parasite found in the feces of some animals and that causes gastrointestinal illness, are causing growing concern over the safety of water supplies in areas with large numbers of cattle. This organism has been implicated in gastroenteritis outbreaks in Milwaukee, Wisconsin (400,000 cases and 100 deaths in 1993) and in Carrollton, Georgia (13,000 cases in 1987). The cost of the Milwaukee outbreak is estimated to exceed $54 million (*Health and Environment Digest*, 1994). While the source of the organism in these outbreaks was never determined, its incidence in many dairy herds has brought some attention to this sector, especially given the proximity of dairies to population centers.

Salinity

Irrigation return flows can carry dissolved salts, as well as nutrients and pesticides, into surface- or groundwater. Dissolved salts and other minerals can have significant impacts on surface- and groundwater quality. Increased concentrations of naturally occurring toxic minerals, such as selenium and boron, can harm aquatic wildlife and degrade recreation opportunities. Increased levels of dissolved solids in public drinking water supplies can increase water treatment costs, force the development of alternative water supplies, and reduce the lifespans of water-using household appliances. Increased salinity levels in irrigation water can reduce crop yields or damage soils so that some crops can no longer be grown.

Dissolved salts and other minerals are an important cause of pollution in the Southern Plains, arid Southwest, and southern California. Total damages from salinity in the Colorado River range from $310 million to $831 million annually, based on the 1976-85 average levels of river salinity. These include damages to agriculture ($113-$122 million), households ($156-$638 million), utilities ($32 million), and industry ($6-$15 million) (Lohman, Milliken, and Dorn, 1988).

The USGS reports mixed trends of salinity in surface water (Smith, Alexander, and Lanfear, 1993). Measures of dissolved solids (mostly ions of calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride) indicate that water quality improved at more stations than it worsened. However, while salinity trends in water for domestic and industrial purposes generally improved during the 1980's, salinity worsened for irrigation purposes. Among USGS cataloguing units (watersheds) having significant irrigation surface-water withdrawals, the percentage of stations having annual average dissolved solids concentrations greater than 500 mg/L increased during 1980-89 from 30 to 33 percent.

Groundwater Vulnerability Indexes

The groundwater vulnerability index for nitrates (GWVIN) was developed by Kellogg and others (1992). It is a function of soil leaching potential, nitrate leaching potential, precipitation, and nitrogen fertilizer use. Excess nitrogen per acre is the difference between the amount of nitrogen from commercial fertilizer and animal manure applied, including credit for nitrogen fixed by previous leguminous crops, and the amount taken up by the crop.

The groundwater vulnerability index for pesticides (GWVIP), also developed by Kellogg and others (1992), is a function of soil leaching potential, pesticide leaching potential, precipitation, and chemical use. It is an extension of the national-level Soil-Pesticide Interaction Screening Procedure (SPISP) developed by the Natural Resources Conservation Service (Goss and Wauchope, 1990). GWVIP does not depend on the amount of chemical applied, but the type of chemical, its leaching potential, and the leaching potential of the soil to which the chemical is applied. The GWVIP can be weighted by persistence and toxicity to further account for potential harm to the environment. Persistence is defined as the soil half-life. Toxicity is defined as the acute oral toxicity to rats. Chronic toxicity or toxicity to fish would have been preferred, but these data are not available for most pesticides. For further discussion of weighting for persistence and toxicity, see chapter 3.2, *Pesticides*.

Reducing Loadings from Agriculture

Farmers can take many steps to reduce loadings of agricultural pollutants to water resources. Both structural and management practices are available to farmers. In a study of 16 of USDA's 242 Water Quality Program projects, 134 different practices were installed, nearly half of which were labeled "new and innovative" (USDA, NRCS, 1996). Water quality practices work by managing water and chemical inputs more efficiently, or by controlling runoff. Practices include pest management, nutrient management, irrigation water management, animal waste management, tillage management, and runoff control (for more on practices, see chapters 4.1-4.6).

USDA has had several programs that provide farmers the means to adopt water quality practices, including the Agricultural Conservation Program, Water Quality Incentive Projects, and the Water Quality Program. Most current programs focus on providing education, technical, and financial assistance to farmers to get them to adopt alternative management systems that protect water quality. Education raises farmer awareness not only of the potential financial and environmental benefits of alternative practices, but also of the link between the practices they implement and local water quality. Technical and financial assistance provide the means for a farmer to actually try a new practice and to acquire the skill to apply it effectively. Failure of voluntary programs to achieve needed changes in farming practices may increasingly result in regulations, already occurring in a number of States (see chapter 6.2, *Water Quality Programs*, for more on Federal and State programs).

Improvements in water quality from farmers' efforts to reduce pollutant loadings often take years to detect and document. The links between improved management and observed changes in water quality are complex. As many as 10 consecutive years of water quality data are needed before long-term changes can be distinguished from short-term fluctuations (Smith, Alexander, and Lanfear, 1993). Phosphorus accumulated in bottom sediments will affect water quality long after conservation practices have dramatically reduced phosphorus loadings in runoff. Similarly, fish, insects, and other biological indicators of a healthy stream may not reach acceptable levels until many years after water quality improves and riparian habitat is restored. Aquifers may take decades to show improvements in quality after chemical management is improved. In most project areas, agriculture is not the only source of pollution.

In addition, many projects do not establish or maintain adequate water quality monitoring for detecting changes in water quality. National water quality monitoring systems already in place are inadequate for detecting changes in small watersheds where water quality programs have generally been targeted. For these reasons, improvements in water quality may in fact be taking place undetected.

Costs and Benefits of Pollution Control

The assessment of policies to reduce pollution from agricultural production requires a complete knowledge of benefits and costs to water users of changes in water quality. Benefits and costs are measured in terms of changes in economic welfare, represented by consumer and producer surpluses. Estimating the economic effects of changes in water quality is complicated by the lack of organized markets for environmental quality. There are no observed prices with which to measure economic value. A number of methods exist for deriving these measures. One method for estimating consumer surplus is to study an individual's behavior in averting the consequences of poor environmental quality, such as expenditures made to prevent household damages from salinity. A second approach is to exploit the relationship between private goods and environmental quality (when it exists) to draw inferences about the demand for environmental quality. A third approach is to ask individuals to reveal directly their willingness to pay for changes in environmental quality.

When water quality is a factor in the production of a market good, the benefits of changes in quality can be inferred from changes in variables associated with the production of the market good. There are two avenues through which benefits can be obtained. The first is through changes in the price of the marketable good to consumers. The second is through changes in incomes received by owners of factor inputs. The choice of approaches for estimating consumer and produce welfare effects depends largely on the availability of data and the nature of demand for water quality.

Economists have conducted numerous studies of the value of water quality over the years. Most of these studies have focused on specific sites or "local" water quality issues (Crutchfield, Feather, and Hellerstein, 1995). Relatively few studies have looked at the costs of water pollution and the benefits of pollution reduction on a nationwide scale, and none have included costs to all classes of water users (table 2.2.3). However, the results of these studies indicate that the annual benefits from improving water quality could total tens of billions of dollars. Water quality benefits from erosion control on cropland alone could total over $4 billion per year (Hrubovcak, LeBlanc, and Eakin, 1995).

Although increasing, public funds spent on nonpoint source pollution are small compared with the expenditures on point sources. Between $80 and $100 billion of public funding was spent on water pollution control during the 1980's (Ervin, 1995), mainly to control pollutants from municipal sources. In contrast, only $1 to $2 billion has been spent on agricultural water quality initiatives over the last two decades (Ervin, 1995). This spending is much less than the potential benefits from improved water quality. However, an increasing amount of financial and other resources is being directed to agricultural nonpoint source pollution. USDA spent $194 million on water quality-related research, education, technical assistance, financial assistance, and data activities in 1995. Such expenditures have doubled since 1989, despite an overall decrease in USDA expenditures for conservation. Farmers themselves have spent an unknown amount on water quality practices, although in many cases changes were made to enhance profitability. In addition, EPA made over $65 million in regional grant awards to States for agricultural nonpoint source programs in 1994-95, an increase of 50 percent over the previous 2-year period. These funds are frequently contracted to cooperating agencies such as local conservation districts to support project implementation. (For more information on water quality programs, see chapter 6.2.)

Table 2.2.3—National estimates of the damages from water pollution or the benefits from water pollution control

Study/year	Estimate of:	Description
Freeman (1982)	National benefits of water pollution control	Total damages to recreational water uses from all forms of pollution: $1.8-$8.7 billion, "best guess" of $4.6 billion (1978 dollars per year).
Russell and Vaughan (1982)	National recreational fishing benefits from controlling water pollution	Total benefits of $300-$966 million, depending on level of pollution control instituted.
Clark et al. (1985)	National water quality damages from soil erosion on cropland	Damages to all uses: $3.2-$13 billion, "best guess" of $6.1 billion (1980 dollars). Cropland's share of erosion-related damages: $2.2 billion.
Ribaudo (1986)	Regional and national water quality benefits of reducing soil erosion	Erosion reductions from 1983 soil conservation programs implied $340 million in offsite benefits. Benefits per ton of erosion reduced were from $0.28 to $1.50.
Nielsen and Lee (1987)	National costs of groundwater contamination	Monitoring costs for presence of agricultural chemicals put at $890 million-$2.2 billion for private wells, and $14 million for public wells.
Ribaudo (1989)	Regional and national water quality benefits from the Conservation Reserve Program	Reducing erosion via retirement of 40-45 million acres of highly erodible cropland would generate $3.5-$4.5 billion in surface-water quality benefits over the life of the program.
Carson and Mitchell (1993)	National benefits of surface-water pollution control	Annual household willingness to pay for maximum water quality improvement of $205-$279 per household per year, or about $29 billion nationally.
Feather and Heller-stein (1997)	National recreation benefits of soil erosion reductions	A total of $286 million in benefits from erosion reductions on agricultural lands since 1982, based on data from a recreation survey.

Source: USDA, ERS, based on Crutchfield, Feather, and Hellerstein, 1995; and Feather and Hellerstein, 1996.

While regulations were used to reduce point sources, efforts to reduce nonpoint sources have primarily relied on voluntary measures. Analysis has shown that many of the management practices that reduce agricultural nonpoint source pollution are not costly to implement, and may even increase net returns (U.S. Congress, OTA, 1995). A highly targeted approach that emphasizes low-cost land management changes—and that is backed by sound science, technical and financial support, and regulations—would provide the best means of achieving most water quality goals.

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References

American Water Works Association (1992). Water Industry Data Base: Utility Profile. Denver, CO.

Barbash, J.E., and E.A. Resek (1995). *Pesticides in Ground Water: Current Understanding of Distribution and Major Influences*. U.S. Geological Survey.

Carson, R.T., and R.C. Mitchell (1993). "The Value of Clean Water: The Public's Willingness to Pay for Boatable, Fishable, and Swimmable Water Quality," *Water Resources Research*, Vol. 29, No. 7, pp. 245-254.

Clark, E.H., II, J.A. Haverkamp, and W. Chapman (1985). *Eroding Soils: The Off-Farm Impacts*. Washington, DC: The Conservation Foundation.

Crutchfield, S.R., P.M. Feather, and D.R. Hellerstein (1995). *The Benefits of Protecting Rural Water Quality: An Empirical Analysis.* AER-701. U.S. Dept. Agr., Econ. Res. Serv., Jan.

Ervin, D.E. (1995). "A New Era of Water Quality Management in Agriculture: From Best Management Practices to Watershed-Based Whole Farm Approaches," *Water Resources Update*. No. 101, pp. 18-28.

Feather, P., and D. Hellerstein (1997). "Calibrating Benefit Function Transfer To Assess the Conservation Reserve Program," *American Journal of Agricultural Economics*. April.

Freeman, A.M, III (1982). *Air and Water Pollution Control: A Benefit-Cost Assessment*. New York: John Wiley and Sons.

Goolsby, D.A., and W.A. Battaglin (1993). "Occurrence, Distribution, and Transport of Agricultural Chemicals in Surface Waters of the Midwestern United States," in Goolsby, D.A., L.L. Boyer, and G.E. Mallard, *Selected Papers on Agricultural Chemicals in Water Resources of the Midcontinental United States*. Open-File Report 93-418, U.S. Geological Survey. pp. 1-25.

Recent ERS Reports on Water Quality Issues

Accounting for the Environment in Agriculture, TB-1847, October 1995 (James Hrubovcak, Michael LeBlanc, and B. Kelly Eakin). Detailed information derived from the national income and product accounts provides the basis for economic interpretations of changes in the Nation's income and wealth. The effects of soil erosion on agricultural productivity and income, the economic effect of decreased water quality, and depletion of water stock are presented as examples of the potential scope of accounting adjustments needed in the agricultural sector.

USDA's Water Quality Program Enters its 6th Year, AREI Update, 1995, No. 11 (Marc Ribaudo). Sixty-five water quality projects were started in 1995, and 6 projects were completed at the end of 1994. Over 400 water quality projects have been started since 1990.

Voluntary Incentives for Reducing Agricultural Nonpoint Source Water Pollution, AIB-716, May 1995 (Peter Feather and Joe Cooper). Data from the Area Studies are used to evaluate the success of existing incentive programs to control agricultural nonpoint source pollution. Because profitability drives production decisions, these programs tend to be most successful when they promote inexpensive changes in existing practices.

The Benefits of Protecting Rural Water Quality: An Empirical Analysis, AER-701, January 1995 (Stephen R. Crutchfield, Peter M. Feather, and Daniel R. Hellerstein). The use of nonmarket valuation methods to estimate the benefits of protecting or improving rural water quality from agricultural sources of pollution is explored. Two case studies show how these valuation methods can be used to include water-quality benefits estimates in economic analyses of specific policies to prevent or reduce water pollution.

Atrazine: Environmental Characteristics and Economics of Management, AER-699, September 1994 (Marc Ribaudo and Aziz Bouzaher). Atrazine is an important herbicide in the production of corn and other crops in the United States. Recent findings indicate that elevated amounts of atrazine are running off fields and entering surface-water resources. The costs and benefits of an atrazine ban, a ban on pre-plant and pre-emergent applications, and a targeted ban to achieve a surface-water standard are examined.

Cotton Production and Water Quality: Economic and Environmental Effects of Pollution Prevention, AER-664, December 1992 (Stephen Crutchfield, Marc Ribaudo, LeRoy Hansen, and Ricardo Quiroga). The most widespread potential water-quality problems from cotton production are nitrate leaching and losses of pesticides to surface waters. Alternative policies for reducing these types of pollution are evaluated.

Estimating Water Quality Benefits: Theoretical and Methodological Issues, TB-1808, September 1992 (Marc Ribaudo and Daniel Hellerstein). Knowledge of the benefits and costs to water users is required for a complete assessment of policies to create incentives for water quality-improving changes in agricultural production. A number of benefit estimation methods are required to handle the varying nature of water quality effects.

Water Quality Benefits from the Conservation Reserve Program, AER-606, February 1989 (Marc Ribaudo). The Conservation Reserve Program was estimated to generate between $3.5 and $4 billion in water quality benefits if it achieves its original enrollment goal of 40-45 million acres. Potential benefits include lower water treatment costs, lower sediment removal costs, less flood damage, less damage to equipment that uses water, and increased recreational fishing.

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Goolsby, D.A., E.M. Thurman, M.L. Pomes, M. Meyer, and W.A. Battaglin (1993). "Occurrence, Deposition, and Long Range Transport of Herbicides in Preceipitation in the Midwestern and Northeastern United States," in Goolsby, D.A., L.L. Boyer, and G.E. Mallard, *Selected Papers on Agricultural Chemicals in Water Resources of the Midcontinental United States*. Open-File Report 93-418, U.S. Geological Survey. pp. 75-88.

Goss, D.W., and D. Wauchope (1990). "The SCS/ARS/CES Pesticide Properties Database: II, Using it With Soils Data in a Screening Procedure," in D.L. Weigman (ed.), *Pesticides in the Next Decade: The Challenges Ahead*, Virginia Water Resources Research Center, Blacksburg, Virginia, pp. 471-493.

Health and Environment Digest (1994). "*Cryptosporidium* and Public Health," Vol. 8, No. 8. pp. 61-63.

Iowa Dept. of Natural Resources (1990). “Livestock Waste Control Programs of Ten Midwest and Western States,” Environmental Protection Division, Nov.

Hrubovcak, J., M. LeBlanc, and B.K. Eakin (1995). *Accounting for the Environment in Agriculture.* TB-1847. U.S. Dept. Agr., Econ. Res. Serv., Oct.

Kellogg, R.L., M.S. Maizel, and D.W. Goss (1992). *Agricultural Chemical Use and Ground Water Quality: Where Are the Potential Problem Areas?* U.S. Dept. Agr., Soil Cons. Serv., Econ. Res. Serv., Coop. State. Res. Serv., and Nat. Cent. for Resource Innovations.

Kolpin, D.W., M.R. Burkart, and E.M. Thurman (1993). *Hydrologeologic, Water-Quality, and Land-Use Data for the Reconnaissance of Herbicides and Nitrate in Near-Surface Aquifers of the Midcontinental United States, 1991.* Open-File Report 93-114. U.S. Geological Survey.

Lohman, L.C., J.G. Milliken, and W.S. Dorn (1988). *Estimating Economic Impacts of Salinity of the Colorado River*. U.S. Dept. of the Interior, Bureau of Reclamation. Feb.

Miltner, R.J., D.B. Baker, T.F. Speth, and C.A. Fronk (1989). “Treatment of seasonal pesticides in surface waters,” *American Water Works Journal*, Vol. 81, No.1, pp. 43-52.

Mueller, D.K., P.A. Hamilton, D.R. Helsel, K.J. Hitt, and B.C. Ruddy (1995). *Nutrients in Ground Water and Surface Water of the United States - An Analysis of Data Through 1992.* Water-Resources Investigations Report 95-4031. U.S. Dept. of the Interior, Geological Survey.

Nielsen, E.G., and L.K. Lee (1987). *The Magnitude and Costs of Groundwater Contamination from Agricultural Chemicals*. AER-576. U.S. Dept. Agr., Econ. Res. Serv., Oct.

Puckett, L.J. (1994). *Nonpoint and Point Sources of Nitrogen in Major Watersheds of the United States.* Water-Resources Investigations Report 94-4001. U.S. Dept. of the Interior, Geological Survey.

Ribaudo, M.O. (1989). *Water Quality Benefits from the Conservation Reserve Program*. AER-606. U.S. Dept. Agr., Econ. Res. Serv., Feb.

Ribaudo, M.O. (1986). *Reducing Soil Erosion: Offsite Benefits.* AER-561. U.S. Dept. Agr., Econ. Res. Serv., Sept.

Ribaudo, M.O., and A. Bouzaher (1994). *Atrazine: Environmental Characteristics and Economics of Management.* AER-699. U.S. Dept. Agr., Econ. Res. Serv., Sept.

Russell, C.S., and W.J. Vaughan (1982). “The National Recreational Fishing Benefits of Water Pollution Control.” *Journal of Environmental Economics and Management*, Vol. 9 pp. 328-354.

Satchell, M. (1996). “Hog heaven—and hell,” *U.S. News & Word Report*, Jan. 22, pp. 55-59.

Smith, R.A., G.E. Schwarz, and R.B. Alexander (1994). *Regional Estimates of the Amount of U.S. Agricultural Land Located in Watersheds with Poor Water Quality.* Open-File Report 94-399. U.S. Dept. of the Interior, Geological Survey.

Smith, R.A., R.B. Alexander, and K.J. Lanfear (1993). “Stream water quality in the conterminous United States - Status and trends of selected indicators during the 1980’s,” in U.S. Dept. of the Interior, Geological Survey, *National Water Summary 1990-91: Hydrologic Events and Stream Water Quality*. Water-Suppy Paper 2400. pp. 111-140.

U.S. Congress, Office of Technology Assessment (1995). *Targeting Environmental Priorities in Agriculture: Reforming Program Strategies*. OTA-ENV-640. Sept.

U.S. Department of Agriculture, Natural Resources Conservation Service (1996). *Physical Impacts of Selected USDA Demonstration and Hydrologic Unit Area Water Quality Projects: Final Assessment Report* (draft). Feb.

U.S. Environmental Protection Agency (1992). *Another Look: National Survey of Pesticides in Drinking Water Wells, Phase II Report*. EPA 579/09-91-020, Jan.

U.S. Environmental Protection Agency (1990). *National Pesticide Survey Phase I Report.* EPA 570/9-90-003, Sept.

U.S. Environmental Protection Agency (1992). *National Water Quality Inventory: 1990 Report to Congress.* EPA 503-9-92-006, Apr.

U.S. Environmental Protection Agency (1994). *The Quality of Our Nation’s Water: 1992*. EPA 841-S-94-002, March.

U.S. Environmental Protection Agency (1995). *National Water Quality Inventory: 1994 Report to Congress Executive Summary*. Dec.