Chapter 4.6

Irrigation Water Management

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Efficient irrigation systems and water management practices can help maintain farm profitability in an era of increasingly limited and more costly water supplies. Improved water management practices may also reduce the impact of irrigated production on offsite water quantity and quality, and conserve water for growing nonagricultural demands. The effectiveness of public water conservation programs depends on how such programs account for diverse farm types and the farm-size characteristics of irrigated agriculture.

Why Manage Irrigation Water?

Agriculture, which accounts for about 90 percent of freshwater consumption in the Western States and over 80 percent nationwide, is increasingly being asked to use less water in order to meet societal demands for other uses (see Chapter 2.1, "Irrigation Resources and Water Costs"). Water demands are increasing for municipal and industrial uses, recreation, fish and wildlife habitat, and Native American trust responsibilities. For example, conservation of farm irrigation water was a key component of recent water transfer agreements between the Imperial Irrigation District and the San Diego County Water Authority, expected to account for 200,000 acre-feet of annual water transfers during 2021-2047 (Schaible, 2004a).

Farm-level irrigation water management (IWM) involves the managed allocation of water and related inputs in irrigated crop production to enhance economic returns and minimize environmental impacts. USDA identifies improvements in IWM as essential to meeting its national priorities for reducing agriculturally induced nonpoint-source pollution, including surface- and groundwater contamination, reductions in soil erosion and sedimentation, and conservation of ground and surface water (USDA, 2004b). The National Research Council in *A New Era for Irrigation* (NRC, 1996) highlights the importance of IWM "to allocate limited water resources equitably."

Improved IWM can help reduce loadings of nutrients, pesticides, and trace elements in irrigation runoff to surface waters, and leaching of agrichemicals into groundwater supplies (Schaible and Aillery, 2003). Strategies to improve the Nation's water quality (see Chapter 2.2, "Water Quality: Impacts of Agriculture") must address the effect of irrigation on surface- and groundwater resources (NRC, 1996).

Improvements in IWM can also help maintain the long-term viability of the irrigated agricultural sector. Irrigated cropland is an important and growing component of the U.S. farm economy, accounting for almost half of total crop sales from just 16 percent of the Nation's harvested cropland in 1997

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(USDA, 2001). Water savings at the farm level can help offset the effect of rising water costs and limited water supplies on producer income. Improved water management may also reduce expenditures for energy, chemicals, and labor, while enhancing revenues through higher crop yields and improved crop quality. Strategic IWM may also enable producers to better withstand the downside risks of drought.

Use of Improved Irrigation Technology and Management

Producers may respond to limited water supplies through various means, with differing implications for crop production, farm returns, resource use, and environmental quality. Water use per acre may be reduced by applying less than a crop's full consumptive requirement, by shifting to alternative crops or varieties that use less water, or by adopting more efficient irrigation technologies and management practices. Producers may even convert from irrigated to dryland farming or retire land from production.

With water increasingly scarce, irrigators will likely continue to rely on improved technologies and water management practices to conserve water. Irrigation efficiency, broadly defined at the field level, is the ratio of irrigation water beneficially used (crop consumptive use plus an allowance for leaching of salts) to that applied, expressed as a percentage (USDA, 1997).

Irrigation application systems may be grouped under two broad types: gravity flow and pressurized. ***Gravity-flow systems*** distribute water across the field via land treatments—such as soil borders and furrows—that control lateral water movement and channel it in the field. Water is conveyed to the field by means of open ditches, above-ground pipe (including gated pipe and flexible tubing), or underground pipe, and released along the upper end of the field through siphon tubes, ditch gates, pipe valves, or pipe orifices. ***Pressurized systems*** include a variety of sprinkler and low-flow irrigation techniques to distribute water across a field.

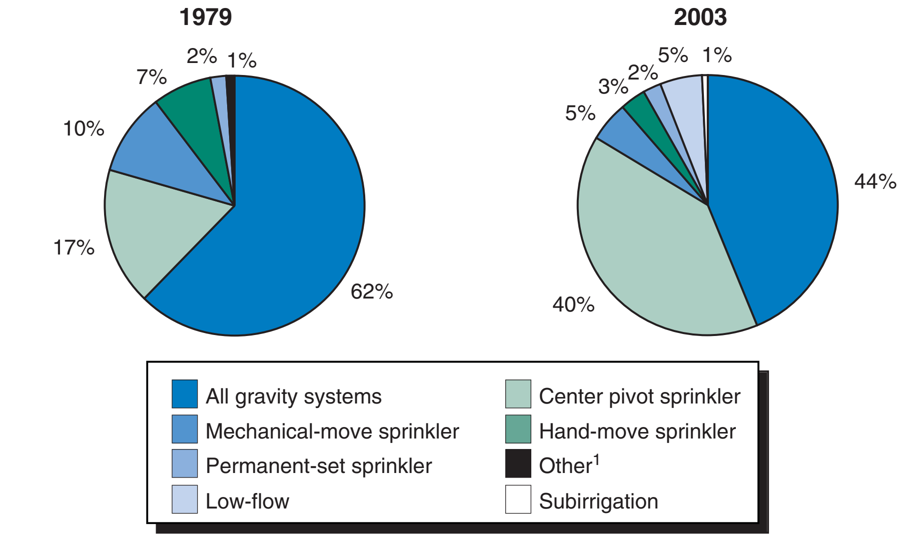
With rare exceptions, the pressure to distribute water involves pumping, which requires energy. Sprinkler systems—in which water is sprayed over the field surface, usually from above-ground piping—may be operated on sloping or rolling terrain unsuited to gravity systems. (See the Glossary in the "Irrigation and Water Use" briefing room on the ERS website for more information on these terms.)

Gravity-Flow Irrigation

Although total acreage in gravity systems has declined by 26 percent since 1979, gravity-flow systems still account for 44 percent of irrigated acreage nationwide, down from 62 percent in 1979 (fig. 4.6.1). Gravity-flow systems, used in all irrigated areas, are particularly dominant in the Southwest, Central Rockies, Southern Plains, and Delta regions (USDA, 2004a). Furrow application comprises about half of the acreage in gravity-flow systems; border/basin and uncontrolled-flood application account for the remaining acreage (table 4.6.2). Much of the uncontrolled flooding is used for hay and pasture production in the Northern and Central Rockies.

Figure 4.6.1

Irrigation systems in 1979 and 2003



[1]Other for 1979 includes both low-flow and subirrigation.

Source: USDA-ERS, based on Farm and Ranch Irrigation Surveys for 1979 and 2003 (USDC, 1982; USDA, 2004a).

Table 4.6.1

Changes in irrigation system acreage, 1979-2003

System	1979	1998	2003	Change 1979-98	Change 1998-2003
	Million acres			*Percent[1]*	
All systems	50.2	54.2[2]	52.6	8	(3)
Gravity-flow systems	31.2	26.8	23.1	(14)	(14)
Sprinkler systems	18.4	24.6	26.9	34	9
Center pivot	8.6	18.5	21.3	115	15
Mechanical move	5.1	3.0	2.7	(41)	(10)
Hand move	3.7	1.9	1.7	(49)	(11)
Solid/permanent set	1.0	1.2	1.2	20	0
Low-flow irrigation (drip/trickle and micro-spray)	0.3	2.2	3.0	633	36
Subirrigation	0.2	0.6	0.3	200	(50)

[1]Numbers in ( ) indicate a decrease.

[2]Based on USDA-NASS 2004 revised estimate for 1998 due to re-weighting for undercoverage. (The sum of subcategories will differ slightly from aggregates because of rounding error.)

Source: USDA-ERS, based on Farm and Ranch Irrigation Surveys for 1979, 1998, and 2003 (USDC, 1982; USDA, 1999, and USDA, 2004a).

Water losses are comparatively high under traditional gravity-flow systems due to percolation losses below the crop-root zone and to surface-water runoff. Field application efficiencies typically range from 40 to 65 percent, although improved gravity systems with proper water management may achieve efficiencies of up to 80-90 percent (USDA, 1997).

Various land treatments, system improvements, and water management measures have been developed to reduce water losses under gravity-flow

Table 4.6.2
Irrigation application systems, by type, 1998 and 2003

	1998		2003	
	Area	Share of all systems[1]	Area	Share of all systems[1]
	Million acres	*Percent*	*Million acres*	*Percent*
All systems	54.2	100	52.6	100
Gravity-flow systems[2]	26.8	50	23.1	44
Row/furrow application	13.8	25	11.7	22
Open-ditch delivery systems	4.6	9	4.4	9
Pipe/poly-tubing delivery systems	9.2	17	7.4	14
Border/basin application	8.3	15	8.8	17
Open-ditch delivery systems	4.8	9	5.5	10
Pipe/poly-tubing delivery systems	3.5	7	3.3	5
Uncontrolled flooding application	3.2	6	2.3	4
Open-ditch delivery systems	2.8	5	2.1	4
Pipe/poly-tubing delivery systems	0.4	1	0.1	*
Other gravity (mostly with unlined ditches)	1.5	3	0.3	*
Sprinkler systems[2]	24.6	45	26.9	51
Center-pivot	18.5	34	21.3	41
High-pressure (60 psi or more)	1.9	4	1.9	4
Medium-pressure (30 to 59 psi)	7.4	14	9.7	18
Low-pressure (under 30 psi)	9.2	17	9.7	18
Other sprinkler systems	6.1	12	5.6	9
Low-flow irrigation (drip or trickle)	2.2	4	3.0	6
Subirrigation	0.6	1	0.3	*

[1]Numbers may not add due to multiple systems on some irigated acres and incomplete survey responses.
[2]For a more detailed breakout of irrigation systems, see the ERS Briefing room on "Irrigation Water Management" on the ERS website.
* = less than 1 percent.

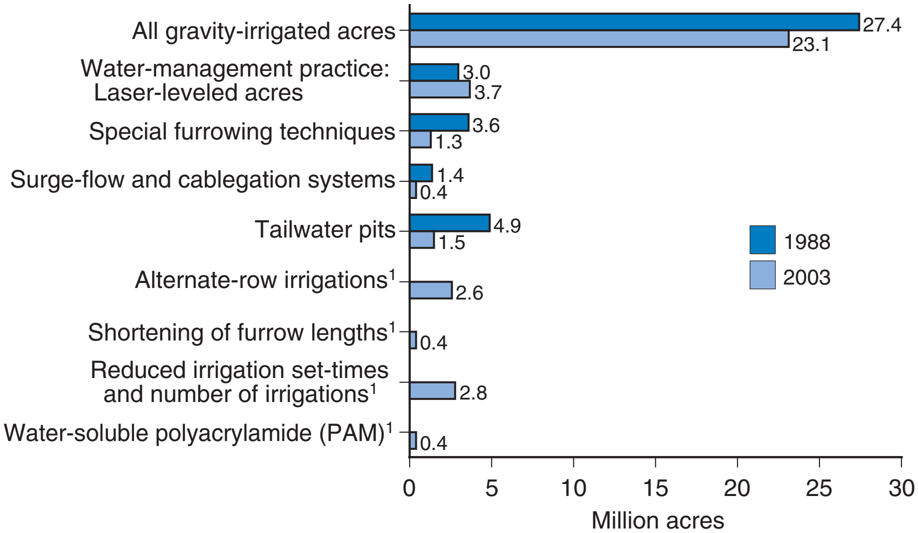
Source: USDA-ERS, based on Farm and Ranch Irrigation Surveys for 1998 and 2003 (USDA, 1999 and 2004a).

systems. For example, precision laser-leveled irrigation is practiced on 3.7 million acres (16 percent of gravity acres), mostly in the Southwest, Delta, and Northern Rockies (Montana, Idaho, and Wyoming) regions. Improved gravity systems generally involve onfarm water conveyance upgrades that increase uniformity of applied water and reduce percolation losses and field runoff. However, open-ditch systems still account for 53 percent of gravity acreage served (table 4.6.2; USDA, 2004a). Improved ditch systems, lined with concrete or another impervious substance, account for only 20 percent of gravity acres served by open ditches. Above-ground, pipeline delivery systems—including gated pipe and flexible (poly or lay-flat) tubing—account for 34 percent of all gravity acreage served, with underground pipe delivery systems serving the remaining 13 percent. Surge-flow and cablegation systems—designed to control water deliveries from gated pipe—were used on 0.4 million acres, representing 2 percent of gravity-flow acres in 2003 (fig. 4.6.2).

Use of improved water management practices for gravity irrigation, while increasing, remains an area of significant growth potential. Alternate-row irrigation is practiced on only 11 percent of gravity-flow acres; special

Figure 4.6.2

Improved gravity water management practices, 1988 and 2003



[1]Not reported for 1988.

Source: USDA-ERS, based on Farm and Ranch Irrigation Surveys for 1988 and 2003 (U.S. Dept. Commerce, 1990; USDA, 2004a).

furrowing practices (wide-spaced, compacted, or diked) on 6 percent; and shortened-furrow water runs on 2 percent. Tailwater-reuse pits, designed to recirculate field drainage flows, are used on about 7 percent of gravity acres, while reduced irrigation set-times are observed on 12 percent. Polyacrylamide—a water-soluble soil amendment designed to reduce soil erosion, enhance water infiltration, and improve nutrient uptake—is used on 2 percent of gravity-flow acres.

Pressurized Irrigation

Sprinkler irrigation has been adopted in many areas as a labor- and water-conserving alternative to gravity-flow systems. Field application efficiencies for properly designed and operated sprinkler systems range from 50 to 95 percent, with most systems achieving 75 to 85 percent (USDA, 1997). Acreage for all pressurized systems expanded from 19 million acres (37 percent of total irrigated acreage) in 1979 to 30 million acres (57 percent) in 2003 (table 4.6.1). Sprinkler systems alone accounted for 27 million acres, or 51 percent of all irrigated acreage in 2003 (table 4.6.2). Acreage in sprinkler systems has continued to expand in recent years, with an increase of nearly 9 million acres (46 percent) since 1988 (USDC, 1990; USDA, 2004a).

Center-pivot sprinkler systems accounted for roughly 79 percent of sprinkler acreage in 2003, or 41 percent of total irrigated acreage (table 4.6.2), increasing by nearly 13 million acres from 1979. Nearly two-thirds of the increase is attributable to net increases in irrigated area under sprinkler, while about a third reflects the net replacement of other sprinkler types with center-pivot systems (table 4.6.1). The more advanced low-pressure center-pivot and linear-move systems, including low-energy precision application (LEPA) systems (below 30 pounds per square inch), combine high application efficiencies with reduced energy and labor requirements. These systems account for 46 percent of center-pivot acreage, and are especially popular in the Southern Plains where irrigation relies heavily on higher-cost groundwater pumping. Current advances in sprinkler technology focus on the variable application of spray heads, as well as remote control of individual sprinklers and nozzles for precision agriculture.

Low-flow systems—including drip, trickle, and micro-sprinklers (with application efficiencies of 95 percent or greater)—were used on 3 million acres in 2003, or just 6 percent of irrigated cropland acreage (table 4.6.2), up from 300,000 acres in 1979 (table 4.6.1). The annual rate of growth (7 percent) was slower during 1998-2003 than the explosive 74-percent rate during 1979-88 (table 4.6.1). Low-flow systems are most commonly used for vegetables and perennial crops such as orchards and vineyards (primarily in California and Florida), although experimentation and limited commercial applications are occurring with some row crops (e.g., cotton).

Irrigation Scheduling and Water-Flow Measurement

Proper irrigation scheduling and precise measurement of water flow help producers match water applied to crop needs. Most irrigated farms continue to use a combination of less sophisticated methods to schedule irrigations (USDA, 2004a). Nearly 80 percent of irrigated farms use mere visual observation to evaluate the "condition of the crop," while some farms (ranging from 6 to 35 percent) simply "feel-the-soil," irrigate "when their neighbor irrigates," use a "personal calendar schedule," use "media daily weather/crop evapotranspiration (ET) reports," or irrigate consistent with "scheduled water deliveries." Most irrigated farms do not use the more advanced, information-intensive methods to schedule irrigation; less than 8 percent of irrigated farms use soil and/or plant moisture sensing devices, commercial or government-sponsored irrigation scheduling services, or computer simulation models. These current statistics suggest a significant potential for greater agricultural water conservation through public policy that promotes broader understanding and more extensive application of such scheduling techniques.

Water-flow measurement devices, for both on- and off-farm conveyance, include weirs, flumes, and in-canal flow meters for open ditches, internal/external meters for pipe delivery systems, and flow meters in wells to monitor groundwater pumping. Of the 380,000 wells used in 2003 to pump ground water for agriculture, only 61,000 (16 percent) used flow meters. While this is a 32-percent increase since 1994, flow meters on wells account for just 1 in 5 acres irrigated with ground water.

Potential for Improvement in Irrigation Conservation

Significant potential still exists for expanding agricultural water conservation. How much can be achieved depends on the combined use of conserving water-management practices and irrigation systems (Schaible, 2004b; USDA, 2004a). Of the 23.1 million gravity-irrigated acres in 2003, only 56 percent benefited from the use of one or more water management practices—accounting for just 53 percent of gravity-irrigated farms (USDA, 2004a). While not all water management practices can (or should) be applied to all gravity-irrigated acres simultaneously, at least 40-60 percent of gravity irrigation could benefit from improved water management (fig. 4.6.2). In addition, while use of low-pressure sprinkler systems increased to 38 percent of total irrigated acres in 2003, at least 39 percent of irrigated acreage likely remains available for improved conservation (fig. 4.6.3). The combined effect of improved systems and water management practices, along with more extensive use of advanced irrigation scheduling and water-flow measurement practices across all irrigation, would likely translate to even greater agricultural water conservation potential.

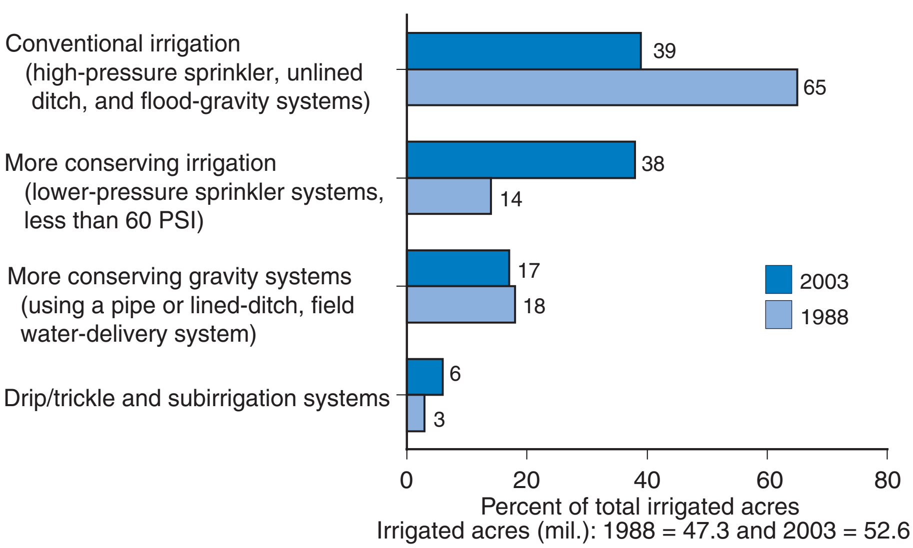
Farm Size and Water Conservation

An ERS analysis of structural characteristics of Western irrigated farms found that size matters in how well water conservation programs serve both USDA conservation and small-farm policy goals (Schaible, 2004b). In the 17 Western States, which account for 77 percent of U.S. irrigated acres, nearly 81 percent of irrigated farms are small - with less than $250,000 in annual farm sales (FS) (fig. 4.6.4). However, large irrigated farms (FS > $250,000) account for 61 percent of irrigated crop acres, nearly 85 percent of irrigated farm sales, and 66 percent of the total farm water applied. The largest 9.5 percent of irrigated farms (FS > $500,000) account for 48 percent of total farm water applied. Average annual water applied ranges from less than 150 acre-feet for the smallest irrigated farms (FS < $100,000) to more than 2,500 acre-feet for the largest farms.

In aggregate, "water-conserving/higher-efficiency" irrigation in the West ranges from 46-78 percent of acreage for pressurized (sprinkler) irrigation to 40-57 percent of acreage for gravity irrigation (Schaible, 2004b). For both

Figure 4.6.3

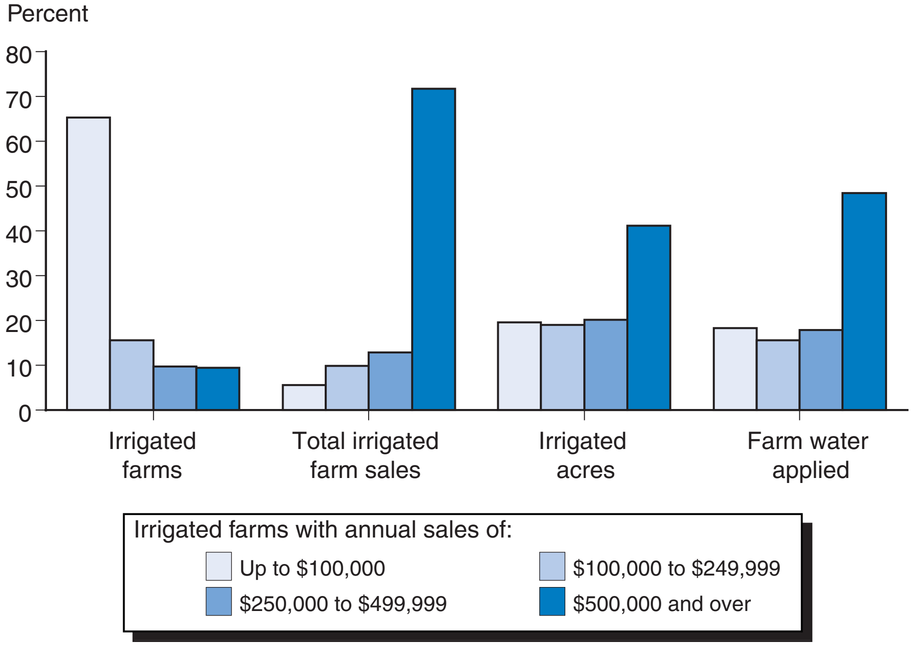
Adoption of water-conserving irrigation systems, 1988 and 2003



Source: USDA-ERS, based on Farm and Ranch Irrigation Surveys for 1988 and 2003 (U.S. Dept. Commerce, 1990; USDA, 2004a).

Figure 4.6.4

Characteristics of irrigated farms by size class, 17 Western States, 1998



Source: USDA-ERS, based on the Farm and Ranch Irrigation Survey (1998) (USDA, 1999; Schaible, 2004b).

categories, relative conservation improvement potential is generally greater for smaller irrigated farms. However, larger farms irrigate many more acres, so aggregate water savings due to a conservation program could be much greater for these farms. While "perceived economic benefits" and "lack of financing ability" are two commonly reported barriers to irrigation system improvements across all irrigated farms, "not investigating the merits of system improvements" is an additional critical barrier to system improvements for smaller irrigated farms.

Producers' Incentives

While survey results demonstrate that irrigators do implement irrigation system improvements to meet environmental goals, improved farm returns is likely the dominant motivating factor (table 4.6.3). From a private economic perspective, producers generally invest in improved irrigation technologies when perceived benefits are greater than additional (net) producer costs. However, Kim et al. (2000) demonstrate that from a public perspective where water quality benefits accrue largely off-farm, public cost-share funding of a more conserving technology may be warranted. For example, in Merrick County, NE, adoption of tailwater recovery or surge-flow gravity systems may be more profitable to the producer although, even with these systems, groundwater quality would continue to deteriorate. A center-pivot sprinkler system would significantly reduce the accumulation of nitrates in ground water after 15 years. However, adoption of center-pivot systems would reduce producer profits by about $9 per acre (in 1990 dollars), so cost-sharing or other incentives might be necessary to encourage adoption of systems that contribute more to improving water quality.

Table 4.6.3
Producer reasons for irrigation conservation improvements, 1999-2003

	Farms
Irrigated farms implementing irrigation improvements during 1999-2003:	70,336
	Percent
Reason for/effect of improvements:	
Improved crop yield or quality	57.6
Reduced energy cost	39.0
Reduced water applied	58.5
Reduced labor cost	39.2
Reduced fertilizer/pesticide losses	14.2
Reduced soil erosion	30.8
Reduced tailwater	22.9
Other	8.4

Source: USDA-ERS, based on the Farm and Ranch Irrigation Survey (2003), Vol. 3, Special Studies, Part I, table 39 (USDA, 2004a).

Federal, State, and local cost-share programs that address farm water delivery, field-level irrigation systems, and farm water management practices are key to improving irrigation efficiency. Only about 13 percent of irrigated farms in the West participated in public cost-share programs for water conservation between 1994 and 1998. Smaller irrigated farms make up 77 percent of participants in USDA cost-share programs designed to encourage irrigation or drainage improvements. Given that such farms account for only 34 percent of farm water applied in the West, these results indicate that farm size matters in the effectiveness of current agricultural water-conservation programs. Cost-share programs that target larger farms would likely conserve more water, making more water available to meet environmental and other objectives, especially when integrated with State-sponsored water markets, water banks, and conserved-water-rights programs (Schaible, 2004b). Integrated Federal/State conservation policy would likely increase opportunities to better balance alternative farm policy objectives—i.e., resource efficiency and potential gains in water saved, with distributional considerations involving cost-share funding allocations.

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