2.2 Irrigation Water Management

Water management is an important element of irrigated crop production. Efficient irrigation systems and water management practices can help maintain farm profitability in an era of limited, higher cost water supplies. Efficient water management may also reduce the impact of irrigated production on offsite water quantity and quality. However, measures to increase water-use efficiency may not be sufficient to achieve environmental goals in the absence of other adjustments within the irrigated sector. As is often the case, technology is not the whole solution anywhere, but is part of the solution almost everywhere.

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The U.S. Department of Agriculture (USDA) identifies improvement in water management—specifically water conservation—as one of its primary agricultural policy objectives (USDA, 2001a). Irrigation water management involves the managed allocation of water and related inputs in irrigated crop production, such that economic returns are enhanced relative to available water and drainage considerations. Conservation and allocation of limited water supplies is central to irrigation management decisions, whether at the field, farm, irrigation-district, or river-basin level.

Why Manage Irrigation Water?

Improved management of irrigation water can provide multiple benefits—conserving limited water supplies, reducing the impacts of irrigation on water quality, and enhancing producer net returns.

Water Conservation

Water savings through improved management of irrigation supplies are considered essential to meeting future water needs for agriculture and other uses. Irrigation is the largest use of water, accounting for nearly 90 percent of freshwater consumption in Western States and roughly 80 percent nationwide (Gollehon and Quinby; USDA, 2001b). However, expanding water demands for municipal, industrial, recreational, and environmental purposes increasingly compete for available water supplies. Since opportunities for large-scale water supply development are limited, additional water demands will almost certainly be met through small local projects and conservation and reallocation of existing irrigation supplies (WWPRAC; CAST; Moore et al.; Vaux; Howe, 1985).

Water Quality

Improved water management can also help minimize offsite water quality impacts of irrigated production. Irrigated agriculture may affect water quality in several ways, including higher chemical use rates associated with irrigated production, increased field salinity and soil erosion due to applied water, accelerated pollutant transport with drainage flows, degradation due to increased deep percolation to saline formations, and greater instream pollutant concentrations due to reduced flows. Strategies to improve the Nation’s water quality must address the effect of irrigation on surface and groundwater bodies (National Research Council).

Farm Returns
Finally, improvements in irrigation water management can help maintain the long-term viability of the irrigated agricultural sector. Irrigated cropland is important to the U.S. farm economy, accounting for about 49 percent of total crop sales from just 16 percent of the Nation's harvested cropland in 1997 (USDA, 2001b). Water savings at the farm level can help offset the effect of rising water costs and restricted water supplies on producer income. Improved water management may also reduce expenditures for energy, chemicals, and labor inputs, while enhancing revenues through higher crop yields and improved crop quality.

Use of Improved Irrigation Technology and Management

How producers respond to higher water costs and limited water supplies is important to policymakers. Producers may respond to higher water costs and limited water supplies through various means, with differing implications for crop production, farm returns, and resource use. Per acre water use may be reduced by applying less than full crop-consumptive requirements, by shifting to alternative crops or varieties of the same crop that use less water, or by adopting more efficient irrigation technologies. In some cases, producers may convert from irrigated to dryland farming or retire land from production. With increasing water scarcity, many irrigators have relied on improved irrigation technologies—often in combination with other water-conserving strategies—and irrigators will likely look to technology as one of several means of conserving water in the future.

Various management practices and irrigation technologies are available to enhance the efficiency of applied water in irrigated agriculture (see box, "Irrigation Water-Use Efficiency"). Irrigation improvements often involve an upgrade in the physical application system, with higher application efficiency and yield potentials. Improved water management practices, such as irrigation scheduling and water-flow measurement, are generally required to achieve the maximum potential of the physical system. In addition, management of drainage flows may be an important concern in many irrigated areas (table 2.2.1). In some cases, the effectiveness of improved irrigation practices may be enhanced when implemented in combination with other farming practices such as conservation tillage and nutrient management.

Irrigation Application Systems
Irrigation application systems may be grouped under two broad system types: gravity-flow and pressurized systems. (For an explanation of irrigation systems discussed here, see boxes "Gravity Irrigation Systems and Practices" and "Pressurized Irrigation Systems and Practices.")

Gravity-Flow Systems. Many irrigation systems rely on gravity to distribute water across the field. Land treatments—such as soil borders and furrows—are used to control lateral water movement and channel water flow down or across the field. Water is conveyed to the field by means of open ditches, aboveground pipe, (including gated pipe and flexible tubing) or underground pipe, and is released along the upper end of the field through siphon tubes, ditch gates, pipe valves, or pipe orifices. Fields are generally rectangular, with water runs typically ranging from one-eighth to one-half mile in length. Gravity systems are best suited to medium- and fine-textured soils with higher moisture-holding capacities. Fields can be flat or graded, but field slope should be minimal and fairly uniform to permit controlled water advance.

Irrigation Water-Use Efficiency

Water-use efficiency measures are commonly used to characterize the water-conserving potential of irrigation systems. Alternative efficiency measures reflect stages of water conveyance and use, levels of spatial aggregation, and temporal assumptions regarding soil-moisture retention and return flow. The actual efficiency of the physical irrigation system is influenced by many factors, including level of management, soil type, crop type and crop-growth stage, climatic factors, and water table considerations.

Irrigation efficiency, broadly defined at the field level, is the ratio of the average depth of irrigation water beneficially used (consumptive use plus leaching requirement) to the average depth applied, expressed as a percentage (USDA, 1997).

Application efficiency is the ratio of the average depth of irrigation water infiltrated and stored in the root zone for crop consumptive use to the average depth applied, expressed as a percentage (USDA, 1997). Crop-water consumption includes water used by the plant for transpiration and tissue building, plus incidental evaporation from plant and field surfaces. The leaching requirement, which accounts for the major difference between irrigation efficiency and application efficiency, is the quantity of water required to flush soil salts below the plant root zone. Field-level losses include surface runoff at the end of the field, deep percolation below the crop-root zone (not used for leaching), and excess evaporation from soil and water surfaces.

Conveyance efficiency is the ratio of total water delivered to the total water diverted or pumped into an open channel or pipeline, expressed as a percentage (USDA, 1997). Conveyance efficiency may be computed at the farm, project, or basin level. Conveyance losses include evaporation, ditch seepage, operational spills, and water lost to noncrop vegetative consumption.

Project application efficiency is calculated based on onfarm application efficiency and both on- and off-farm conveyance efficiency, and is adjusted for drainage reuse within the service area. Project efficiency may not consider all runoff and deep percolation a loss since some of the water may be available for reuse within the project.

Other measures of irrigation water-use efficiency, based on water use per unit yield and economic return per unit of water applied, are also used.

Although total acreage in gravity systems has declined by 20 percent since 1979, gravity-flow systems still account for half of irrigated acreage nationwide (table 2.2.2; fig.2.2.1). Gravity-flow systems are used in all irrigated areas, and are particularly dominant in the Southwest (California, Nevada, Arizona, New Mexico), Central Rockies (Wyoming, Colorado, Utah), Southern Plains (Texas, Oklahoma), and Delta (Arkansas, Louisiana, Mississippi) regions (USDA, 1999). The dominance of gravity systems in arid regions of the West reflects early project development on broad, flat alluvial plains, high crop water-consumption requirements, and increased soil salt-leaching requirements. Furrow application systems comprise about half of the acreage in gravity-flow systems; border/basin and uncontrolled-flood application systems account for the remaining acreage (table 2.2.3). Much of the uncontrolled flooding is used for hay and pasture production in the Northern Mountain region.

Table 2.2.1—Irrigation technology and water management: conventional methods and improved practices

System and aspect	Conventional technology or management practice	Improved technology or Management practice
Onfarm conveyance	Open earthen ditches.	Concrete or other ditch linings; aboveground pipe; belowground pipe.
Gravity application systems:		
Release of water	Dirt or canvas checks with siphon tubes.	Ditch portals or gates; gated pipe; gated pipe with surge flow or cablegation.
Length of irrigation run	Length of field, often one-half mile or more.	Shorter runs, one-quarter mile or less.
Field gradient	Natural field slope, often substantial; uneven field surface.	Land leveled to reduce and smooth field surface gradient.
Field runoff	Water allowed to move off field.	Applications controlled to avoid runoff; tailwater return systems.
Furrow management	Full furrow wetting; furrow bottoms uneven.	Alternate furrow wetting; furrow bottoms smooth and consistent.
Pressurized application systems:		
Pressure requirements	High pressure, typically above 60 pounds per square inche (psi).	Reduced pressure requirements, often 10-30 psi.
Water distribution	Large water dispersal pattern.	More narrow water dispersal through sprinkler droptubes, improved emitter spacing, and low-flow systems.
Automation	Handmove systems; manually operated systems.	Self-propelled systems; computer control of water applications.
Versatility	Limited to specific crops; used only to apply irrigation.	Multiple crops; various uses—irrigation, chemigation, manure applications, frost protection, crop cooling.
Water management:		
Assessing crop needs	Judgment estimates.	Soil moisture monitoring; plant tissue monitoring; weather-based computations.
Timing of applied water	Fixed calendar schedule.	Water applied as needed by crop; managed for profit (not yield); managed for improved effectiveness of rainfall.
Measurement of water	Not metered.	Measured using canal flumes, weirs, and meters; external and in-pipe flow meters.
Drainage:	Runoff to surface-water system or Evaporation ponds; percolation to aquifers.	Applications managed to limit drainage; reuse through tailwater pumpback; dual-use systems with subirrigation.

Source: USDA, ERS.

Gravity Irrigation Systems and Practices

Open-ditch conveyance systems are the traditional means to supplying gravity irrigation systems. Open ditches may be earthen, although improved systems are typically lined with concrete or other less permeable materials to reduce seepage loss. Water is delivered to gravity-flow fields through siphon tubes, portals, or ditch gates.

Furrow systems, the dominant gravity application system, are distinguished by small, shallow channels used to guide water downslope across the field, with only part of the ground surface covered with water. Furrows are generally straight, although they may be curved to follow the land contour on steeply sloping fields. Row crops are typically grown on a ridge or bed between furrows, spaced from 2-4 feet apart. Corrugations—small, closely spaced furrows—may be used for close-growing field crops.

Border (or flood) application systems divide the field into strips, separated by parallel ridges. Water flows downslope as a sheet, covering the surface of the ground, guided by ridges 10-100 feet apart. On steeply sloping lands, ridges are more closely spaced and may be curved to follow the land contour. Border systems are suited to orchards and vineyards, and close-growing field crops such as alfalfa, pasture, and small grains.

Uncontrolled flooding is a gravity-flood system without constructed ridges, relying on natural slope to distribute water.

Improved Systems and Practices:

Pipeline conveyance systems are often installed to reduce labor and maintenance costs, as well as water losses to seepage, evaporation, spills, and noncrop vegetative consumption. *Underground pipeline* constructed of steel, plastic, or concrete is permanently installed; *aboveground pipeline* generally consists of lightweight, portable aluminum, plastic, or flexible rubber-based hose. One form of aboveground pipeline—*gated pipe*—distributes water to gravity-flow systems from individual gates (valves) along the pipe. Flexible conveyance hoses designed for 1 year of use—termed *polytubing* or *lay-flat tubing*—are readily transportable, easily adapted to irregular field sizes, and generally less expensive than permanent water conveyance systems.

Field leveling involves grading and earthmoving to eliminate variation in field gradient, thereby smoothing the field surface and often reducing field slope. Field leveling helps to control water advance and improve uniformity of soil saturation under gravity-flow systems. Precision leveling is generally undertaken with a laser-guided system.

Level basin systems differ from traditional border application systems in that field slope is level and field ends are closed. Water is applied at high volumes to achieve an even, rapid ponding of the desired application depth within basins. Higher application efficiencies reflect uniform infiltration rates and elimination of surface runoff.

Shortened water runs reduce the length of furrow (or basin) to increase uniformity of applied water across the field. Reduced water runs are most effective on coarse soils with high soil-water infiltration rates. Water runs of one-half to 1 mile in length may be reduced to one-quarter mile or less (with reorganization of the onfarm conveyance system).

Surge flow is an adaptation of gated-pipe systems in which water is delivered to the furrow in timed releases. Initial water surges travel partway down the furrow, and all standing water is allowed to infiltrate. The wetted soil surface forms a water seal permitting successive surges to travel further down the furrow with less upslope deep percolation. This technique significantly reduces the time needed for water to be distributed the full length of the field, thereby increasing application efficiency.

Cablegation is a gated-pipe system in which a moveable plug passes slowly through a long section of gated pipe, with the rate of movement controlled by a cable and brake. Due to the oversizing and required slope of the pipe, water will gradually cease flowing into the first rows irrigated as the plug progresses down the pipe. Improved water management is achieved by varying the speed of the plug, which controls the timing of water flows into each furrow.

Alternate furrow irrigation involves wetting every second furrow only. This technique limits deep percolation losses by encouraging lateral moisture movement. Applied water and time required per irrigation may be significantly less than under full furrow systems, but more irrigations may be required to supply crop needs. This technique is very effective when the desired strategy is to irrigate to a “less-than-field-capacity” level in order to more fully utilize rainfall.

Special furrows have been employed to enhance water management. *Wide-spaced furrows* function much like alternate furrow irrigation, except that every row is irrigated with rows spaced further apart. *Compacted furrows* involve packing the soil within the furrow to provide a smooth, firm surface to speed water advance. *Furrow diking* places dikes in the furrows to capture additional rainfall, eliminating runoff and reducing irrigation needs. Furrow diking on gravity-irrigated fields is typically used in combination with alternate furrow irrigation.

Tailwater reuse systems recover irrigation runoff in pits below the field and pump it to the head of the field or an adjacent field for reuse.

Pressurized Application Systems and Practices

Pipeline conveyance is most often used to deliver water to fields with pressurized systems. Water, once under pressure, requires a pipeline for conveyance. Pipelines may be above or below ground.

Center-pivot sprinklers are the dominant pressure technology. A center-pivot sprinkler is a self-propelled system in which a single pipeline supported by a row of mobile A-frame towers is suspended 6-12 feet above the field. Water is pumped into the pipe at the center of the field as towers rotate slowly around the pivot point, irrigating a large circular area. Sprinkler nozzles mounted on or suspended from the pipeline distribute water under pressure as the pipeline rotates. The nozzles are graduated small to large so that the faster moving outer circle receives the same amount of water as the slower moving inside. Typical center-pivot sprinklers are one-quarter mile long and irrigate 128- to 132-acre circular fields. Center pivots have proven to be very flexible and can accommodate a variety of crops, soils, and topography with minimal modification.

Linear or **lateral-move systems** are similar to center-pivot systems, except that the lateral line and towers move in a continuous straight path across a rectangular field. Water may be supplied by a flexible hose or pressurized from a concrete-lined ditch along the field edge.

Hand-move is a portable sprinkler system in which lightweight pipeline sections are moved manually for successive irrigation sets of 40-60 feet**.** Lateral pipelines are connected to a mainline, which may be portable or buried. Hand-move systems are often used for small, irregular fields. Hand-move systems are not suited to tall-growing field crops due to difficulty in repositioning laterals. Labor requirements are higher than for all other sprinklers.

Solid set refers to a stationary sprinkler system. Water-supply pipelines are generally fixed—usually below the soil surface—with sprinkler nozzles elevated above the surface. In some cases, hand-move systems may be installed prior to the crop season and removed at or after harvest, effectively serving as solid set. Solid-set systems are commonly used in orchards and vineyards for frost protection and crop cooling, and are widely used in turf production and landscaping.

Big gun systems use a large sprinkler mounted on a wheeled cart or trailer, fed by a flexible hose. The sprinkler is usually self-propelled while applying water. The system may require successive moves to irrigate the field. Big guns require high operating pressures, with 100 pounds per square inche (psi) not uncommon. These systems have been adapted to spread livestock waste in many locations.

Side-roll wheel-move systems have large-diameter wheels mounted on a pipeline, enabling the line to be rolled as a unit to successive positions across the field. A gasoline engine generally powers the system movement. This system is roughly analogous to a hand move system on wheels. Crop type is an important consideration for this system since the pipeline is roughly 3 feet above the ground.

Improved Systems and Practices:

Improved center pivots and lateral-move systems have been developed that reduce both water application losses and energy requirements**.** Older systems, with the sprinklers attached directly to the pipe, operate at relatively high pressure (60-80 psi) with wide water-spray patterns. Newer systems usually locate the sprinklers on tubes below the pipe and operate at lower pressures (15-45 psi). Many existing center pivots have been retrofitted with innovations to reduce water losses and energy needs.

LEPA (Low-energy precision application) is an adaptation of center-pivot (or lateral-move) systems that uses droptubes extending down from the pipeline to apply water at low pressure below the plant canopy, usually only a few inches above the ground. Applying water close to the ground cuts water loss from evaporation and wind and increases application uniformity. On soils with slower infiltration rates, furrow dikes are often used to avoid runoff.

Low-flow irrigation systems include *drip or trickle* and *micro-sprinkler* systems. *Drip or trickle* systems use small-diameter tubes placed on or below the field's surface. Frequent, slow applications of water are applied to soil through small holes or emitters. The emitters are supplied by a network of main, submain, and lateral lines. Water is dispensed directly to the root zone, precluding runoff or deep percolation and minimizing evaporation. *Micro-sprinklers* use a similar supply system, with low-volume sprinkler heads located about 1 foot above the ground. (Micro-sprinklers are used in place of multiple drip emitters when wetting a broader area or perimeter). Low-flow systems are generally reserved for perennial crops, such as orchard products and vineyards, or other high-value vegetable crops.

Table 2.2.2—Changes in irrigation system acreage, 1979-98

System	1979	1998	Change 1979-98
	Million acres		Percent
All systems	50.2	50.0	0
Gravity-flow systems	31.2	25.1	-20
Sprinkler systems	18.4	23.0	25
Center pivot	8.6	17.3	100
Mechanical move	5.1	2.8	-44
Hand move	3.7	1.7	-54
Solid set and permanent	1.0	1.1	15
Low-flow irrigation (drip or trickle)	0.3	2.1	554
Subirrigation	0.2	0.5	126

Source: USDA, ERS based on USDC, 1982 and USDA, 1999.

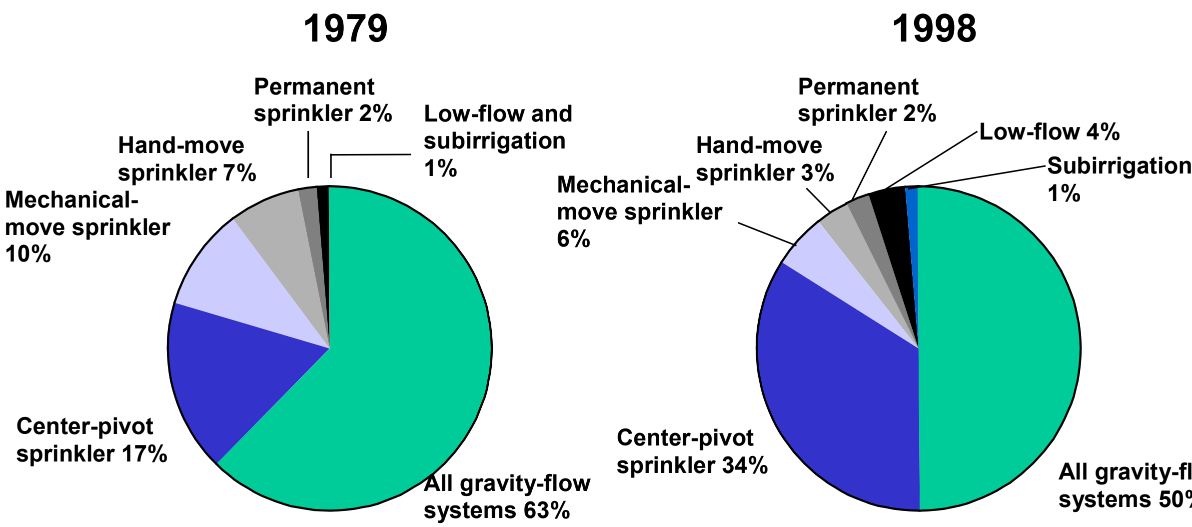
Water losses are comparatively high under traditional gravity-flow systems due to percolation losses below the crop-root zone, and water runoff at the end of the field. Field application efficiencies typically range from 40-65 percent (Negri and Hanchar), although improved systems with proper management may achieve efficiencies of up to 85 percent (USDA, 1997).

Various land treatment and management measures have been developed to reduce water losses under gravity-flow systems (table 2.2.1). Measures include improved onfarm water-conveyance systems, precision field leveling, shortened water runs, alternative furrow irrigation, surge flow and cablegation, and tailwater reuse.

Water-conveyance system upgrades are often an important component of an improved irrigation system—reducing water losses to evaporation and percolation and enhancing field application efficiencies through controlled water flows. System upgrades include ditch reorganization, ditchlining, and pipeline installation. According to the 1998 Farm and Ranch Irrigation Survey (FRIS), open-ditch systems remain the principal means of onfarm water conveyance for gravity-flow systems, serving 45 percent of all gravity-flow acreage (USDA, 1999). Improved ditch systems, lined with concrete or another impervious substance, account for a quarter of gravity-flow acreage served by open ditches. Aboveground pipelines—including gated pipe and flexible tubing—account for 37 percent of gravity-flow acreage served (alone, or in conjunction with open-ditch systems), with underground lines serving the remaining acreage.

Improvements in traditional gravity-flow systems can increase the uniformity of applied water, thereby reducing percolation losses and minimizing field runoff. Use of gravity-system innovations varies across regions. Gated-pipe systems and layflat tubing are used increasingly in the Northern and Southern Plains and Delta regions. Surge-flow and cablegation systems—designed to control water deliveries from gated pipe—accounted for 3 percent of gravity-flow acreage in 1998, predominantly in the Plains States. Alternative-row irrigation is practiced on 15 percent of gravity-flow acres, predominantly in the Northwest, Plains, and Delta regions; special furrows (widespaced, compacted, or diked) are applied on about 7 percent of gravity-flow acres. Roughly 3

Figure 2.2.1-- Irrigation systems in 1979 and 1998



percent of FRIS respondents indicated that water runs had been shortened to facilitate water management, primarily in the Southwest (Arizona, California) and Southern Plains. About 15 percent of all irrigated acres have been precision leveled using lasers, predominantly on gravity-flow systems in the Southwest, Delta, and Southeast regions. High-efficiency level-basin systems are concentrated in the Southwest. Reduced irrigation sets to optimize limited water supplies are practiced on roughly 12 percent of gravity-flow acres, with primary acreage concentrations in the Southwest.

Pressurized Systems. The decline in gravity-flow acreage has been accompanied by an increase in acreage under pressurized systems. Pressurized systems—including sprinkler and low-flow irrigation systems—use pressure to distribute water. With rare exceptions, the pressure to distribute water involves pumping, which requires energy. Acreage in pressurized systems expanded from 19 million acres (37 percent of total irrigated acreage) in 1979 to 25 million acres (50 percent) in 1998 (table 2.2.2).

Sprinkler systems—in which water is sprayed over the field surface, usually from aboveground piping—accounted for 23 million acres, or 46 percent of irrigated acreage in 1998 (table 2.2.3). Acreage in sprinkler systems has expanded in recent years, with an increase of 1.5 million acres (7 percent) since 1994. Concentrations of sprinkler acreage are highest in the Northern Pacific, Northern Plains, and Northern Mountain regions. Sprinkler systems are also used extensively to supplement precipitation during the growing season in Eastern States.

Sprinkler irrigation is used in many areas as a water-conserving alternative to gravity-flow systems. Field application efficiencies for properly designed and operated sprinkler systems range from 50-95 percent, with most systems in the range of 75-85 percent (USDA, 1997).

Table 2.2.3—Irrigated application systems, by type, 1998

	Area	Share of all systems[1]
	Million acres	*Percent*
All systems	50.2	100
Gravity flow systems	25.1	50
Row/furrow application	12.9	26
Open ditches - lined	2.7	5
Open ditches - unlined	7.5	15
Aboveground pipe	7.5	15
Underground pipe	1.1	2
Border/basin application	7.8	16
Open ditches - lined	1.1	2
Open ditches - unlined	3.4	7
Aboveground pipe	1.5	3
Underground pipe	1.8	4
Uncontrolled flooding application	3.0	6
Open ditches - lined	0.2	0
Open ditches - unlined	2.4	5
Aboveground pipe	0.3	1
Underground pipe	0.1	0
Sprinkler systems	23.0	46
Center-Pivot	17.3	34
High-pressure	1.8	4
Medium-pressure	6.9	14
Low-pressure	8.6	17
Linear move	0.3	1
Side-roll, wheel-move, and other mechanical move	1.9	4
Traveller or big gun	0.7	1
Hand-move	1.7	3
Solid set & permanent	1.1	2
Low-flow irrigation (drip or trickle)	2.1	4
Subirrigation	0.5	1

[1]/ Numbers may not sum precisely due to multiple systems on some irrigated acres and incomplete survey responses.

Source: 1998 Farm and Ranch Irrigation Survey

Sprinklers may be operated on sloping or rolling terrain unsuited to gravity systems, and are well suited to coarser soils with higher water infiltration rates. Sprinkler design is important, and careful consideration of soil type, wetting area per spray nozzle, operating pressure, and the rate of sprinkler movement is required to avoid plant stress from too little water and excess runoff from too much water.

Capital costs for sprinkler systems are typically higher than for gravity-flow systems, although gravity-flow system installation often requires greater expenditures for land preparation. Operating costs for sprinkler systems are generally higher than for gravity-flow systems due to higher energy demands and more sophisticated technical and management requirements. Labor costs are typically lower under sprinkler systems, particularly with self-propelled systems.

Sprinkler technologies encompass a wide range of adaptations, with significant shifts in technology shares in recent years. The development of self-propelled center-pivot systems in the 1960s greatly expanded the acreage suitable for irrigation, and accounted for much of the growth in acreage irrigated during the 1970s. Acres irrigated with center pivots increased by nearly 9 million acres from 1979 to 1998, including an additional 2.4 million acres—or 600,000 acres annually—since 1994. About half of the increase is attributable to net increases in irrigated area under sprinkler systems, and about half reflects the net replacement of other sprinkler types with center-pivot (table 2.2.2). Center-pivot systems accounted for roughly 75 percent of sprinkler acreage in 1998, or 35 percent of total irrigated acreage (table 2.2.3). The largest acreage concentrations are in the Northern Plains, Southern Plains, and Delta regions.

Center-pivot technology serves as the foundation for many technological innovations—such as low-pressure center-pivot, linear-move, and low-energy precision application (LEPA) systems—which combine high application efficiencies with reduced energy and labor requirements. Approximately half of center pivots in 1998 were operated under low pressure (below 30 pounds per square inch (psi)), with just 10 percent operating at high pressure (above 60 psi). The trend from high- to low-pressure systems has been significant in recent years—high-pressure systems accounted for 42 percent of center pivots as recently as 1988 and 22 percent in 1994. Adoption of low-pressure systems has been particularly strong in the Southern Plains, reflecting heavy reliance on higher cost groundwater pumping. Current advances in sprinkler technology focus on location of spray heads and low-pressure rotating sprinklers and nozzles. In addition, advances are being made in remote control of sprinklers and individual nozzle control for precision agriculture.

Sprinkler systems other than center-pivot—including linear-move, hand-move, mechanical-move, and solid set—made up about 25 percent of total sprinkler acreage in 1998, down from 53 percent in 1979. Linear-move systems (258,000 acres) are concentrated in California, the Northern Pacific and Northern Mountain regions. Side-roll, wheel-move, and other mechanical-move systems total 1.8 million acres, with significant acreages in the Northern Pacific and Northern Mountain regions. Acreage in hand-move systems declined by 54 percent since 1979; mechanical-move systems declined by 45 percent (table 2.2.2). Acreage declines reflect generally higher labor and energy requirements and reduced application precision under conventional sprinkler systems.

Low-flow irrigation systems are a form of pressurized system in which water is applied in small, controlled quantities near, on, or below ground level. Low-flow irrigation systems—including drip or trickle, and micro-sprinklers—comprised 2.1 million acres in 1998, or 4 percent of irrigated cropland acreage (table 2.2.3), up from just 300,000 acres in 1979 (table 2.2.2). Drip acreage has continued to expand steadily in recent years, although the 75,000-acre average annual increase since 1994 is down from the average annual growth of

100,000 acres over the 1979-94 period. Low-flow systems are most commonly used for production of vegetables and perennial crops such as orchards and vineyards, although experimentation and limited commercial applications are occurring with some row crops (e.g., cotton). Low-flow irrigation systems are located primarily in California and Florida, reflecting large acreages in specialty produce and citrus production.

Irrigation application efficiency of 95 percent or greater can be achieved under low-flow systems, although proper design is required to avoid moisture stress and soil-salinity accumulation. High capital costs and short lifespan of components characterize most systems, although improvements are lowering costs and extending the useful life. Filtration of the water supply and careful system maintenance is generally required to prevent clogging of small orifices in the nozzles of low-flow system equipment. Advances in low-flow technology are focusing on field depth and spacing of tubing, emitter spacing, durability of materials, and reduced costs.

Water Management Practices

Determining when and how much irrigation water to apply is an important part of the irrigation management process. Overapplication of irrigation water relative to crop needs can result in waterlogging, increased soil salinity, erosion, and surface and groundwater quality problems associated with nutrients, pesticides, and pathogens. Deficit water applications at less than full crop-consumptive need, while occasionally implemented as a strategy to extend limited water supplies, can result in an accumulation of salinity in the soil, less efficient use of nutrients and pesticides, and a reduction in yields and economic returns. Improved water management practices—including *irrigation scheduling* and *water-flow measurement*—increase the likelihood that water is applied according to crop needs. While improved management practices are often more cost-effective than structural improvements alone, accompanying structural upgrades may be required to achieve the highest management potential.

Irrigation Scheduling. Scheduling involves the application of irrigation water based on a systematic monitoring of crop soil-moisture requirements. Scientific irrigation scheduling methods—based on sensors, microprocessors, and computer-aided decision tools—can be used to determine the optimal timing and depth of irrigation to meet changing crop needs over the production season.

Various methods are available to assess crop water needs. Crop water requirements can be indirectly estimated through climate variables. Local weather-station data—including temperature, humidity, wind speed, and solar radiation—are applied in formulas to calculate water needs for a wide range of crops and locales. Soil moisture available for plant growth can also be measured directly through periodic soil testing. Shovels or soil probes are used to obtain soil samples at various depths for "feel and visual" evaluation. More sophisticated devices—including moisture blocks, tensiometers, neutron probes, and various electrical conductivity devices—can be used to accurately quantify the amount of water removed from the soil profile. Finally, plant moisture monitors may be used to detect crop water availability and stress in plant tissue.

In separate Farm and Ranch Irrigation Surveys from 1984 through 1998, irrigators were asked to indicate all methods used in deciding when to irrigate (USDC, 1986, 1992, 1996; USDA, 1999). Survey results suggest that a slightly larger share of irrigators are using advanced, information-intensive methods to schedule irrigation, but that current levels indicate potential for much improvement. In the 1998 FRIS, 8 percent of irrigators used soil moisture-sensing devices, 4 percent used commercial scheduling, 5 percent used media reports on plant water requirements, and 1 percent used computer simulations. Approximately $7.4 million was invested in 1998 for computers and related software for improved irrigation water management.

Water flow measurement. Measurement is an important component of water management, both on- and off-farm. Measurement of water flows to and through the onfarm conveyance system ensures optimal water deliveries to the field, as determined by irrigation scheduling methods. Measuring devices—often installed in conjunction with conveyance system upgrades—include weirs, flumes, in-canal flow meters for open ditches, and external and internal meters for pipe. Flow meters may also be used in wells to monitor groundwater pumping. Of 374,000 usable wells in the U.S., nearly 59,000 (16 percent) use flow meters—a 21-percent increase in usage between 1994 and 1998.

Irrigation Drainage Systems

The collection and disposal of drainage flows from irrigation and precipitation is an important management consideration in many irrigated areas, both in terms of farm profitability and offsite water quality. Irrigation drainage includes surface runoff and deep percolation from applied water to meet crop consumptive needs. In some areas, periodic preseason flooding of fields may also be required to leach soil salts from the crop-root zone, often increasing the need for drainage systems.

Irrigation drainage is often collected and reused in irrigated production. Tailwater systems recover drainage flows below the field (or in low-lying areas of the farm), recirculating the water to the top of the field or to an adjacent field for reuse. Tailwater reuse systems have been installed on roughly 11 percent of gravity-flow system acreage, with California leading both in total acreage (1.1 million) and share of gravity-flow acres (36 percent) with tailwater systems. Drainage flows may also be used as irrigation supplies downslope, both on- and off-farm. In some cases, drainage systems may be used to drain excess water during wet periods as well as subirrigate during dry periods by regulating underlying water tables. Subirrigation systems used for water application and drainage purposes were used on 500,000 acres in the U.S. in 1998. In many cases, drainage flows of poor quality become a disposal issue. Primary disposal methods include onfarm evaporation ponds, direct discharge to off-farm surface water through drainage canals, and reuse in salt-tolerant crop and tree production.

Other Practices Affecting Irrigation

Other practices—while not water management practices *per se*—can be important components of an irrigated farming system. Such practices, in combination with improved irrigation systems, may enhance returns to irrigated production while reducing offsite environmental impacts.

Nutrient and Pest Management. Irrigation affects the optimal timing and application rate of chemical applications for nutrient and pest management. Fertilizer use is typically greater for high-value, high-yield irrigated production. Weed and pest conditions may also increase under irrigated field conditions, necessitating increased use of pesticides, herbicides, and fungicides. Careful nutrient and pest management increases the effectiveness of water and applied chemicals, while reducing offsite impacts.

Chemigation—or the application of fertilizers, pesticides, and other chemicals through irrigation water—permits controlled applications when used in conjunction with highly efficient irrigation systems. Chemigation can reduce the costs of applying chemicals by reducing the need for equipment and soil compaction. Chemigation is used on all major crops, with the largest reported use on irrigated orchard crops, hay, and corn—and the greatest concentration of use in irrigated potato, vegetables, cotton, and sugarbeet production. Backflow prevention devices—to prevent chemical contamination of ground water due to pumping—were used on more than 60 percent of wells in 1998, up from 56 percent in 1994 (USDA, 1999).

Erosion Control. Soil erosion can be a serious problem for irrigation systems on sloping fields. Erosion creates barriers to even water flow in furrows, reduces long-term field productivity, and contributes to offsite water quality problems. Irrigation-induced erosion is particularly severe in areas of the Northern Pacific, Southern Pacific, and Mountain regions (USDA, 1992).

Measures to improve uniformity of applied irrigation water can help control soil loss. Gravity-flow systems may be modified to reduce flow velocity or field slope in accordance with soil-water infiltration rates. Soil erosion may also be a problem with sprinkler systems, particularly on steeply sloping fields and under outer spans of center-pivot systems where water application rates are higher. System adjustments to reduce erosion include reduced water applications per irrigation set, larger pattern sprinkler heads, and booms to increase sprinkler head spacing.

Other practices limit soil erosion on irrigated fields. Crop residue management to maintain vegetative material on the soil surface increases infiltration while protecting the soil. In some cases, deep tillage can reduce runoff through increased infiltration. Land treatment measures may be installed to slow runoff and trap sediment. These include furrow dikes in the field, vegetative filter strips below the field, mini-basins in tailwater ditches, larger sediment ponds constructed in drainage ditches, and tailwater reuse systems.

Polyacrylamide (PAM) is used to stabilize soil and water-borne sediment under irrigated production systems. PAM may be added to irrigation water—either directly to the water stream or through contact with granules applied at the head of the field. Proper application of PAM prior to the first irrigation has substantially reduced soil erosion in furrow systems under medium- and fine-textured soils, and is being used increasingly under sprinkler irrigation. Potential benefits include reduced topsoil loss, enhanced water infiltration, improved uptake of nutrients and pesticides, reduced furrow-reshaping operations, and reduced sediment-control requirements below the field. Commercial application of PAM in irrigation systems was first available in 1995. Approximately 1 million irrigated acres were treated with PAM in the U.S. by 1999, with adoption concentrated in the Pacific Northwest and Northern Mountain regions (Sojka et al.).

Irrigation Technology and Environmental Benefits

Adoption of improved irrigation technology has been advanced as a means to reduce offsite water quantity and quality problems, and may substantially increase water-use efficiency at the farm level. Whether technology adoption can achieve significant water savings for nonfarm and instream uses, however, will depend on many factors. The effectiveness of technology in achieving environmental goals has important implications for regional water policy.

Implications of Improved Irrigation Efficiency for Water Conservation

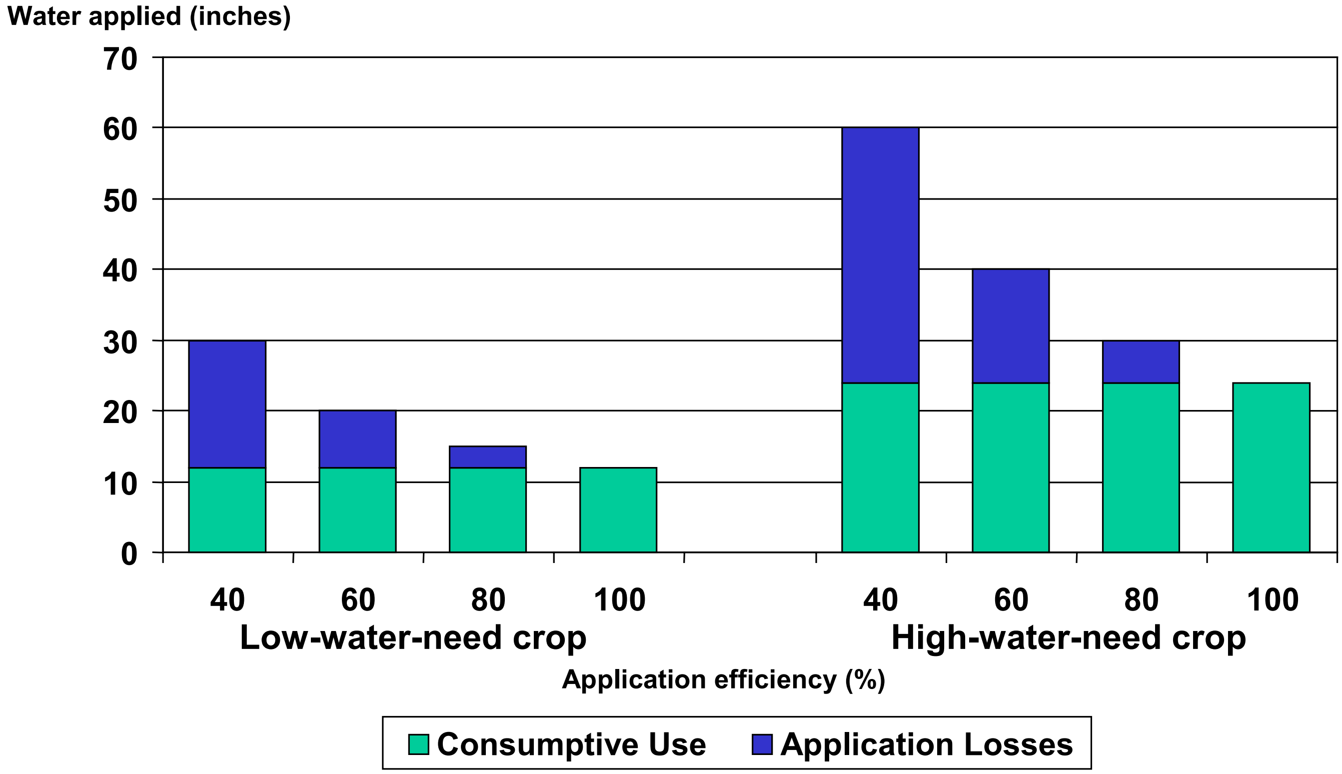
The potential effect of improved irrigation efficiency on farm-level water savings depends, in part, on base conditions at the field level. A given percentage increase in application efficiency will generally yield a less-than-proportional reduction in applied water. For example, a 50-percent increase in application efficiency—from 40 percent to 60 percent—may reduce applied water by one-third (fig.2.2.2). Actual water savings depend in part on the crop irrigated; the more water a crop requires, the greater the potential water savings through improved water management. Water savings also reflect the initial condition of the irrigation system. Improvements in inefficient systems may result in substantial water savings, often at relatively low cost. Under more efficient systems, a comparable increase in efficiency results in lower water savings at a higher cost. For example, an increase from 40 percent to 60 percent in application efficiency will yield greater water savings than an increase from 60 percent to 80 percent for the same crop. The increase from 40 percent to 60 percent can generally be achieved at lower cost through less expensive system modifications and management adjustments. As the target application efficiency increases, there are fewer, more expensive technologies and management practices available to achieve the additional water savings.

The effect of improved irrigation efficiency on *net* water supplies within the hydrologic basin requires a comprehensive accounting of farm water use and disposition. Water withdrawn for irrigation purposes is either consumed in a beneficial or nonbeneficial use, or accounted for as nonconsumptive use—excess runoff, deep percolation, and evaporation. Of the possible dispositions of irrigation withdrawals shown in table 2.2.4, water consumptively used to grow crops is represented by cell 1. Leaching applications for soil salinity control (cells 3, 5) represent a nonconsumptive, beneficial use. A limited amount of field runoff may be regarded as "reasonable," and thus considered a nonconsumptive, beneficial use. Irrigation efficiency at the field level reflects the share of applied water (cells 1 through 6) attributed to beneficial uses (cells 1, 3, 5). Historically, measures to increase irrigation efficiency have focused on reducing nonbeneficial irrigation-system losses (cells 2, 4, 6), without adequately considering the effect on drainage return flows and consumptive use.
Improved irrigation efficiency reduces nonbeneficial water losses (cells 2, 4, 6), which may be either reusable or nonreusable. Reductions in nonreusable field loss (cells 2, 4) under improved systems represent a direct water savings. In contrast, reductions in reusable field loss (cell 6) may not translate into net water savings at the farm level, since some portion of this water may be used to supply additional fields. In addition, reusable field loss that contributes to surface-water return flow and aquifer recharge represents an important water source for downstream withdrawals and environmental flows in many basins. The portion of system losses that reenters the hydrologic system as downstream water supply varies greatly depending on hydrologic, soil, and topographic factors. Moreover, reusable loss does not necessarily imply that the water is readily available in a timely fashion. Runoff and subsurface flows may be discharged downstream of primary withdrawal areas while temporal lags in the transport of runoff and recharge to accessible water sources may be measured in months, years, or decades. Water quality impairment of collecting water bodies may also be an important concern.

Efforts to increase irrigation efficiency can *directly* affect crop consumptive use (cell 1) in two ways. First, the greater uniformity of applied water associated with many improved technologies may result in higher crop yields, with resulting increases in consumptive water requirements. That is, the water "saved" through improved efficiency is used to augment crop yield on the same field. Second, if consumptive water use (and crop yield) per acre remains constant, water saved through improved efficiency may be used on other irrigated lands—both onfarm and across farms—subject to conveyance and legal restrictions. Improved irrigation efficiency can also affect consumptive use *indirectly* by altering returns to land and water across crops. Changes in relative crop returns may prompt substitution among land, water, management, and other inputs; resultant changes in cropping patterns and onfarm water use can involve substantial shifts in water applied at the regional level.

While opportunities exist to increase water-use efficiency in irrigated agriculture, the quantity of "new" water acquired through reduced irrigation losses will depend on various factors. The effectiveness of onfarm improvements in augmenting water flows for instream and nonfarm uses may be limited by increased consumptive water use from expanded onfarm production, reduced irrigation return flows to surface-water systems, and limits on efficiency gains due to widespread irrigation improvements already in place. In addition,

Figure 2.2.2 -- Irrigation water conservation for alternative crop-water consumptive requirements and application efficiencies



the availability and use of conserved water offsite depends on the physical storage and delivery system, the structure of water rights, and the availability of water to satisfy all claims. Where "saved" flows are available as increased non-reserved flows, and junior water-right holders receive only partial entitlements, water conserved upstream may be claimed by downstream irrigation interests. Unintended environmental impacts that can accompany improved efficiencies—such as reductions in downstream wetland habitat, reduced groundwater recharge, and modified stream return flow—may be a concern in some areas.

As targeted gains in irrigation efficiency are achieved, conservation efforts based on improved irrigation efficiency alone will need to be broadened to meet emerging water demands. Net water savings at the sub-basin level may require reductions in both consumptive use and nonreusable, nonconsumptive losses (shaded area of table 2.2.4, cells 1 through 4). Policies to reduce water demand may need to target reductions in crop consumptive use—through improved crop varieties, crop substitution, deficit irrigation, and acreage reductions.

Assessment of nonreusable drainage loss and nonbeneficial consumptive use is site-specific and often difficult to quantify, but may be an important source of water savings in some areas. In addition, the reusable portion of irrigation applications (cells 5 and 6) should also be examined for conservation potential, recognizing spatial and temporal effects on surface and subsurface drainage flows. If the policy goal is to provide water for downstream urban and environmental uses, an effective water conservation program may require reform of water rights and regulations to ensure allocation of conserved water for the desired purpose (Huffaker and Whittlesey).

Table 2.2.4—Use and disposition of irrigation withdrawals

	Consumptive use	Nonconsumptive use	
	Nonreusable	Nonreusable	Reusable
Beneficial uses	Cell #1 Crop evapotranspiration, evaporation for climate control, wet soil evaporation, and water harvested with crop	Cell #3 Nonreusable portion of: deep percolation for salt leaching and runoff regarded as reasonable	Cell #5 Reusable portion of: deep percolation for salt leaching and runoff regarded as reasonable
Nonbeneficial uses	Cell #2 Phreatophyte evapo-transpiration and evaporation from sprinklers, open water, and excess wet soil area	Cell #4 Nonreusable portion of: excess deep percolation, excess runoff, and canal spills	Cell #6 Reusable portion of: excess deep percolation and excess runoff

Source: USDA, ERS, based on Allen et al. and Burt et al.

Related ERS Research

Various ERS-supported research has examined the effects of irrigation water policy on water use and conservation. Significant water savings are more likely to be observed at the extensive margin—through changes in irrigated land base and acreage by crop—rather than through adjustments in per acre water applications (Moore et al.). While limited water savings can often be achieved at lower cost through efficiency gains, more significant water savings generally require reductions in consumptive use—with implications for producer profit (Bernardo and Whittlesey). In addition, substitutions among crops and inputs can result in significant indirect water savings (Schaible et al.; Moore et al.; Bernardo and Whittlesey). Schaible et al. found that improvements in onfarm water-use efficiency increased the level of regional water savings attributable to crop substitution.

Several ERS studies have addressed the effect of water-conserving technology on water quality. Findings suggest that onfarm technologies can have important water-quality impacts, although benefits are sensitive to the type of practice and the attributes and uses of collecting water bodies. Research findings on nitrate contamination of groundwater in eastern Oregon (Kim et al., 1994) and south-central Nebraska (Magleby et al.) indicate the potential benefit of technology adoption, with water-quality effects dependent on depth to water table and rates of groundwater flows. Research findings on sediment control in south-central Idaho (Magleby et al.) suggest that irrigation practices can help to reduce sediment loadings in collecting streams. However, environmental benefits may vary significantly across irrigation investment categories, with the highest potential returns to nonstructural water management practices. Research on agriculture and ecosystem restoration in South Florida (Aillery et al.) suggests that limited increases in cropland soil-water retention to restrict soil subsidence and phosphorus discharge can be implemented with minimal losses in agricultural income. In many cases, improved water quality can be an important joint product with onfarm water-use efficiency, and the combined benefits must be considered in developing conservation strategies (Kim et al., 2000).

Factors Affecting Technology Adoption

The choice of irrigation technology is highly site-specific, reflecting locational, technical, and market factors (Negri and Brooks; Caswell et al.). Field characteristics—such as field size and shape, gradient, and soil type—

are perhaps the most important physical considerations in selecting an irrigation system. Other important factors include technology cost (useful life, financing options); water supply characteristics (cost, quality, reliability, flow rate); crop characteristics (spacing, height); climate (precipitation, temperature, wind velocity); market factors (crop prices, energy cost, labor supply); producer characteristics (farm size, farming traditions, management expertise, risk aversion, tenant/owner status, commitment to farming); and regulatory provisions (groundwater pumping restrictions, drainage discharge limits, water transfer provisions). In many cases, current technology choice is limited by fixed investments in existing systems at the site.

The 1998 FRIS reports that a third of irrigated farms made system improvements over the 1994-98 period. Farms reporting improvements tended to be larger, accounting for 55 percent of the irrigated acres. Benefits cited include improved crop yield (57 percent of farms reporting), reduced energy cost (43 percent), reduced water applied (62 percent), and reduced labor costs (48 percent). However, many producers elected not to invest in system improvements over the survey period. FRIS collected information on several key factors that potentially limit the rate of adoption. Survey data suggest that capital requirements, technology uncertainty, water cost, and water-supply considerations were the major barriers to adoption.

Capital Requirements

Improvements in irrigation systems are often highly capital-intensive. FRIS reports that investment in onfarm irrigation equipment, facilities, and land improvements totaled nearly $1.1 billion in 1998, or roughly $18,000 per reporting farm (USDA, 1999). Capital expenditures included $643 million for irrigation equipment and machinery, $138 million for construction and deepening of wells, $190 million for permanent storage and distribution systems, and $83 million for land clearing and leveling. Replacement of existing systems accounted for the largest share of irrigation capital expenditures (74 percent), followed by irrigation expansion (4 percent) and conservation improvements (22 percent). Approximately 4 percent of farms invested in equipment to conserve water. Conservation investments include $7.4 million for computer hardware and software for improved irrigation water management

While improved irrigation technologies are often economically profitable in a longrun farm plan, high capital outlays may limit adoption. FRIS reports that approximately one-third of respondents indicated that installation of improved practices was either too expensive or could not be financed (USDA, 1999). Smaller farms were less likely to invest in improvements, reflecting more limited financial resources and difficulties in adapting some types of improved systems to smaller fields. Roughly 12 percent of respondents cited landlords not sharing in cost as a barrier to adoption. Approximately 16 percent of respondents felt that system improvements were not justified due to plans to discontinue farming the land.

Technology Uncertainty

Lack of information on the availability, use, and profitability of improved irrigation technologies may limit adoption rates. Improved technologies are less familiar and often more sophisticated than traditional practices, requiring additional technical and management expertise. In some cases, improved irrigation systems may necessitate changes in current farming practices and equipment. For many producers, production uncertainties associated with new technologies are a significant barrier to adoption. Of the irrigators responding to the issue of adoption, 18 percent cited risk of reduced yield or poor crop quality as a contributing factor (USDA, 1999).

Water Cost

Limited cost savings for water conservation reduce incentives to adopt improved irrigation practices. Limited cost savings reflect low water prices and, in some cases, low energy expenditures for pumping and pressurization. In some cases, the cost of irrigation water is substantially less than both the value of water to producers and the opportunity costs of water in nonfarm uses. (For more discussion of water sources and cost, see chapter 2.1, *Water Use and Pricing in Agriculture.*)

Prices paid for off-farm surface-water supplies averaged $16 per acre-foot, or $41 per acre, in 1998 (USDA, 1999). Surface-water prices are generally based on operation and maintenance costs of the delivery system. Deliveries are often charged on a fixed rate per irrigated acre, and are not necessarily adjusted for reduced water demand with improved management. Groundwater costs are generally limited to the cost of access, or variable and fixed costs of pumping. Variable energy costs for groundwater pumping average $32 per acre, although expenses vary greatly depending on well yield, pumplift, power source, and other factors. In areas with significant groundwater pumplifts or high-cost surface water, water cost is an incentive to adopt conserving technologies.

According to the 1998 FRIS, 33 percent of respondents felt that water cost reductions through irrigation water conservation were not sufficient to cover costs of system improvements. Adoption incentives are greatest for producers relying on high-cost water supplies; producers using low-cost ground- and surface-water are less apt to invest in improved technologies (Caswell and Zilberman; Negri and Brooks).

Water Supply

The off-farm water storage and delivery system may limit improvements in irrigation management at the farm level. High onfarm water-use efficiency depends on adequate and timely supplies of water. This requires a flexible surface-water system with sufficient off-farm storage and conveyance capacity, and effective control facilities and operating policies. Many older conveyance systems cannot be adapted to delivering water on demand without capital improvements. Limited off-farm water storage may further restrict water deliveries. Coordination is needed between the off-farm conveyance system and onfarm irrigation system to ensure compatible design and water-scheduling procedures.

Uncertainty of water supplies is an additional limiting factor. Surface-water supplies for junior water-right holders often vary significantly with water storage conditions and other factors. Producers may apply excessive water during peak-flow periods in an attempt to buffer the effects of potential late-season shortages. Variable water supplies may also restrict investment in more efficient structural system improvements, while favoring the use of portable systems and development of supplemental groundwater supplies. Risk of loss of future water rights further limits incentives to invest in water-conserving technologies. Of irrigators responding to the 1998 FRIS question on barriers to adoption, 13 percent indicated that uncertainty over future water rights was a critical concern (USDA, 1999). Not surprisingly, the greatest concentration of farmers with this concern are in States with growing urban and environmental demands.

Policies and Programs Promoting Improved Irrigation Water Management

Policies and programs to promote improved water management in irrigated agriculture include direct public incentive programs, such as cost sharing and technical assistance for water-conserving practices, and various institutional reforms that increase producer incentives to adopt conserving practices.

Public Incentive Programs

In some cases, an improved practice may not be readily adopted at the farm level, although it could offer substantial offsite economic and environmental benefits. Public investment in onfarm cost sharing and technical assistance may be justified where market incentives alone are insufficient to achieve desired rates of technology adoption.

Onfarm Cost-Sharing. The Environmental Quality Incentives Program (EQIP), established under the Federal Agriculture Improvement and Reform Act (FAIR) of 1996, is the primary source of USDA cost sharing for irrigation water management. EQIP provides technical and financial assistance to farmers and ranchers for water conservation measures, as well as cropping and grazing systems; sediment control; manure, nutrient, and pest management; and wildlife habitat. EQIP replaced most previous USDA programs providing financial assistance for irrigation water management in 1996, including the Agricultural Conservation Program, the Water Quality Incentives Program, the Colorado River Basin Salinity Control Program, and the Great Plains Conservation Program.

Under EQIP, cost-share and incentive payments are available for a range of eligible structural and management practices. Prior to the 2002 Farm Act, payments were based on a targeting process, subject to payment limitations by individual and practice. Funds are allocated based on several criteria, including (1) significance of the resource problem in the area; (2) environmental benefits per dollar expended; (3) State or local contributions toward treatment costs; and (4) the effectiveness in meeting water-quality standards or other environmental objectives under Federal or State law. EQIP was authorized at $130 million in FY 1996 and $200 million annually for fiscal years 1997-2002, with half of the funding dedicated to livestock production practices. In FY 2001, a total of 3,373 irrigation management systems benefited from treatment measures under EQIP, accounting for nearly 600,000 acres irrigated nationwide. In the 2002 Farm Act, funding was increased to $400 million annually in FY 2002, increasing to $1.3 billion annually in FY 2007.

Cost sharing for irrigation water management is also provided through the U.S. Department of the Interior's Bureau of Reclamation. Cost-share funds are targeted primarily to Irrigation Districts to assist in development of Water Conservation Plans, as required under revised rules of the 1982 Reclamation Reform Act (RRA; P.L. 97-293, Section 210). While this cost sharing is typically provided for improvements in off-farm irrigation delivery systems (e.g., canal lining, flow measuring devices, conveyance system automation), limited funding has been provided for onfarm water-conservation measures. Funding for Bureau of Reclamation water conservation initiatives is organized by region. For example, the Bureau's Mid-Pacific Region—encompassing much of California, Nevada and southern Oregon—spent $1.8 million for water management planning, conservation education, innovative technology demonstration in 2000, and implementation of conservation measures, with an additional $1.4 million coming from "participating" agencies.

State and local governments may also provide financial support for water conservation. Various States—including Arizona, Colorado, Kansas, Montana, Texas, Utah, and Washington—offer grants for water-conserving practices. Kansas, for example, has recently initiated cost sharing for irrigation improvements designed to slow the decline in groundwater reserves. Many States provide low-interest loans or tax credits specifically for water-conserving equipment.

The 1998 FRIS reports that nearly 21,000 irrigated farms received USDA cost-share funding for irrigation or drainage improvements over the 1994-98 period, for roughly 8 million irrigated acres treated nationwide. Non-

USDA Federal programs provided cost sharing for 12,000 irrigated farms, with 3 million irrigated acres treated. State, local, and Irrigation District programs provided additional cost sharing to over 13,000 irrigated farms, accounting for 4 million irrigated acres treated.

Technical Assistance. Technical assistance for selection, design, and operation of improved irrigation technologies is available through various public agencies and institutions. USDA's Natural Resources Conservation Service (NRCS) provides technical assistance through local conservation districts. Under the NRCS Conservation Technical Assistance program, technical assistance for irrigation management systems served 715,000 acres in FY 2001; additional USDA technical assistance was also provided through the EQIP program. The Bureau of Reclamation also provides technical assistance to western irrigators receiving Federal project water. Much of this technical assistance is targeted to Irrigation Districts for improvements in water-delivery systems and development of onfarm demonstration projects. At the State level, technical assistance is available through irrigation and farm management specialists associated with the Cooperative Extension system and land-grant institutions. Private irrigation consultants, Irrigation Districts, and irrigation equipment dealers are also important sources of water management information.

FRIS reports that the most commonly used sources of water management information are neighboring farmers, (49 percent of farms), extension agents or university specialists (42 percent), and irrigation equipment dealers (35 percent). Irrigation specialists from Federal agencies, water suppliers, private consultants, media reports, and other sources each serve less than 20 percent of farms (USDA, 1999). Larger farms tend to rely on multiple sources, with greater emphasis on private consultants, irrigation specialists from universities and government agencies, and irrigation equipment dealers. In general, most producers rely on more than one information source for guidance in irrigation decisions.

Water Policy Reform

Water policy adjustments at the State and Federal level have encouraged improved water management in irrigated agriculture. However, the type and magnitude of adjustments vary widely across States, and Federal reforms have generally not been comprehensive.

Water pricing. Changes in Federal water prices involving higher rates, per unit water charges, and block-rate pricing may help to induce adoption of water-conserving technologies. However, pricing reform alone is not likely to prompt the level of overall water conservation desired on federally financed projects. Moore and Dinar conclude that irrigators supplied by Federal water projects in southern California view water as a quantity-rationed input. While price adjustments have distributional impacts, water use is not likely to be significantly affected by small price increases under the current institutional system. Studies have suggested that irrigation water, in general, has a low price elasticity of demand, implying that prices would have to increase significantly in order to conserve meaningful quantities of water (Moore et al.; Negri and Brooks; Caswell and Zilberman). Substitution of groundwater supplies, where physically available and economically viable, may further limit the effect of public water-pricing policy on investment in conserving technologies. Water-pricing policies may be more effective when implemented in conjunction with other determinants of technology choice and crop production.

Water transfers. Market provisions for the sale of water rights or temporary lease of water would encourage the conservation of agricultural water by providing farmers compensation for unused water entitlements. However, legal and institutional barriers at the Federal, State, and local levels have restricted widespread development of operational markets for water (Gollehon). For most Federal water projects, changes in water deliveries are subject to administrative review, and water is generally not transferred beyond the project service area. Further, laws governing water use and transfer are vested with the individual State. In most States, irrigators do not retain rights to water conserved through improved irrigation efficiency. Thus, water saved is not available for transfer and is most often used on the farm for higher yields or irrigation expansion. Meanwhile, political concerns have focused on downstream impacts and secondary effects of reduced agricultural activity on local communities.

In recent years, barriers to water marketing have been reduced in some locations. Statutory changes at the State level have increasingly recognized both the need to transfer water to meet new demands and rights to water "salvaged" through conservation. Recent reform of water transfer policies under the Central Valley Project Improvement Act may suggest a relaxing of constraints on transfers involving Federal water supplies.

Water Conservation Programs. The Federal Government requires development of irrigation conservation plans—specifying improved irrigation management systems and practices—under certain conditions. USDA conservation plans must be in place for farms with highly erodible soils to qualify for program funding. An approved plan is also required for farmers receiving cost-share and incentive payments under EQIP. In addition, access to publicly financed water supplies is increasingly tied to improved water management. Water districts receiving Federal water through the Bureau of Reclamation are required to develop water conservation plans, including explicit contractual language on goals, implementation measures, and timetables in some cases.

States are assuming an increasing role in irrigation water conservation, although legal authorities and program activities vary widely. Many States, mostly in the West, have established water conservation programs. States may require local water conservation plans, and several have established local management areas in critical water resource areas. State-level activities include conservation planning, water-use permitting with conservation provisions, program monitoring and evaluation, financial support for conservation practices, and technical assistance.

Water policy reform—involving water pricing, transfer provisions, and conservation programs—provides increased incentives for improved management of water supplies at the farm level. Meanwhile, opportunities for improved water management have expanded with advances in irrigation equipment and practices, lower technology costs, and expanded information resources. As regional water-supply pressures intensify, agriculture will rely increasingly on improved water management to sustain productivity and increase the economic value of irrigation water.
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