4.6. 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 part of the solution almost everywhere.

Contents

The U.S. Department of Agriculture identifies improvements in water management as one of the primary agricultural policy objectives for the 1990's (USDA, 1994). Irrigation water management (IWM) involves the managed allocation of water and related inputs in irrigated crop production, such that economic returns are enhanced relative to available water. 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?

Irrigation water is managed to conserve water supplies, to reduce water-quality impacts, and to improve producer net returns.

Water Conservation. Water savings through improved management of irrigation supplies are considered essential to meeting future water needs. Irrigation is the most significant use of water, accounting for over 95 percent of freshwater withdrawals consumed in several Western States and roughly 80 percent nationwide (see chapter 2.1, *Water Use and Pricing)*. 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 must be met largely through conservation and reallocation of existing irrigation supplies (Moore, 1991; Schaible and others, 1991; Vaux, 1986; Howe, 1985).

Water Quality. Improved water management can also help minimize offsite water-quality impacts of irrigated production. Irrigated agriculture affects water quality in several ways, including higher chemical-use rates associated with irrigated crop production, increased field salinity and 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 ground water bodies (National Research Council, 1996).

Farm Returns. Finally, improvements in IWM 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 40 percent of total crop sales with just 15 percent of the Nation's harvested cropland in 1992 (USDC, 1994). 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 reduce water use per acre by applying less than full crop-consumptive requirements (deficit irrigation), shifting to alternative crops or varieties of the same crop that use less water, or adopting more efficient irrigation technologies. In some cases, producers may convert from irrigated to dryland farming or retire land from production. Many irrigators have responded to water scarcity through the use of 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 efficiency of applied water in irrigated agriculture (see box, "Irrigation Water-Use Efficiency"). Irrigation improvements often involve upgrades in physical application systems, with improved field application efficiencies and higher yield potentials. Improved water management practices, such as irrigation scheduling and water-flow measurement, may also be required to achieve maximum potentials of the physical system. In addition, management of drainage flows may be an important concern in many irrigated areas (table 4.6.1). 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 Water-Use Efficiency

Water-use efficiency measures are commonly used to characterize the water-conserving potential of irrigation systems. Alternative efficiency measures reflect various stages of water use and levels of spatial aggregation. **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. **Application efficiency** is the ratio of the average depth of irrigation water stored in the root zone for crop consumptive use to the average depth applied, expressed as a percentage. Crop-water consumption includes stored water used by the plant for transpiration and tissue building, plus incidental evaporation from plant and field surfaces. 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. 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 efficiency** is calculated based on onfarm irrigation 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.

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 (Pressurized) Irrigation Systems and Practices," pp. 229-230.)

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 the field. Water is conveyed to the field by means of open ditches, above-ground pipe (including gated pipe), or underground pipe, and released along the upper end of the field through siphon tubes, ditch gates, or pipe valves. Fields are

Table 4.6.1—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; above-ground pipe; below-ground pipe.
Gravity application systems:		
Release of water	Dirt or canvass checks with siphon tubes.	Ditch portals or gates; gated pipe; gated pipe with surge flow or cablegation.
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.
Field gradient	Natural field slope, often substantial; uneven field surface.	Land leveled to reduce and smooth field surface gradient.
Length of irrigation run	Length of field, often 1/2 mile or more.	Shorter runs, 1/4 mile or less.
Pressurized application systems:		
Pressure requirements	High pressure, typically above 60 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 water.	Multiple crops; various uses—irrigation, chemigation, manure application, 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 inpipe 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.

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; field slope should be minimal and fairly uniform to permit controlled water advance.

Although total acreage in gravity systems has declined by 20 percent since 1979, gravity-flow systems still account for over half of irrigated acreage nationwide (table 4.6.2). Gravity-flow systems are used in all irrigated areas, and are particularly predominant in the Southwest (California, Nevada, Arizona, New Mexico), Central Rockies (Wyoming, Colorado, Utah), Southern Plains (Texas, Oklahoma), and Delta (Arkansas, Louisiana, Mississippi) regions. The predominance 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-

Table 4.6.2—Changes in irrigation system acreage, 1979-94

System	1979	1994	Change 1979-94
	Million acres		*Percent*
All systems	50.1	46.4	-7
Gravity-flow systems	31.2	25.1	-20
Sprinkler systems	18.4	21.5	17
Center pivot	8.6	14.8	72
Mechanical move	5.1	3.7	-27
Hand move	3.7	1.9	-48
Solid set and permanent	1.0	1.0	2
Low-flow irrigation (drip/trickle)	.3	1.8	445
Subirrigation	.2	.4	49

Source: USDA, ERS, based on USDC, 1982 and 1996.

leaching requirements. Furrow application systems comprise nearly 60 percent of all gravity-flow systems; border/basin and uncontrolled-flood application systems account for the remaining acreage (table 4.6.3).

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 to 65 percent, although improved systems with proper management may achieve efficiencies of up to 85 percent (Negri and Hanchar, 1989).

Various land treatment and management measures have been developed to reduce water losses under gravity-flow systems (table 4.6.1). Measures include improved onfarm water-conveyance systems, precision field leveling, shortened water runs, alternate furrow irrigation, surge flow and cablegation, and tailwater reuse.

Improved water-conveyance systems are an important potential source of farm-level water savings. System upgrades include ditchlining, ditch reorganization, and pipeline installation. According to the 1994 Farm and Ranch Irrigation Survey (FRIS), traditional open-ditch systems remain the principal means of onfarm water conveyance for gravity-flow systems, with almost 60 percent of gravity-acreage served (USDC, 1996). Above-ground pipelines—including gated pipe—accounted for a third of gravity-flow acreage

Table 4.6.3—Irrigation application systems, by type, 1994

System	Acres	Share of all systems
	Million	*Percent*
All systems	46.4	100
Gravity flow systems	25.1	54
Row/furrow application	14.2	31
Open ditches	5.0	11
Above-ground pipe	7.4	16
Underground pipe	1.8	4
Border/basin application	7.5	16
Open ditches	5.1	11
Above-ground pipe	.9	2
Underground pipe	1.5	3
Uncontrolled flooding application	2.3	5
Open ditches	2.3	5
Above-ground pipe	.0	0
Underground pipe	.0	0
Sprinkler systems	21.5	46
Center pivot	14.8	32
High pressure	3.2	7
Medium pressure	5.9	13
Low pressure	5.7	12
Mechanical move	3.7	8
Linear and wheel-move	3.0	7
All other	.6	1
Hand move	1.9	4
Solid set & permanent	1.0	2
Low-flow irrigation (drip/trickle)	1.8	4
Subirrigation	.4	1

Note: Percents may not sum to totals due to multiple systems on some irrigated acres and rounding.
Source: USDA, ERS, based on USDC, 1996.

served, with underground lines serving the remaining acreage.

Improvements in traditional gravity technology can increase the uniformity of applied water, while reducing percolation losses and minimizing water runoff. Gated-pipe systems are concentrated in the Northern and Southern Plains and Delta regions. Surge-flow and cablegation systems—designed to control water deliveries from gated pipe—are used on 5 percent of gravity-flow acreage, predominantly in

Gravity Irrigation Systems and Practices

Open-ditch conveyance systems have been 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. Furrows are generally straight, although they may be curved to follow the land contour on steeply sloping fields. Row crops are typically grown on the ridge or bed between the furrows, spaced from 2 to 4 feet apart. Corrugations—or 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, guided by ridges 10 to 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 System 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; ***above-ground pipeline*** generally consists of lightweight, portable aluminum, plastic, or flexible rubber-based hose. One form of above-ground pipeline—***gated-pipe***—distributes water to gravity-flow systems from individual gates (valves) along the pipe.

Field leveling involves grading and earthmoving to eliminate variation in field gradient—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 one 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 alternative 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 for reuse.

Pressurized Irrigation 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 to 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.

Hand move is a portable sprinkler system in which lightweight pipeline sections are moved manually for successive irrigation sets of 40 to 60 feet. Lateral pipelines are connected to a mainline, which may be portable or buried. Handmove systems are often used for small, irregular fields. Handmove 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, handmove 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 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 handmove 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 have been developed that reduce both water application losses and energy requirements. Older center pivots, with the sprinklers attached directly to the pipe, operate at relatively high pressure (60-80 psi), with wide water-spray patterns. Newer center pivots 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 system innovations to reduce water losses and energy needs.

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.

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/trickle*** and ***micro-sprinkler*** systems. ***Drip and 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 high-valued vegetable crops.

the Plains States. Alternate furrow irrigation is practiced on over 20 percent of gravity-flow acres, with special furrows (widespaced, compacted, or diked) applied on more than 10 percent of acres. Roughly 5 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 12 percent of all irrigated acres have been precision laser-leveled, predominantly on gravity-flow systems in the Southwest, Delta, and Southeast regions. High-efficiency level-basin systems are concentrated in the Southwest. Deficit irrigation techniques—such as reduced irrigation set-times, partial-field irrigation, and reduced irrigations—are practiced on roughly 10 percent of gravity-flow acres, with highest acreage concentrations in the Northwest (Washington, Oregon, Idaho). Tailwater reuse systems—which recirculate runoff water on the field—have been installed on over 20 percent of gravity-system acreage nationwide. Tailwater reuse systems are disbursed throughout the major gravity-irrigated States, with California leading both in total acreage (1.9 million) and share of gravity acres (38 percent) with tailwater systems.

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 23 million acres (50 percent) in 1994 (table 4.6.2).

Sprinkler systems—in which water is sprayed over the field surface, usually from above-ground piping—accounted for 46 percent of irrigated acreage in 1994 (table 4.6.3). Concentrations of sprinkler acreage are highest in the Northern Pacific, Northern Plains, and Northern Mountain States. Sprinkler systems are also used extensively for supplemental irrigation and specialty-crop irrigation in the humid eastern States.

Sprinkler irrigation has been adopted in many areas as a water-conserving alternative to gravity-flow systems. Field application efficiencies typically range from 60 to 85 percent under proper management (Negri and Hanchar, 1989). Sprinklers may be operated on moderately 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 are required to avoid plant stress from too little water and excess runoff from too much water.

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

Sprinkler technologies include a wide range of adaptations, with significant shifts in technology shares in recent years. The development of self-propelled center-pivot systems in the 1960's greatly expanded the acreage suitable for irrigation, and accounted for much of the growth in acreage irrigated during the 1970's. Acres irrigated with center pivots increased by 6.2 million acres from 1979 to 1994, with about half of the increase attributable to net increases in irrigated area under sprinkler and about half from the net replacement of other sprinkler types with center pivot (table 4.6.2). Center-pivot systems accounted for nearly 70 percent of sprinkler acreage in 1994, or 32 percent of total irrigated acreage (table 4.6.3). Largest acreage concentrations under center-pivot are in the Northern Plains, Southern Plains, and Delta regions.

Sprinkler systems other than center pivot—including hand move, mechanical move, and solid set—made up about 31 percent of total sprinkler acreage in 1994, down from 53 percent in 1979. Acreage in handmove systems has declined by nearly one-half since 1979; mechanical-move systems have declined by more than 25 percent (table 4.6.2).

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 40 percent of center pivot acres in 1994 were operated under low pressure (below 30 pounds per square inch (psi)), with just 22 percent operating at high pressure (above 60 psi). (Forty-two percent of center pivot acres were high-pressure systems as recently as 1988.) Adoption of low-pressure systems has been particularly strong in the Southern Plains, reflecting higher-cost groundwater pumping in much of the region. Current advances in sprinkler technology focus on location of spray heads and low-pressure sprinklers and nozzles; the trend is toward energy- and water-conserving nozzles located closer to the soil. In addition, advances are being made in remote control of sprinklers and individual nozzle control for precision agriculture.

Low-flow irrigation systems are a form of pressurized system in which water is applied in small, controlled quantities near or below ground level. Low-flow irrigation systems—including drip, trickle, and micro-sprinklers—comprise 4 percent of irrigated cropland acreage (table 4.6.3), up more than four-fold since 1979 (table 4.6.2). 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 certain row and field crops. Low-flow irrigation systems are located primarily in California and Florida, reflecting large acreages in specialty produce and orchard production.

Field 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. Filtration of the water supply and careful system maintenance may be required to prevent clogging of small orifices. Advances in low-flow technology focus 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. Well-informed decisions increase the likelihood that water is applied according to crop needs, with minimal water loss. Improved management practices are often more cost-effective than structural improvements, although structural upgrades may be required to achieve highest management potential.

Irrigation scheduling involves the application of irrigation water based on a systematic monitoring of crop soil-moisture requirements. Sophisticated scheduling methods—based on sensors, microprocessors, and computer-aided decision tools—may 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 crop water needs for a wide range of crops and locales. Soil moisture available for plant growth may also be measured directly through periodic soil testing. Soil probes are used to obtain soil samples at various depths for “feel and visual” evaluation. More sophisticated devices—such as 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 Surveys for years 1984 and 1994, irrigators were asked to indicate all methods used in deciding when to irrigate (USDC, 1986 and 1996). 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 1994 FRIS, 10 percent of irrigators used soil moisture-sensing devices (up from 8 percent in 1984), 5 percent used commercial scheduling (up from 3 percent), 4 percent used media reports on plant water requirements (down 1 percent), and 2 percent used computer simulations (not asked in 1984).

Water flow measurement is an important component of water management at the farm level. Measurement of water flows 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, and in-canal flow meters for open ditches, and external and internal meters for pipe.

Irrigation Drainage Systems

The collection and disposal of drainage flows from irrigation and precipitation is an important management consideration in many irrigated areas. Irrigation drainage includes surface runoff and deep percolation from water applied to meet crop consumptive needs. In some areas, periodic 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 for reuse. Drainage flows may also be used as irrigation supplies downslope, both onfarm 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. 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 bodies 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-valued, high-yielding 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, while avoiding equipment use and soil compaction. Chemigation is used on all major crops, with the largest treated acreages in orchard crops, hay, and corn—and the greatest concentration of use in potato, rice, and sugarbeet production (USDC, 1996).

Erosion Control. Soil erosion can be a serious problem for less efficient irrigation systems on sloping fields. Soil 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, particular 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 may also limit soil erosion on irrigated fields. Crop residue management to maintain vegetative material on the soil surface increases infiltration while protecting the soil from erosive water flow. In some cases, deep tillage can reduce runoff through increased infiltration. Land treatment measures may be installed to slow runoff and trap sediment on the farm. 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.

A promising new soil amendment—Polyacrylamide, more commonly known as PAM—may be added to irrigation water to stabilize soil and water-borne sediment. Under experimental field-trial conditions, proper application of PAM with the first irrigation has substantially reduced soil erosion in furrow systems. 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. An estimated 50,000 irrigated acres were treated with PAM after just 1 year on the market, including 30,000 acres in the Pacific Northwest. Research is underway to determine the best PAM formulations and application techniques (Sojka and Lentz, 1996).

Irrigation Technology and Environmental Benefits

Adoption of improved irrigation technology has been advanced as a means to reduce offsite water quantity and quality problems. The effectiveness of technology in achieving environmental goals has important implications for regional water policy.

Water Conservation

Improved irrigation and conveyance technologies may substantially increase onfarm water-use efficiency. Whether technology adoption can achieve significant

Table 4.6.4—Irrigation water conservation for alternative crop-water consumptive requirements and field application efficiencies

Hypothetical crop	Consumptive water use	Application efficiency	Irrigation water applied	Application losses
	Inches	*Percent*	*Inches*	
Low water need	12	40	30	18
	12	60	20	8
	12	80	15	3
	12	100	12	0
High water need	24	40	60	36
	24	60	40	16
	24	80	30	6
	24	100	24	0

Source: USDA, ERS.

water savings for nonfarm and instream uses, however, will depend on many factors.

In general, a given percentage increase in field application efficiency will yield a less-than-proportional reduction in applied water. For example, a 50-percent increase in field application efficiency—from 40 percent to 60 percent—may reduce applied water by one-third (table 4.6.4). Actual quantities of 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 to 60 percent in field application efficiency will yield greater water savings than an increase from 60 to 80 percent for the same crop (table 4.6.4). The increase from 40 to 60 percent can generally be achieved at lower cost through less expensive system modifications and management adjustments. As the target field application efficiency increases, there are fewer, more expensive technologies and management practices available to achieve the additional water savings.

Water withdrawn for irrigation purposes is either consumed in a beneficial or nonbeneficial use, or accounted for as nonconsumptive use—evaporation, field runoff, and deep percolation. Of the possible dispositions of irrigation withdrawals shown in table 4.6.5, 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. 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

Table 4.6.5—Use and disposition of irrigation withdrawals

	Consumptive use	Nonconsumptive use	
	Nonreusable	Nonreusable portion	Reusable portion
Beneficial uses	Cell #1: Crop evapotranspiration	Cell #3: Nonreusable deep percolation for salt leaching due to quality impairment	Cell #5: Reusable deep percolation for salt leaching
Nonbeneficial uses	Cell #2: Noncrop evapotranspiration and evaporation from sprinklers, open water, and excess wet soil area	Cell #4: Nonreusable runoff and excess deep percolation due to quality impairment	Cell #6: Reusable runoff and excess deep percolation

Source: USDA, ERS, based on Allen and others, 1996.

contribute directly to reduced water demand. However, reductions in reusable field loss (cell 6) may not translate into water savings. Reusable field loss—including surface-water return flow and aquifer recharge—represents an important water source for downstream withdrawals and environmental purposes in many locations. The portion of applied irrigation water that re-enters the hydrologic system as downstream water supply varies greatly depending on physical, hydrologic, and topographic factors. Further, reusable supply does not necessarily imply the water is immediately available. Runoff and subsurface flows may be discharged downstream of the need area while temporal lags in transporting runoff and recharge to useable water sources may be measured in months, years, or decades.

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 land and water opportunity values across crops. Changes in relative values 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, 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.

Conservation efforts based on improved irrigation efficiency alone may 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 4.6.5, 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 conservation program may require reform of water rights and regulations to ensure allocation of conserved water for the desired purpose.

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 and others, 1994). While limited water savings can often be achieved through lower-cost efficiency gains, more significant water savings generally require reductions in consumptive use—with implications for producer profit (Bernardo and Whittlesey, 1989). In addition, substitutions among crops and inputs can result in significant regional water savings (Schaible and others, 1995; Moore and others, 1994; Bernardo and Whittlesey, 1989). Schaible and others (1995) found that improvements in onfarm water-use efficiency increased the level of regional water savings attributable to crop substitution. A mix of conservation policies may help to distribute the costs of water conservation across water users and regions (Schaible and others, 1995).

Water Quality

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 ground water in eastern Oregon (Kim and others, 1994) and south-central Nebraska (Magleby and others, 1995) indicate the beneficial effect of technology adoption on water quality. However, the ability to affect water quality through improved irrigation technology depends, in part, on underlying aquifer conditions, including the depth to water table and rates of groundwater flows.

Research findings on sediment control in south-central Idaho (Magleby and others, 1989) suggest that irrigation practices can help to reduce sediment loadings in collecting streams. Environmental benefits may vary significantly across irrigation investment categories, however, with highest potential returns to non-structural water management practices. The effectiveness of improved irrigation practices in achieving water-quality benefits may be enhanced when implemented in combination with other conservation practices, such as conservation tillage and filter strips.

Polices to improve water quality may need to target both high-priority areas and cost-effective conservation practices in a whole-farm context. In many cases, improved water quality can be an important joint product with water conservation. Together, the combined benefits of increased onfarm efficiency may justify improved technologies, and may help to speed adoption at a rate greater than water savings alone can justify.

Factors Affecting Technology Adoption

The choice of irrigation technology is highly site-specific, reflecting locational, technical, and market factors. Field characteristics—such as field size and shape, field 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 (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 1994 FRIS reports that 38 percent of farms made system improvements from 1990 to 1994, while no improvements were reported on 56 percent of farms. Those farms reporting improvements tended to be larger, accounting for 58 percent of the irrigated acres. Potential benefits of improved irrigation reflect, in part, the rate of technology adoption. FRIS collected information on several key factors affecting technology adoption, including capital requirements, technology information, water-pricing policy, and water-supply considerations.

Capital Requirements

Improvements in irrigation systems are often highly capital-intensive. FRIS reports that investment in onfarm irrigation equipment, facilities, and land improvements totaled $800 million in 1994, or nearly $10,000 per farm reporting expenditures (USDC, 1996). Capital expenditures included $573 million for irrigation equipment and machinery, $92 million for construction and deepening of wells, $82 million for permanent storage and distribution systems, and $51 million for land clearing and leveling. Replacement of existing systems accounted for the largest share of irrigation capital expenditures (64 percent), followed by irrigation expansion (19 percent) and conservation improvements (17 percent).

While improved irrigation technologies are often economically profitable in a long-run farm plan, high capital outlays may limit their adoption. FRIS reports that nearly 30 percent of respondents indicated that installation of improved practices was either too expensive or could not be financed (USDC, 1996). 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.

Technology Information

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 complements. For many producers, the benefits of new technologies are uncertain. Of farmers reporting no system improvements over 1990-94, 74 percent were unaware of improvements that "fit" their operation (explained in part by insufficient information), while 20 percent indicated heightened production risk as a contributing factor (USDC, 1996).

Water Cost

Limited cost savings for water conservation reduce incentives to adopt improved irrigation practices. Limited cost-savings reflect low purchased-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.*)

Prices paid for off-farm surface-water supplies averaged $16 per acre-foot, or $36/acre, in 1994 (USDC, 1996). 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—variable and fixed cost of pumping—and 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 1994 FRIS, irrigators recognize the benefits of conservation since only 6 percent of survey respondents reported that water-conserving practices have no economic benefit. 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, 1985; Negri and Brooks, 1990).

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 those irrigators responding to the question on barriers to adoption, almost 20 percent indicated that future water rights was a critical concern (USDC, 1996). Not surprisingly, the greatest concentration of farmers with this concern are in States with growing urban and environmental demands—California, Idaho, Texas, Nebraska, Colorado, Oregon, Washington, Utah, and Florida.

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 its use could result in 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. With the signing of the Federal Agricultural Improvement and Reform Act of 1996, USDA cost-sharing enters a new era. Under the new legislation, the Environmental Quality Incentives Program (EQIP) was established to provide technical and financial assistance to farmers and ranchers for improved irrigation management, as well as improvements in cropping and grazing systems; wildlife habitat; sediment control; and manure, nutrient, and pest management. EQIP replaces most previous USDA programs providing financial assistance for IWM, 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. Payments are based on a targeting process, subject to payment limitations by individual and practice. Funds are to be 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 fiscal year 1996 and $200 million annually for fiscal years 1997-2002, with half of the funding dedicated to livestock production practices.

Limited cost-sharing for water conservation measures is also provided through the Bureau of Reclamation, U.S. Department of Interior. Under provisions of the 1992 Central Valley Project Improvement Act (CVPIA; P.L. 102-575), the Bureau of Reclamation is authorized to provide cost-sharing to irrigators supplied by the federally financed Central Valley Project (CVP) in central California. The Bureau may fund up to 100 percent of the cost of water-conserving measures. In return, the Federal Government receives a proportionate share of water conserved—equal to its financial contribution—to be used to meet Federal obligations for restoration of fish and wildlife habitat in the Central Valley region.

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.

Technical Assistance. Technical assistance for selection, design, and operation of improved irrigation technologies is available through various public agencies and institutions. The USDA Natural Resources Conservation Service (NRCS) provides technical assistance under its conservation operations program and the EQIP program through local conservation districts. The Bureau of Reclamation also provides technical assistance to western irrigators receiving Federal project water. At the State level, technical assistance is available through irrigation and farm management specialists associated with the Cooperative Extension Service 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 extension agents or university specialists, 44 percent of farms; neighboring farmers, 44 percent; irrigation equipment dealers, 37 percent; and irrigation specialists from NRCS and other Federal agencies, 26 percent. Media reports, water suppliers, private consultants, and other sources each serve less than 20 percent of farms (USDC, 1996). 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 (1995) 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 and others, 1994; Negri and Brooks, 1990; Caswell and Zilberman, 1985). 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. 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 CVPIA 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 cost of many technologies, 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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