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Water Conservation Through Irrigation Technology

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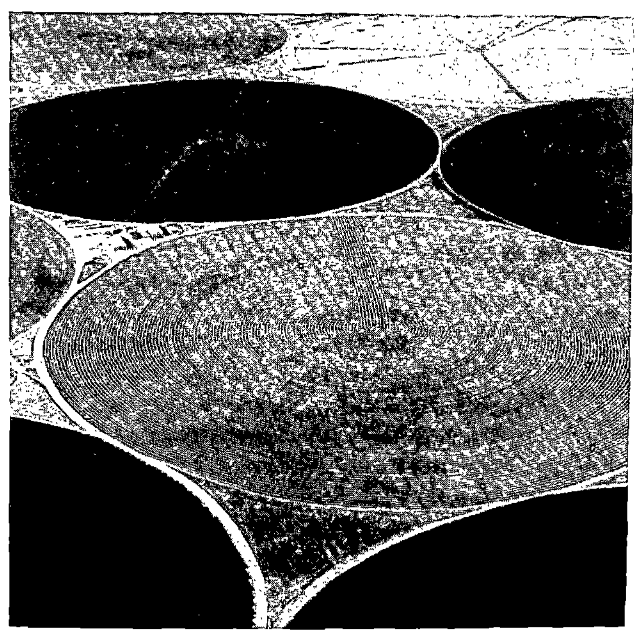
In this report... *Improved irrigation technology and advanced farm management practices offer an opportunity for agriculture to use water more efficiently. Farmers may install new equipment, such as drip irrigation systems, or adopt advanced water management practices to conserve water without sacrificing crop yields. While farmers' decision to adopt water-saving irrigation technology responds to the cost of water, physical properties of the land such as topography or soil texture dominate the choice of irrigation technology.*

Irrigated agriculture surely faces a future of increased water scarcity and higher water prices. Although the demand for water from irrigation and industrial uses leveled off in the 1980's, continued growth in urban water use and awareness of environmental and recreational values of water point toward sustained demand growth. Water supply development is not keeping pace with expanding demand, creating fierce competition for existing supplies. Improved irrigation technology and related developments in water management on the farm offer an opportunity for agriculture to alleviate water scarcity and more efficiently allocate water.

Increased water supplies from surface or ground water sources are not the solution for meeting water scarcity that they were in the past. Today, dwindling opportunities to develop new surface supplies, large Government budget deficits, and increasing concern for environmental and recreation values make large-scale water projects such as dams and reservoirs unlikely. Concurrently, ground water users in many areas are facing declining ground water tables, reduced well yields, and higher energy costs.

In the absence of supply expansion, growing competition for water must be resolved through more efficient allocation and conservation. Agriculture is a logical target for water conservation and reallocation since it consumes over 80 percent of the Nation's water resources.

A question of considerable importance to policymakers concerns how farmers will adjust production to conserve water in response to less water and higher water prices. The response may take a variety of forms: farmers may adopt more efficient irrigation technology, convert irrigated land to dryland farming, shift to crops that use less water, apply less water per acre for a given technology and crop, or retire land from production. Irrigators often responded to water scarcity in the past by adopting improved water-saving technology. In response to increases in the price of water, irrigators will most likely again look to technology as a viable method of conserving water.



Agriculture Faces Competition for Water

Agriculture competes with households, industries, and other interests for limited water resources, many of which were developed with Government support.

Beginning in the late 1800's, Government policies and legal tenets governing water rights encouraged water supply development, particularly in the arid West. These policies promoted the exploitation of rivers, streams, and ground water aquifers for irrigated agriculture, and fostered the successful settlement of arid and semiarid western lands.

Today, irrigated agriculture consumes the largest portion of the Nation's water resources. Water consumption occurs when water is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the water environment. Total freshwater consumptive use in the United States was estimated at 103 million acre-feet during 1985 with irrigation accounting for approximately 83 percent of the total (fig. 1). (One acre-foot is the amount of water needed to cover an acre of land to a depth of 1 foot, and is equal to 325,850 gallons.)

In return, irrigated agriculture contributes a substantial amount to the total value of agricultural products sold. Irrigated lands account for 13 percent of the Nation's harvested cropland acres, and contribute about 30 percent to the value of cropland production (fig. 2, table 1).

Government Played a Key Role in Developing Water Supplies

Water storage and conveyance facilities that were financed and constructed by the Federal Government provide irrigation water to about one-fourth of the irrigated acreage in the West. Since 1902 the Bureau of Reclamation has constructed an irrigation infrastructure of 355 water-storage reservoirs, 254 diversion dams, and thousands of miles of transportation canals, pipelines, tunnels, and laterals. In many cases, these facilities provided—and still provide—water to municipal, industrial, and agricultural users at prices below cost.

Competition for Water Resources Is Growing

The demands placed on the Nation's water resources by competing uses are increasing and the trend is expected to continue. Water withdrawal occurs when water is removed from the ground or diverted from a surface source for use. Some of the water withdrawn is returned to the stream. Water consumption implies that the water is not available for reuse. Water demands for traditional uses (for example, agriculture, energy, domestic, and industrial) are expected to increase as population grows, even though withdrawals declined slightly from 1980 to 1985.

Competition may also originate from two relatively new sources of water demand. First, growing awareness of environmental and recreational consequences of water diversions has increased the value of water remaining in rivers and streams. Of particular importance is the growing recognition that water has value for water-quality improvement, fish propagation, and recreation when left instream.

A second source of water competition is currently arising from outstanding Indian claims to reserved water rights. When Indian reservations were created, the Federal Government implicitly established Indian water rights. The amount of water associated with the rights, if sustained, is uncertain but potentially large.

In many cases, increasing demands from traditional sources and new sources of demand conflict with existing appropriations among agriculture, urban, industrial, or hydroelectric uses.

Era of Water Supply Expansion Has Ended

In the past, the development of abundant sources of supplies resolved competing demands for scarce water resources and relieved pressure to adopt more efficient allocation mechanisms. Abundant water supplies and subsidized prices from many Government water projects stimulated consumption and discouraged efficient use. In the era of abundant supply, efficient water allocation was not a high priority. That era has run its course.

Three significant revisions in Federal water policy testify that the era of large-scale surface water supply development has ended. First, Congress has authorized only one new water project in the last 12 years. Second, the mission of the Bureau of Reclamation has recently changed from water development to water management. The Bureau of Reclamation will devote fewer resources to the development of new water supplies and more resources to the efficient management and use of existing water supplies.[1] Third, the Federal

[1] U.S. Dept. of the Interior, Bureau of Reclamation, *Assessment '87: A New Direction for the Bureau of Reclamation*, 1987.

Government is expanding protection of rivers and streams from all forms of development. At the beginning of 1988, 7,700 miles of rivers and streams had been protected from development under the Wild and Scenic Rivers Act of 1968.

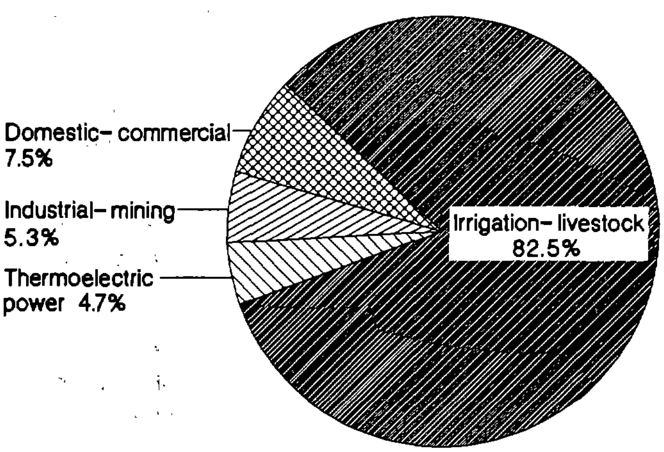
Ground water constitutes the second major source of water supply, comprising 30 percent of total freshwater use from all sources. But the availability of ground water is also shrinking in many areas as water tables and well yields fall. The average annual rates of ground water decline in 11 States identified as problem areas range from one-half to 4 feet. Declining ground water tables, higher energy costs, and increasing ground water contamination have diminished the availability and increased the cost of ground water.

Efficient Allocation and Conservation Can Alleviate Water Scarcity

In the absence of supply expansion, efforts to resolve increasing competition for water resources must stress conservation and efficient allocation among competing uses. Agriculture is a likely target of efforts to more efficiently allocate water, since it is the largest consumer.

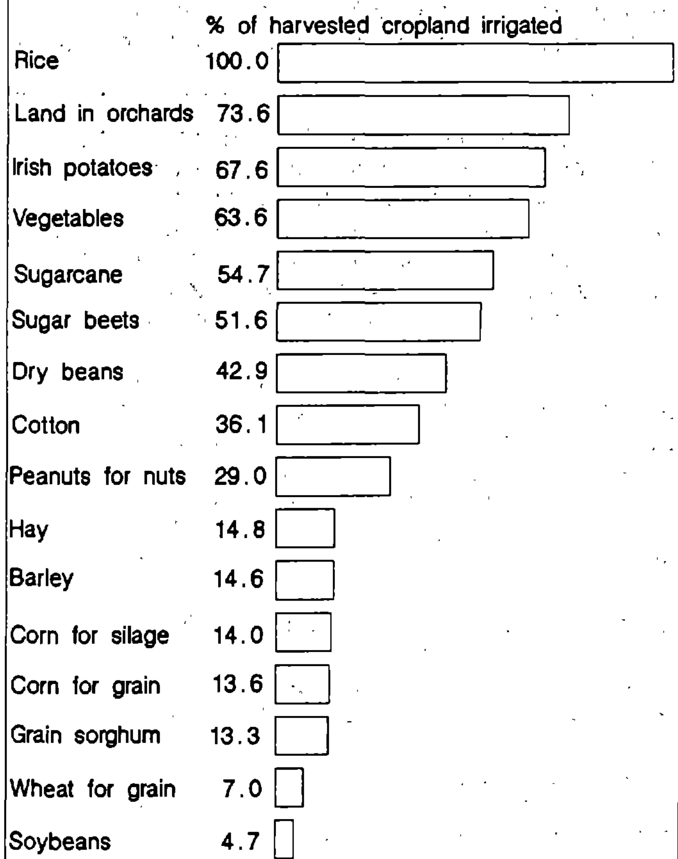
With water supply development unlikely, higher water prices and less water for irrigated agriculture are inevitable. Although the mechanisms for more efficient water allocation are still evolving, water conservation through more efficient water use is the leading candidate for alleviating water scarcity. More efficient irrigation technology and new water management practices have the potential to conserve water with little or no loss in agricultural production.

Figure 1
Irrigation consumes the largest share of U.S. water resources



1985 data. Source: U.S. Geological Survey.

Figure 2
Importance of irrigation to U.S. agriculture



1987 data. Source: Census of Agriculture.

Table 1—Acreage and value of irrigated agriculture, 1982

Crop	Irrigated acres	Share of cropland	Irrigated value	Share of crop value
	1,000 acres	*Percent*	*Million dollars*	*Percent*
Corn	9,604	12.3	3,440	17.2
Sorghum	2,295	17.0	901	53.2
Wheat	4,650	6.6	1,144	16.7
Barley and oats	2,098	11.8	375	20.0
Rice	3,233	100.0	1,226	100.0
Cotton	3,424	35.0	1,883	58.4
Soybeans	2,321	3.6	491	4.4
Irish potatoes	812	64.0	1,261	81.7
Hay	8,507	15.0	2,275	27.7
Vegetables and melons	2,029	60.7	3,375	79.7
Orchard crops	3,343	70.4	4,732	85.1
Sugar beets	550	53.2	491	77.7
Other crops	2,428	17.9	2,424	25.4

Irrigation Technology and Management Practices Can Save Water

Irrigators can choose better technology and improve their methods of using water to conserve scarce water supplies without sacrificing crop yields.

Water-conserving irrigation technology and water management practices are playing an increasingly important role in reducing both energy costs and water use. Not all of the water applied to the field is available for use by the plant, since some fraction is lost to evaporation, deep percolation, or runoff. Irrigation technology and management practices—by substituting more capital, labor, and management skills for water—reduce water loss through increased application efficiency with little or no loss in yields. However, the efficiency of an application system depends not only on the attributes of the irrigation system but also on the physical characteristics of the farm such as soil texture, topography, and weather.

Irrigation Technology That Conserves Water

Water distribution systems available to early irrigators were limited to gravity flow systems such as simple stream diversions, flooding, and ditch and siphon systems. Gravity flow systems use the force of gravity to distribute water across the surface of the field. Water is supplied to the upper end of a field by a ditch or pipe and then applied to the field through a siphon tube or gate. Since water percolates down below the root zone as it flows across the field, excess water must be applied to the upper end of the field to ensure that sufficient water reaches the lower end of the field. Guaranteeing a fully irrigated field often requires that water be allowed to run off the tail end of the field. Furrow irrigation, where water flows over the soil only in shallow channels between the crop rows, can reduce water lost to deep percolation.

Sprinkler Systems

As economic conditions changed and technology improved, water-saving sprinkler irrigation systems became more attractive alternatives. Most sprinkler irrigation technologies save water relative to gravity flow systems by distributing water evenly on the field, reducing percolation below the root zone and eliminating runoff. Sprinkler systems spray water onto the field through nozzles attached to a network of pressurized pipes.

Examples of some early sprinkler systems include solid set, hand move, and side roll. A major advancement in sprinkler irrigation technology was the center pivot irrigation system.

Primarily in response to increased costs of water and a greater interest in water conservation, irrigators recently have begun adopting advanced irrigation systems. These improved technologies can achieve exceptionally high application efficiencies. Examples of advanced sprinkler systems include drip irrigation, low-pressure sprinklers, and low-energy precision application (LEPA). (Illustrations and descriptions are on pages 6-7).

Improved Gravity Systems

Economic conditions have also spawned improved gravity irrigation technologies such as surge flow or cablegation. These technologies can significantly improve application efficiencies by controlling runoff and reducing deep percolation.

Surge flow and cablegation techniques modify gated pipe furrow irrigation systems so that the timing and quantity of flow from the gates of the pipeline are more efficiently controlled. The irrigator can thus apply water more uniformly across the field.

Water Management Practices That Conserve Water

Technological advances in irrigation efficiency have also occurred in water management. Water management practices can significantly reduce water use for a given irrigation system. Management practices typically involve more labor and water management skills. Sophisticated management practices applied to gravity-irrigated fields can achieve efficiencies comparable to sprinkler systems. Management practices include precision field leveling, furrow diking, limited irrigation-dryland farming, computer-aided irrigation scheduling, and reusing field runoff (tailwater).

Deficit irrigation saves water through reduced water application rates for a given cropping pattern and irrigation technology. Deficit irrigation is the practice of stressing crops and lowering crop yield with reduced water application rates. Maximizing net return may dictate lower application rates, forfeiting higher yields in exchange for lower water use. In many cases, water can be reduced considerably without significantly reducing crop yield. Careful timing of water application and efficient application minimize yield losses.

Technology and Management Improve Irrigation Efficiency

Greater irrigation efficiencies associated with improved irrigation technology and advanced water management practices allow farmers to meet the water needs of the plant while applying less water. Water use efficiency is a measure used to compare irrigation systems. It measures the amount of water used for plant growth as a percentage of total water applied.

Numerous experimental and empirical studies have shown that sprinkler technology reduces water use compared with gravity flow systems. Water use efficiencies range from 35 to 85 percent for gravity and 50 to 85 percent for sprinkler systems (table 2). For LEPA irrigation systems, for example, of the total water applied, 80-90 percent is used for plant growth. The rest runs off the field, evaporates, or percolates below the plant's roots. Actual irrigation efficiency depends on the physical texture of the field including soil texture, topography, and climate. Drip irrigation and LEPA systems can achieve efficiencies ranging from 80 to 90 percent. Tailwater reuse pits, by recirculating field runoff, can produce water savings from 10 to 30 percent over conventional gravity depending on topography and soil characteristics.

Table 2—Water use efficiencies of irrigation systems

System	Field efficiency
	Percent
Gravity:	
Flood	35-50
Furrow	55-70
Improved gravity[1]	75-85
Sprinklers:	
Big gun	50-65
Center pivot[2]	70-85
Side roll	65-80
Solid set	65-80
Hand move	55-65
Low Energy Precision Application (LEPA)	80-90
Drip-trickle	80-90

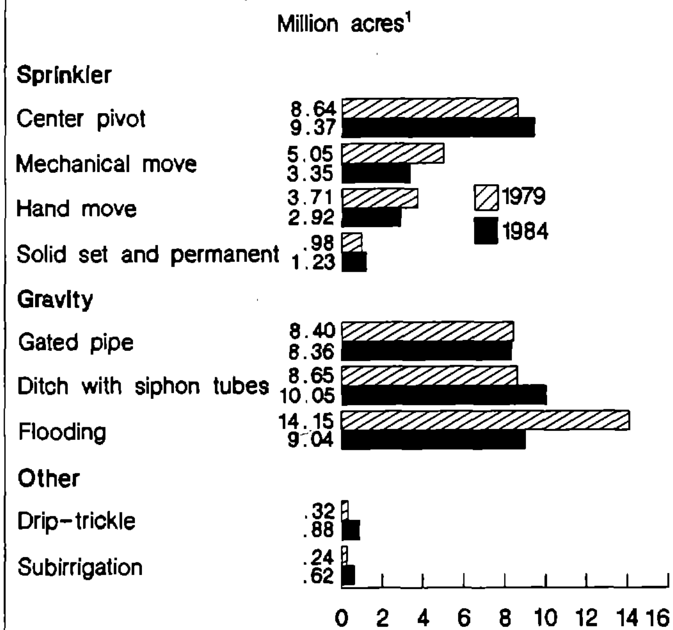
[1] Includes tailwater recovery, precision land leveling, and surge flow systems.
[2] Includes high- and low-pressure center pivot.

Of the total amount of water applied, 80-90 percent is used for plant growth. The rest runs off, evaporates, or percolates below the plant's roots.

Irrigators Are Adopting New Technology

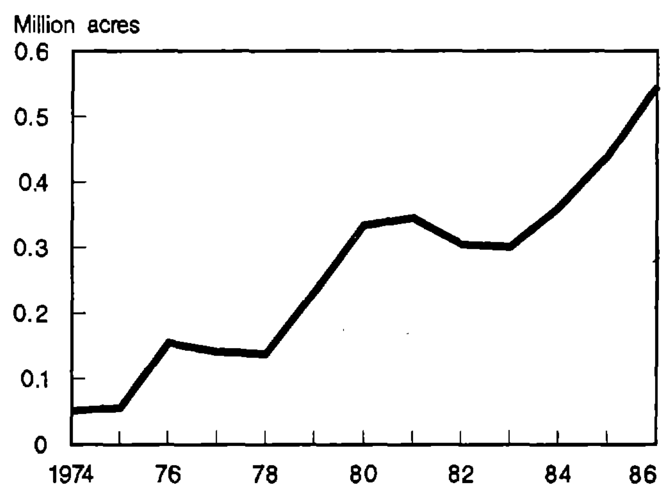
Figures 3 and 4 show the increase in water-saving irrigation technologies in use. Although drip or trickle systems cover a relatively small number of acres, use of this very efficient method more than doubled between 1979 and 1984. Thus far these systems are typically used on tree crops, on grapes, and in nurseries.

Figure 3
Trends in use of irrigation systems



1/ Conterminous United States.
Source: 1979 and 1984 Farm and Ranch Irrigation Survey.

Figure 4
Expansion of drip-trickle irrigation in 17 Western States, 1974-86



Main Features of Irrigation Systems and Practices

Sprinkler Systems

Solid Set is a stationary sprinkler system often used in orchards. Supply pipelines are fixed, usually below the surface, and sprinkler nozzles are elevated above the surface.

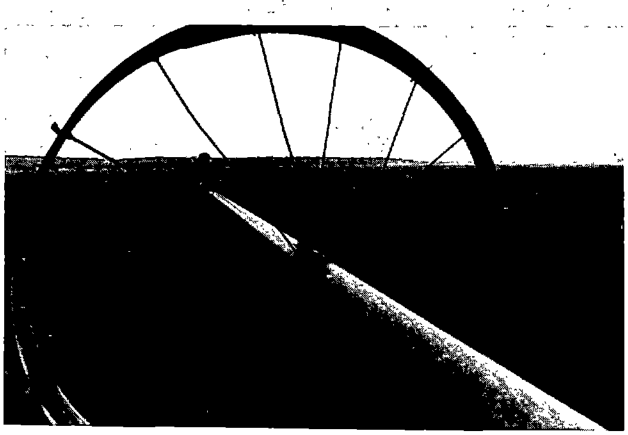
Hand Move is a portable sprinkler system in which the irrigator moves the supply pipelines in sections from one position to the next.

Side Roll is a portable sprinkler system in which the pipeline acts as an axle for a series of large diameter wheels. An engine mounted in the center of the pipeline moves the system across the field.

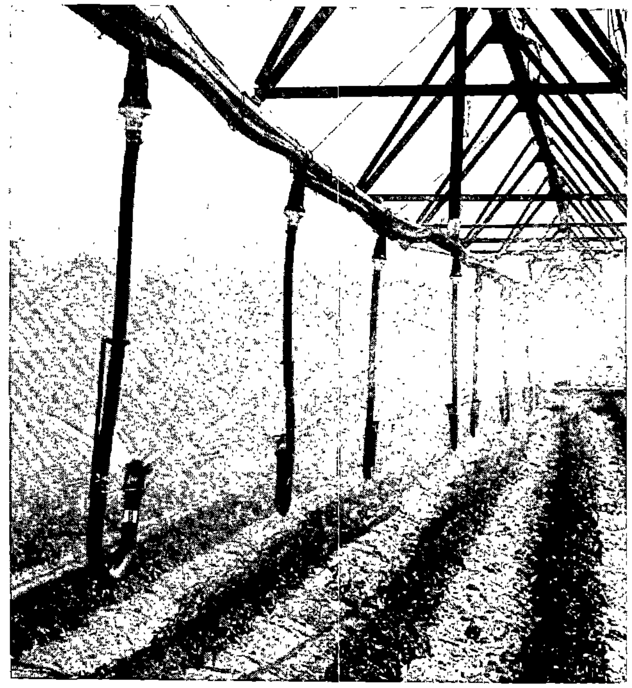
Center Pivot is a self-propelled sprinkler system in which the pipeline is suspended above the field on a row of mobile towers. Water is pumped into the pipe at the center of the field, and the towers rotate slowly around the pivot point. Sprinkler nozzles mounted on the pipeline distribute water under pressure to the field as the pipeline rotates. This basic system has been adapted to both high (45 to 100 pounds per square inch) and low (15 to 45 pounds per square inch) pressure systems.

LEPA (Low Energy Precision Application) is an adaptation of the center pivot system that uses tubes extending down from the pipeline to apply water at low pressure below the plant canopy. Emitting the water close to the ground cuts water loss from evaporation and wind and increases application uniformity.

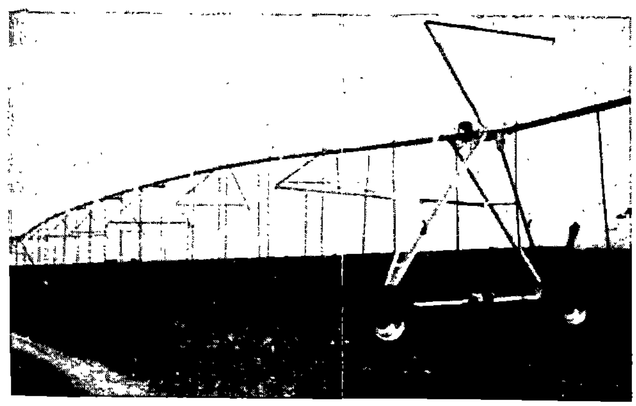
Drip or Trickle Irrigation uses small-diameter tubes placed above or below the field's surface near the plant's root zone. Water emitters in the tubes dispense water directly to the root zone, precluding runoff or deep percolation and minimizing evaporation.



Side roll



Low-pressure center pivot



LEPA

Drip-trickle

Gravity Systems

Ditch with Siphon Tubes supplies water by siphoning water from the irrigation ditch to the field.

Gated Pipe supplies water through a series of openings in a supply pipe. This system has been improved to allow irrigators more control over timing and quantity of water flows.

Surge Flow delivers water to the furrow in timed releases. After a surge the soil forms a water seal permitting the next surge of water to travel further down the furrow. This technique significantly reduces the time needed for irrigation water to be distributed the full length of the field, reducing deep percolation and results in higher water application efficiency.

Cablegation delivers water to furrows automatically and sequentially using a plug attached to a cable inside the supply pipe. The water savings is based on the same principle as surge flow.

Water Management Practices

Precision Field Leveling (also called laser leveling) grades a field so there is little variation in field contour. Precise leveling promotes uniform water application across the field.

Limited Irrigation-Dryland Farming irrigates only the upper end of the field leaving the lower end of the field solely dependent on rainfall. This technique minimizes or eliminates field runoff and reduces deep percolation and evaporative losses.

Irrigation Scheduling monitors soil moisture and climate to precisely regulate water applications. Monitoring soil moisture involves precision instruments (such as tensiometers, gypsum blocks, and neutron probes) which accurately measure the moisture available for plant growth. The operator delivers water to the field during critical crop growth stages in precise quantities.

Furrow Diking places dikes in the furrows to capture additional rainfall.

Tailwater Reuse captures field runoff in pits dug in low-lying areas of the farm and recirculates the water to the top of the field. Rising water costs have made tailwater reuse a popular conservation measure.

Ditch with siphon tubes

Gated pipe

Furrow diking

Many Factors Affect Producers' Choice of Irrigation Technology

While the decision to adopt water-saving irrigation technology responds to the cost of water, physical properties of the land such as topography or soil texture dominate the choice of irrigation technology.

Physical properties of the irrigated land and economic principles together determine the most profitable irrigation system for the farm. This section reports on selected results of a study relating the choice of irrigation system or management practice to the physical and economic characteristics of the farm.

Physical characteristics of the farm, like climate, soil texture, or land topography, restrict the technology options available to the farm operator. Gravity systems, for example, require flat topography so that irrigation water can flow evenly over the field. In some cases, physical characteristics may dictate a particular technology. Steep slopes are not suited to gravity irrigation without costly modification.

Even where the physical characteristics do not preclude irrigation technology or management options, they may still favor one alternative over another. Hot and windy regions, for example, favor gravity irrigation because a large share of water sprayed into the air through sprinklers evaporates.

Of course, economics also plays an important role in irrigation technology choice. Higher water costs or water scarcity encourage more efficient use of water on the farm. Indeed, farmers facing high water costs may adopt more efficient irrigation technology than their low-cost counterparts. Although more efficient water application systems reduce water use and associated costs over time, the system itself can represent a substantial investment over traditional gravity irrigation. A center pivot system irrigating 130 acres can cost $60,000 or more. Advanced water management practices, on the other hand, do not require large capital investments but often require more labor and expertise than high-technology equipment.

The study examined to what extent choosing more advanced technology, such as sprinkler irrigation or tailwater reuse pits, depends on the cost of water, the price of labor, climate, land topography, soil characteristics, and farm size. The analysis considered two broad categories of irrigation technology, sprinkler and gravity irrigation, but did not distinguish between various types of systems within the two categories. For those irrigators who selected gravity systems, the choice of adopting tailwater reuse pits was also examined.

A separate analysis examined whether irrigators implemented deficit irrigation techniques.

Research Shows Multiple Factors Affect Irrigation Choice

The results indicate that both physical characteristics of the land and economics play an important role in choosing an irrigation system. The probability that producers will adopt water-saving technology responds to the cost of water, but only marginally. For example, in 1984 the average cost of pumping an acre-foot of ground water was $15.78. The analysis suggests that a 10-percent increase in price to $17.34 would produce a 0.3-percent increase in acreage irrigated by sprinkler.

If the results are applied to the 45 million irrigated acres in the United States, this translates into 156,000 additional acres converted to sprinkler irrigation. If water costs increase an average of $5 to $20.77, an increase of almost one-third, then nearly 600,000 acres would convert to sprinkler irrigation. Assuming that sprinklers save 15 percent more water than gravity irrigation, the total water savings would amount to 156,000 acre-feet, or enough water to serve a city of almost 1 million for 1 year.

Analysis of irrigation technology choice on the farm indicates that physical characteristics of the farm dominate the decision. Soil characteristics including slope, texture, and quality, and, to a lesser extent, climate and labor costs have significant effects on the technology choice. Specifically, the research shows:

- Irrigators who farm soils with low water-holding capacity are more likely to adopt sprinkler systems. Porous soils or steep slopes are unsuitable for gravity because deep percolation or inadequate coverage inhibit efficient water application.

- Farmers in regions with high rainfall are more likely to adopt sprinkler systems. Irrigation in these regions is primarily supplemental. Sprinkler irrigation, by providing greater control over the water quantity applied, can prevent crop damage and inefficient water use which might result from an unexpected rainfall following a heavy irrigation.

- Farmers in hot or windy regions are more likely to adopt gravity since a large fraction of water applied with sprinkler systems evaporates under these climate conditions.

- Since gravity irrigation systems tend to be more labor-intensive than sprinkler, high labor costs induce a shift to laborsaving sprinkler irrigation.

Tailwater Reuse

For gravity irrigators an analysis of factors that determine the adoption of tailwater recirculation reveals results similar to those obtained for sprinkler irrigation choice. Onfarm physical characteristics have the greatest impact on the selection probabilities. Selected results show:

- Tailwater reuse is an effective water-saving practice only on soils with high water-holding capacity since high water intake rates associated with sandy or porous soils limit water runoff.

- Where soils have high salt content, irrigators avoid recirculating runoff water to prevent further salt concentration.

- Compared with sprinkler adoption, water cost is more effective in inducing gravity irrigators to adopt water-saving recirculation practices.

- More rainfall reduces the effectiveness and the need for tailwater reuse because less irrigation water is applied and conservation is less essential.

Deficit Irrigation

Deficit irrigation is the practice of reducing water application rates with consequent lower yields. This management practice trades high yields for lower water costs to maximize net returns rather than yields.

The effects of water prices, weather, soil conditions, and farm characteristics on water applied per acre for various crops were statistically analyzed. Results provide little evidence that farmers engage in deficit irrigation of crops in response to higher water prices. Statistical measures indicate that once farmers decide to irrigate a crop with a particular technology, they do not reduce water applied per acre in response to high water prices. Rather, they appear to maximize crop yield. Instead of deficit irrigating, farmers adjust other components of water demand. For example, farmers may choose a more efficient irrigation technology or change the crop planted to one that uses less water.

How Do Farmers Respond to the Cost of Water?

Price Elasticity for Water

Higher water prices will reduce agricultural water use, but by how much? Several studies of agricultural water demand place the price elasticity of demand in the range of -0.15 to -0.25. Thus, a 10-percent increase in the price of water would produce a 1.5- to 2.5-percent reduction in the water demand.

While the response is inelastic, at current water withdrawal levels the corresponding water savings range from 2.3 to 3.8 million acre-feet per year, enough water to serve between 12 and 19 million people per year. Moreover, price elasticities are apt to increase as more technological substitutes are introduced and awareness of new water-saving management practices grows.

The results were different for pastureland. Farmers with expensive water forfeit yields on pastureland. As pumping costs increase, farmers tend to apply less water to pasture and accept the lower production associated with the lower water use. The reason is that irrigated pasture tends to be a marginal use of water. As water becomes more expensive, irrigators would be expected to allocate water away from marginal uses, such as pasture.

Although water application rates for most crops were insensitive to water price, application rates for many crops were quite sensitive to the physical characteristics of the farm.

Rainfall reduces the amount of irrigation water required to meet the water needs of crops. Farmers tend to apply less water per acre as the amount of rainfall increases.

Soil conditions influence water use for several crops. Farmers tend to apply less water per acre to sorghum, wheat, barley, hay, and pasture grown on clay soils compared with loam soils. Clay soils have a higher water-holding capacity than loams. Crops with deep and profuse root systems (for example, small grains, grain sorghum, and alfalfa hay) are able to exploit the increased soil moisture levels present in clay soils. Therefore, the water needs of crops grown on clay soils relative to loams may be met by a lower level of water applied.

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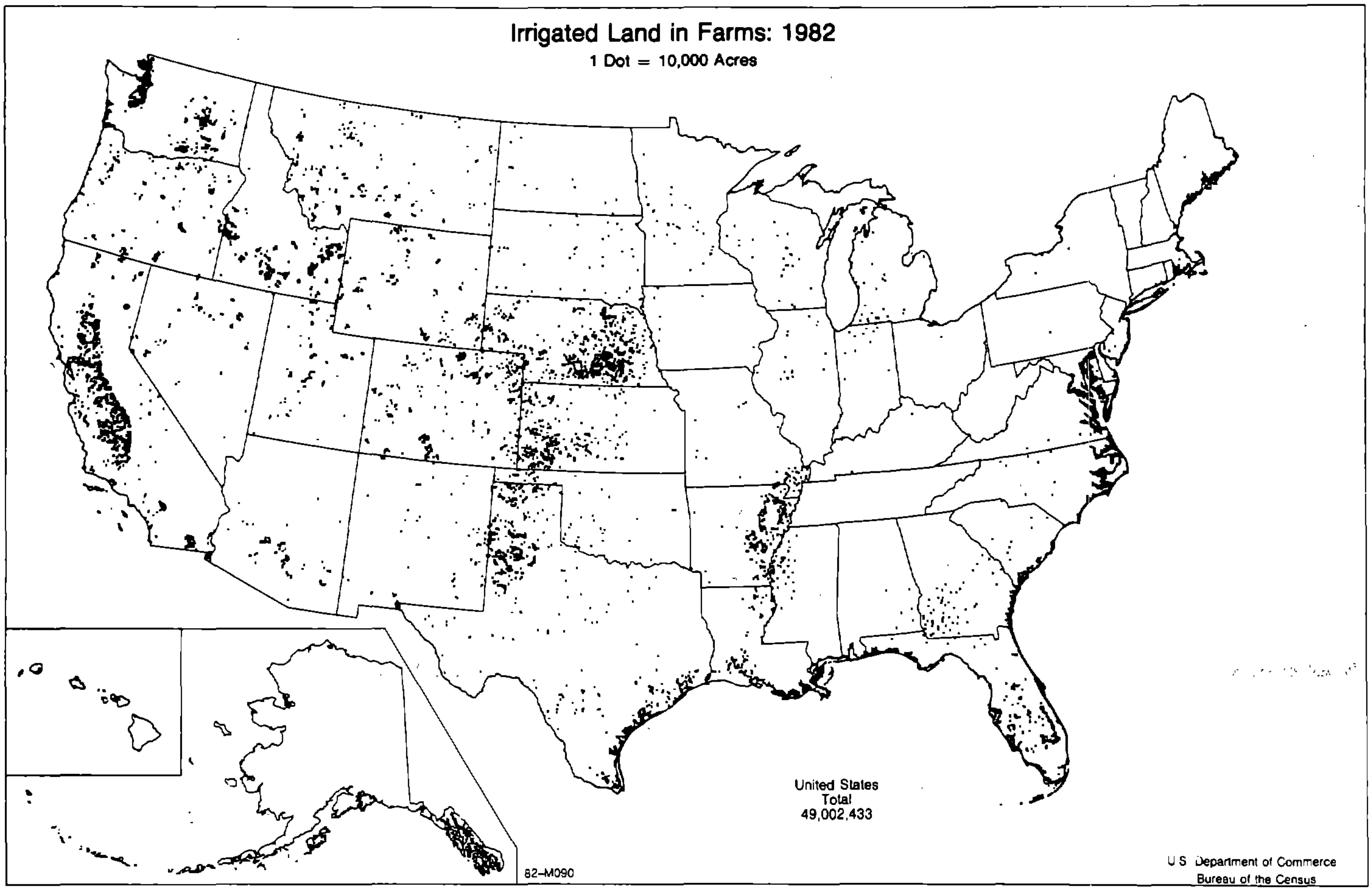

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