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# Economic and Technical Adjustments in Irrigation Due to Declining Ground Water

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**Economic and Technical Adjustments in Irrigation Due to Declining Ground Water.** By William Crosswhite, Clif Dickason, and Robert Pfeiffer. Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture, Staff Report AGES-9018.

## Abstract

This report examines the changes that irrigators are likely to make as the cost of water rises due to increasing pumping lift and decreasing well yields in areas with ground water mining. A decline in ground water supplies exerts pressure on irrigators to adjust irrigation systems and production practices in order to increase the efficiency of irrigation water use. The adjustment strategies of irrigators are expected to respond to changing water costs and supply conditions. In the early stages of ground water decline, new wells, improved pumps, water conservation practices, and improved irrigation systems are used to maintain the availability of water in the short run and to conserve water. The crop mix is altered as water becomes increasingly costly to pump, and may ultimately revert to rain-fed or dryland farming.

**Keywords:** Irrigation, irrigation systems, water use, water supply, water conservation, ground water mining, farm adjustments.

## Acknowledgments

The authors wish to acknowledge the contributions and helpful comments of William Anderson, Kenneth Baum, David Bush, Kazim Konyar, Ronald Lacewell, Norman Landgren, Larry Schluntz, and Harold Stults concerning this study. Also, the authors are especially appreciative of the assistance provided by Lucille Milligan for her typing of this manuscript.

1301 New York Avenue, NW
Washington, D.C. 20005-4788

February 1990

## Contents

# Summary

The long-term trend in declining water supplies in ground water mining areas exerts pressure on irrigators to adjust to rising water costs and reduced availability of water. A framework developed for this study outlines the relationships between water supply conditions, adjustment strategies, and management and technical options that irrigators are likely to adopt in ground water mining areas. Research results from other studies of relationships outlined in the framework are cited. A case study was conducted in a declining ground water area of Kansas to analyze the economic feasibility of alternative irrigation systems and related irrigation technology.

Large changes in crop prices, crop yields, and input prices, such as that which occurred in crop and energy prices in the 1970's, influence both annual and long-term adjustments in irrigation. Declining ground water levels, in contrast, primarily influence longrun changes in irrigation systems. In any given year, only small increases occur in the cost of pumping irrigation water due to greater lift and declining well yields. In the longer run, the cumulative effects of small annual changes in pumping costs and water availability require adjustments in farm enterprises, organization, and operation.

Farmers can choose from a number of strategies and economically feasible practices to adjust water use to anticipated changes in production and market conditions. These include actions to maintain the available quantity of water, to improve water use efficiency, and to reduce total water use. The availability of irrigation water can be maintained for a while by drilling new wells, operating pumps for longer periods, and using smaller pumps as well yields decline. In the longer run, water conservation, new cropping patterns, and increasing nonirrigated crop acreage may be necessary to adjust to declining water supplies.

Irrigation systems vary widely in their efficiency and, thus, in their water application rates. Water conservation practices increase the efficiency of irrigation water use by lowering the rate at which water is applied to each acre of crop and by reducing runoff. Systems with low application efficiency can be replaced by more efficient systems and new technologies (such as laser leveling), surge flow systems, and management systems (such as irrigation scheduling). These technologies can be combined with improved irrigation systems to reduce the amount of water applied per acre and reduce the cost of pumping. As water use per acre declines, irrigators tend to continue existing cropping patterns in the short run.

Over the longer term, when the water supply is severely reduced, irrigators have a greater incentive to change cropping patterns and reduce irrigated acreage by reverting to dryland or rain-fed farming. The shift to dryland farming may be made gradually by planting crops with small water requirements instead of crops with large water requirements and shifting some acreage to crops

that are adapted to dryland farming. Limited irrigation of crops during critical growing stages, a practice that has been used on cotton in fringe areas of the Texas High Plains since the 1950's, is receiving increased attention as an effective and economical way to use a limited water supply.

Farmers typically shift to dryland farming when economic depletion of the ground water occurs. Dryland farming is a well-established system of managing crops and soils under conditions of low precipitation in semiarid and dry climates. Crops commonly include sorghum, small grains, seed legumes, safflower, and sunflowers.

The study results indicate that irrigators' adjustment strategies depend very closely upon ground water supply conditions. The adjustment period depends upon a variety of factors, including irrigators' responsiveness to changes in the cost of obtaining ground water, commodity prices, and availability and profitability of new irrigation technology.

The public policy significance of the findings is as follows: the increasing cost of pumping from a declining underground reservoir tends to brake and finally halt irrigation water mining. Public measures that add to, or subtract from, irrigators' costs tend to set, respectively, a shallower or deeper underground depth where economic exhaustion occurs for irrigation. If additional water supplies lie deeper than the economic exhaustion depth for irrigation in certain locales, they remain available to other, higher valued uses, such as municipal and industrial uses.

# Economic and Technical Adjustments in Irrigation Due to Declining Ground Water

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## Introduction

The U.S. Geological Survey's National Water Summary, 1984 indicated that water supply problems exist in most States, with some areas facing declining ground water levels (U.S. Department of the Interior). Ground water mining occurs when the amount of water removed from the aquifer exceeds the amount of recharge, causing a decline in ground water levels. Ground water levels are falling significantly in several States. Approximately 14 million acres, 45 percent of the irrigated acreage in the 11 major ground water irrigation States, were located in ground water mining areas in 1985 (Sloggett and Dickason) (fig. 1). Cropland irrigated from ground water sources in these States declined between 1977 and 1983.

Irrigated acreage declined in ground water mining areas within the last decade. The increasing cost of pumping irrigation water affects agricultural production in ways that foster changes in farm operations. A rise in the cost of pumping resulting from a decline in the availability of water exerts economic pressures on irrigators to adopt new irrigation systems and production practices and make changes in cropping programs in order to use irrigation water more efficiently.

This report presents an analysis of adjustments by farmers in arid and semiarid regions in response to declining ground water supplies. Specific objectives of the study were to identify adjustment strategies and management and technical options for irrigators in ground water mining areas and analyze the economic feasibility of adjustments that irrigators may make in response to declining ground water supplies.

The study develops a framework for examining the relationship between adjustment strategies and management and technical options that farmers adopt in adjusting to declining ground water. Major irrigation areas in which ground water levels are declining are identified, and adjustments that are likely to be made by irrigators and nonirrigators in areas with different water supply situations are analyzed. Types of adjustment include changes in cropping pattern, agricultural production, farm size, tenure, input use, and operating costs. Research results from previous studies are cited in examining the strategies irrigators follow in adjusting to changes in ground water levels.

A case study was conducted in Kansas, a major area of declining ground water levels. Partial budget analysis was used to evaluate changes that farmers are likely to consider in adjusting to rising water costs and declining water supplies. Results of the study provide information for implications of farm policies influencing farm adjustments in declining ground water areas.

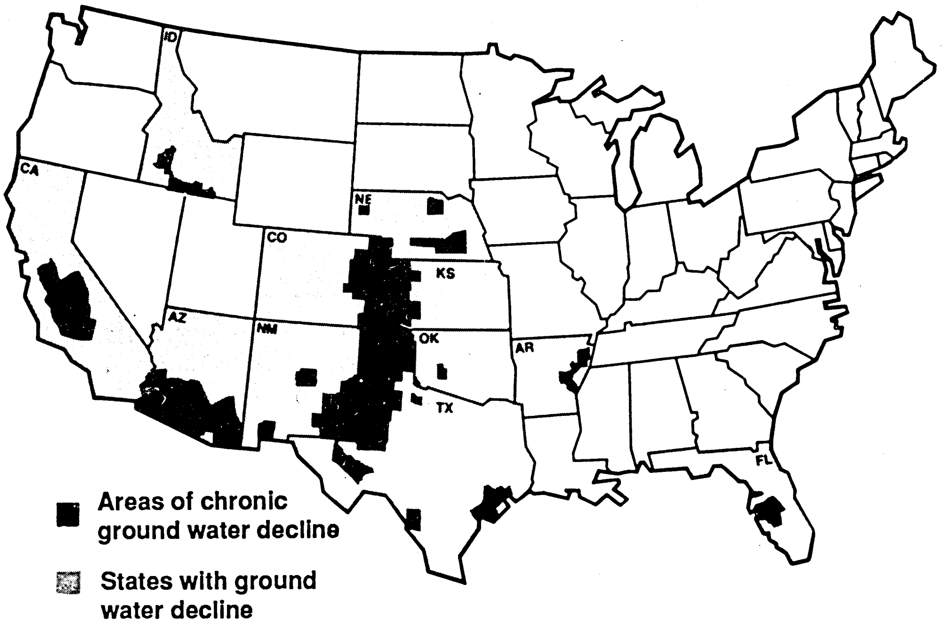
## Factors Affecting Ground Water Mining

Ground water mining, especially in arid and semiarid regions, is a consequence of the long-term irrigation use of ground water at rates exceeding aquifer recharge. Numerous resource, market, and institutional factors influence the profitability of irrigation and the use of irrigation water. Crop prices, Federal program supports, tax law concerning ground water mining, energy and other input prices, irrigation systems and management practices, water laws, ground water supplies, soils, and climate determine the value (demand) and cost (supply) of irrigation water from ground water sources and the profitability of irrigation.

The use of ground water for irrigation within a production period may vary widely. In areas where pumps are in place, shortrun expectations determine the rate of ground water mining. In the longer run, increases in the rate of mining of ground water will

Figure 1

**States with ground water decline and areas with chronic ground water decline**



*Determinations were made by U.S. Geological Survey. Each of these 11 states has more than 500,000 acres in groundwater irrigation. Taken together, they account for 85 percent of the total U.S. area irrigated with groundwater.

be determined by expectations of longrun profitability in irrigation. Favorable expectations of profitability encourage irrigators to invest in more efficient irrigation systems, expand existing systems and make other adjustments to changes in ground water cost and availability. Also, water management legislation by State and local governments may directly affect ground water mining by restricting withdrawals and encouraging water conservation.

Long-term trends in ground water mining include rising pumping costs and declining availability of water. Increases in pumping costs are typically quite gradual because of small declines in well yields and relatively small average annual increases in pumping lifts of 0.5 to 5.0 feet in the 17 Western States and Florida. Pumping costs in wells with a shallow remaining water amount, however, rise at an increasing rate because additional reductions in the saturated thickness of the aquifer begin to have a larger and larger effect on well yields (Sloggett and Dickason). While irrigators tend to adjust to the increases in pumping costs, it is the reduced availability of water over the long term that limits irrigation expansion and provides the larger incentive for water conservation, cropping changes, and shifts to dryland farming.

## Resource Characteristics

Soils, climate, topography, aquifer characteristics, and ground water supplies influence the selection of irrigation systems, investment requirements, operating costs, cropping patterns, management practices, and the location of irrigated agriculture. In the humid East, irrigation is quite limited and is concentrated on the lighter, sandy soils and in specialty high-value crop production. Irrigation in an area centering around the western portions of Kansas, Oklahoma, and Texas is highly influenced by the availability of ground water from major aquifers such as the Ogallala, a relatively shallow aquifer lying under portions of seven States. Partly because of natural low rates of recharge in this aquifer, the occurrence of ground water mining has been growing. Agriculture in each of the 17 Western States is heavily dependent on irrigation from both surface and ground water sources, with 65-97 percent of a given State's harvested cropland being irrigated. While many aquifers in Arizona, California, and Idaho characteristically have low recharge rates, they are deeper and have a greater saturated thickness than the aquifers that underlie the arid plains to the east of the Rocky Mountains.

## Crop Prices

Domestic crop prices are affected by trade policies, farm programs, and, as described above, general economic conditions. The per acre profitability of irrigation, relative to dryland farming, is much more sensitive to fluctuations in commodity prices. This is because, in a given locale, irrigated yields tend to be larger than dry-crop yields, a phenomenon which magnifies the effect of price changes on revenues.

Federal price-support and other farm-subsidy programs that include allotments based on past cropland acreage farmed tend, over the long term, to increase the profitability of irrigation relative to dryland farming, given a scarcity of idle cropland that qualifies for acreage allotments and subsidies.

Yield differences between irrigated and dryland farming further magnify the effect of changes in commodity prices. The 1973-86 cycles of commodity prices are an example. Irrigated acreage increased by 25 percent between 1978 and 1982 in response to high prices for crops but declined between 1982 and 1986 as a result of falling prices, declining water levels, and higher energy costs. Farm programs and trade policies that provide supported crop prices, reduce price fluctuations, and increase the availability of capital tend to encourage irrigation expansion. Major irrigation expansion is not expected, especially in the 17 Western States, because of ground water mining and the fact that the West's surface water is almost fully appropriated. In addition, political and market pressures are increasing to shift some surface water out of agriculture for more highly valued nonagricultural uses, such as industrial and domestic use.

## Water Conservation

Certain public programs that increase onfarm efficiency of irrigation water use may not achieve a long-term net reduction in water use in an area. Water conservation activities and practices that increase the profitability of irrigation may bring about an increase in irrigated acreage on existing farms and encourage additional farms to start irrigating. If the increase in irrigated acreage is large enough to more than offset the reductions in water use per acre arising from water conservation, total long-term water use in an area will increase.

## Public Ground Water Management

State water laws are changing to deal with the problems of water scarcity. The trend is an increasing involvement of State and local governments in ground water management to control ground water withdrawals and to improve technical and economic efficiency in developing, allocating, and using ground water. Public management and control options that have not been previously exercised in ground water management include restrictions on numbers of new wells created, ground water withdrawals, and offsite uses in designated critical ground water areas. The overall effects of public ground water management in many situations tend to limit total water use and encourage water conservation.

Tax regulations of the U.S. Internal Revenue Service that permit a ground water depletion allowance for irrigators increase the rate and depth of ground water mining.

Types of public management options that have not been fully explored include taxation of water quantities mined, cancellation or curtailment of the existing Federal water-depletion tax allowance, and curtailment of Federal crop subsidies.

## Irrigator Decision Framework

The quantity of water stored in aquifers is large in relation to annual use. In ground water mining areas, irrigators experience only small annual changes in pumping lifts and well yields. Over the longer term, however, these small annual changes accumulate which fosters adjustments in irrigation practices and cropping patterns.

Farmers can select from a number of strategies involving management and technical options in adjusting to water supply conditions that arise from declining ground water levels. The four water supply conditions outlined in table 1 were selected to represent limitations imposed as a result of declining ground water levels. These conditions typically occur sequentially, in the order listed, as ground water supplies are developed and used. Because of aquifer characteristics, farmers in a declining ground water area will likely experience a range of water supply conditions at any given time.

An adjustment strategy has been identified for each water supply condition outlined in table 1. For the sake of simplicity, management and technical options for carrying out the various strategies are described as mutually exclusive for each water supply condition. It is recognized that a number of changes may be made either together or in different sequences. Because of this, the interdependence between various strategies and management and technical options is not highlighted.[1]

The time interval or the length of time during which specific water supply conditions exist depends upon numerous factors such as stability of commodity and energy prices, characteristics of the aquifer, irrigation technology, and the rate of irrigation expansion. The length of time it takes to deplete the water supply will affect the economic feasibility of adopting various production practices and investing in irrigation systems, wells, pumps, and improved delivery systems.

### Increases in Pumping Costs

Early indications of a decline in the level of ground water include increases in pumping lift and decreases in the well yields. The number of hours the pumps are operated can be increased to offset a decline in well yields in order to maintain the desired quantity of irrigation water. Longer pumping time and greater lifts will increase energy use and the cost of pumping. As water availability declines because of the continuing fall in well yields, irrigators find it necessary to lower the depths of existing wells, install new wells, and/or install more efficient pumps in order to maintain an adequate

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[1] Irrigators typically apply a number of interrelated management options in carrying out an adjustment strategy related to supplying and using irrigation water.

Table 1--Strategies and options for farm level adjustments to declining ground water supplies under selected water supply conditions

| Water supply condition | Adjustment strategy | Options |  |
|---|---|---|---|
|  |  | Technique | Management |
| Condition 1:<br>Increase in pumping costs due to greater pumping lifts and reductions in well yields | Maintain the quantity of water that is available for irrigation | Deepen wells<br>Install small improved pumps<br>Install new wells | Increase hours of pumping operations |
| Condition 2:<br>Reduced availability of water, an acceleration of condition 1. | Conserve water to reduce water use per acre and improve technical water use efficiency | Low-pressure nozzles<br>Improve water delivery and distribution<br>Higher efficiency systems such as sprinkler and drip<br>Laser leveling | Schedule irrigation<br>Optimize water use<br>Integrate crop production |
| Condition 3:<br>Severely reduced water supply | Reduce total water use |  | Alter the crop mix<br>Limit irrigation |
| Condition 4:<br>Economic depletion of the water supply | Revert to dryland farming<br>Expand crop acreage |  | Improve dryland farming system |

supply of water. Pumping efficiencies can be maintained by replacing large pumps with smaller pumps as well yields decline. The development of smaller, more efficient pumps has enabled irrigators to control pumping costs and, in some instances, to lower pumping costs in the short run. The sharp increase in energy prices in the 1970's was an important factor in the adoption of improved pumping technology. Also, the timing of investments in wells and water supply developments is influenced by the availability of new technology and the rate of irrigation expansion in a locale.

## Reduced Availability of Water

The availability of water may be maintained for several years under condition 1 by increasing the number of wells, improving pumping efficiency, and implementing water use restrictions. Continued withdrawals, however, eventually bring about a decline in the quantity of available water in many areas which cannot be economically offset by supply development. As water availability declines, irrigators typically adopt a strategy of water conservation which may include changing the irrigation system, improving water delivery and distribution systems, and adopting new technical and management options such as laser leveling, irrigation scheduling, row diking, using low pressure nozzles, and improving methods to harvest rainfall.

When water is readily available at a low cost, irrigators may find that irrigation water is not a constraint on production and may apply water in relatively fixed amounts per acre to achieve maximum production per acre. As the decline in the availability of water becomes more evident and pumping costs rise, there is an incentive for farmers to vary the water applied per acre in an optimizing fashion to achieve maximum profit. Applying irrigation water to achieve the condition that the marginal value product of water equals the marginal cost of pumping water may conserve large amounts of water when compared with applying water to maximize yields. Improvements in water use may also involve methods to achieve efficient use of all inputs, an approach known as integrated crop production.

## Limiting Water Use

Alteration of the cropping pattern may be required in addition to water conservation options when irrigation water is severely limited. Crops with low irrigation water requirements may be substituted for crops with high water requirements. Some crops may be shifted to dryland farming. Changes such as these can be phased over a number of years by shifting, for example, from corn to sorghum to small grains or some other less water-consuming crop in an increasing proportion.

## Economic Exhaustion

Economic exhaustion of the irrigation water supply occurs when the cost of pumping equals or exceeds the value of increases in crop yields due to irrigation. Economic exhaustion commonly occurs before there is physical depletion. With economic exhaustion of ground water supplies, the marginal cost of pumping water equals or exceeds the marginal value of the product attributed to irrigation, causing irrigated cropland to be abandoned or shifted to dryland farming uses. As the proportion of nonirrigated cropland increases, irrigators may expand dry cropland acreages or make other changes in order to minimize any fall in net income.

## Adjustment Strategies

This section examines the various strategies and management options outlined in table 1 by citing research results from other studies and examining and analyzing new data. Ground water mining has been occurring in several areas since the 1950's. Many irrigators have made adjustments suggested in table 1. Thus, many of the research results cited here are from studies carried out in response to changing conditions as they occurred over a long period.

### Maintaining Water Availability

The economic effect of a decline in the level of ground water in an aquifer is to increase the unit pumping cost of water due to increased pumping lifts and reduced water yield of wells. While annual changes in pumping cost may be small, the cumulative change over a number of years may be large.

> "Groundwater mining has two adverse effects on water costs. First, there is the increased pumping lift. On a regional or statewide basis, this may not average more than one to three feet a year, generally signifying a 1 or 2 percent per annum increase in pumping lift. On a farm-by-farm basis, however, there is a great deal of variation, and an individual irrigator may face a more rapidly declining water level. A second effect is the decrease in saturated thickness as the aquifer is mined. As saturated thickness declines, so does well yield. Eventually, additional wells and pumps are needed to maintain the flow. For example, a center pivot distribution system requires a minimum well yield of 600 gallons per minute (gpm). At lower yields, farmers must either adopt a new system requiring fewer gallons per minute, add to the number of wells, or be satisfied with less than optimum coverage. These alternatives tend to increase production costs or decrease crop yields. In Texas, where declines in saturated thickness are especially serious, some farmers have installed eight to nine smaller pumps each yielding 75 to 150 gpm to reach adequate output. On farms with a center pivot or other sprinkler system, the decline in saturated thickness and its resulting problems may have a greater impact on water costs than do the increased energy costs resulting from greater pumping lifts." (Frederick and Hanson).

Sloggett and Dickason reported a wide variation in the rate of decline in ground water levels in major ground water irrigated States, ranging from 0.5 to 5.0 feet per year (table 2). The rate of irrigation water use is influenced by cropping patterns, management practices, irrigation development, commodity and input prices, weather, new technology, and public policies and programs. Economic exhaustion for field crops generally occurs at about the 300-foot pumping depth. At that point, pumping cost averages approximately $36 per acre foot.

The effect of a decline in well yield is to reduce the average number of acres irrigated from each well (table 3). In Texas, Hansford and Sherman Counties with thick underlying aquifers and Lynn and Cochran Counties with thin underlying aquifers were compared to analyze the influence of water availability. The few available aggregated data permit certain conclusions to be drawn, among which is the fact that the number of acres irrigated per well in Hanford and Sherman Counties is double that for Lynn and Cochran Counties. Often the initial response to declining well yields is to increase the number of hours of pumping operations (table 4). As ground water levels continue to fall, investments are made to increase well depths, drill new wells, and install improved pumps. These improvements enable irrigators in many situations to maintain the quantity of water that is available

Table 2--Pumping lift and annual ground water decline in major ground water irrigation states[1]

| State | Pumping lift | Annual decline |
|---|---|---|
| | Feet | |
| Arizona | 75-535 | 2.0-3.0 |
| Arkansas | 50-120 | .5-1.4 |
| California | 100-260 | .5-3.5 |
| Colorado | 175-275 | 2.0 |
| Florida | 250 | 2.5 |
| Idaho | 200-375 | 1.1-5.0 |
| Kansas | 190-275 | 1.0-4.0 |
| Nebraska | 25-250 | 0.5-2.0 |
| New Mexico | 100-200 | 1.0-2.5 |
| Oklahoma | 100-275 | 1.0-2.5 |
| Texas | 50-100 | 1.0-4.0 |

[1] The pumping lift and the annual rate of decline in ground water levels are ranges for each State.

Source: Sloggett and Dickason.

for irrigation for a number of years and, thus, allow continuation of the same irrigated acreage and cropping pattern. New wells installed today are likely to be drilled to the bottom of the aquifer, and pumps are then lowered as ground water levels decline.

A declining ground water supply influences the useful life and economic feasibility of investments in supply developments such as drilling new wells and deepening existing wells. New water pumping technology has been used by some irrigators to adjust to rising energy costs. Even so, increases in the cost of energy in the late 1970's and early 1980's were quite large, relative to

Table 3--Average number of acres irrigated per well in selected Texas counties

| Aquifer thickness and county | 1959 | 1964 | 1969 | 1978 | 1982 |
|---|---|---|---|---|---|
| | | | Acres | | |
| Thick aquifer: | | | | | |
| Hansford | 810 | 754 | 661 | 516 | 525 |
| Sherman | 630 | 570 | 470 | 370 | 353 |
| Thin aquifer: | | | | | |
| Lynn | 442 | 342 | 268 | 207 | 182 |
| Cochran | 352 | 344 | 320 | 267 | 259 |

Source: U.S. Department of Commerce, 1959-82.

Table 4--Estimated pumping hours to meet an unchanging irrigation water requirement for corn, Kansas, 1984

| System[1] | 150-foot lift | 160-foot lift | 175-foot lift |
|---|---|---|---|
| | | Hours | |
| Center pivot | 1,280 | 1,385 | 1,530 |
| Gated pipe with: | | | |
| Tailwater pit | 980 | 1,060 | 1,180 |
| Surge flow | 1,040 | 1,130 | 1,250 |
| Design leveling | 1,190 | 1,285 | 1,430 |
| Partial treatment | 1,390 | 1,500 | 1,670 |
| Open ditch | 1,660 | 1,800 | 2,000 |

[1] Center pivot system assumed to cover 130 acres. All others represent 100 acres.

Source: Kansas Cooperative Extension Service, 1984.

the size of cost reductions which could be achieved by adopting new pump technology. The net effect was an increase in pumping costs. The decline in energy cost which occurred in 1986 reduced pumping costs, but only by a relatively small amount.

Well measurements in 1947-49 indicated that well yields averaged 800 gallons per minute (gal./min.) in Swisher, Briscoe, and Floyd Counties, Texas. Similar measurements conducted in 1965 indicated average well yields of about 200 gal./min. (Harman, Hughes, Graves). Between the late 1920's and 1950, irrigation construction activities in these three counties centered on deepening wells and lowering pumps, drilling additional and replacement wells, and installing smaller pumps and underground concrete pipe distribution systems. In the late 1940's, the average well supplied water for 151 acres of irrigated land. By 1964, the average well served only 59.9 acres of irrigated land.[2]

### Water Conservation

Ground water supply development, as noted above, can maintain adequate water quantities for irrigation for a limited but critical period of time. When a rise in the cost of water occurs, however, a variety of water conservation practices can be used to increase water use efficiency and reduce the amount of water applied per crop acre. These technologies typically have large initial capital costs for structures and equipment. Because of capital and operating costs, there is continuing interest among irrigators in the analysis of benefits and costs of new water-conserving technology and integrated production systems which improve the use of fertilizer and other inputs in addition to improving the use of the water input.

There is a wide variation in the efficiency of irrigation systems and the amount of water applied to satisfy the water requirements of crops (table 5). The selection of an irrigation system is influenced by soils, crops, topography, cost of water, and other technical and economic factors.

Modifications have been made in gravity irrigation systems to increase the effectiveness and the efficiency of those systems. Laser leveling is a water-conserving technology that may increase farm profits (Daubert and Ayer). Laser planing to slope can increase the application efficiency of irrigation water in traditional slope-furrow systems from 50-60 percent to 85-90 percent and achieve water savings of 5 to 15 applied inches under arid climatic conditions. Lower energy costs per acre achieved with laser leveling provide both water conservation benefits and reduce the cost of using the systems. Laser leveling was found

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[2] It was noted, however, that the observed change in well yields may not have been due entirely to a change in well capacity but may have been influenced by a reduction in acreage due to participation in wheat and feed grain price support programs. It was also noted that the rate of decline in ground water would allow only a relatively short period in which to recover investments in water development and, thus, reduce the economic feasibility of continued investments.

to be profitable at the existing cost of water on many Arizona farms.

Test results show that drip irrigation systems can reduce water use by as much as 64 percent with most drip experiments providing more than a 30-percent water savings over conventional sloping-furrow irrigation (Wilson, Ayer, and Snider). Drip achieves only limited water reduction on flat, fine textured soils. Crop yields were increased by 7-29 percent in field experiments.

Technologies and farming practices that are in limited use but are likely to increase in the future include limited tillage, improved furrow (gravity) irrigation, control of irrigation water runoff, and use of the low-energy precision application system (LEPA) (Ellis, Lacewell, and Reneau). Limited tillage is used on 25 percent of irrigated acres, and many farms control irrigation water runoff.

Limited or minimum tillage involves plant residue management, reduced energy use, and conservation of soil and water. Improved furrow systems include alternate furrow irrigation, furrow diking, surge flow, automated flow, and tailwater recovery. LEPA sprinkler systems deliver water directly to the furrow at very low pressures (5-10 pounds per square inch) and are generally used in conjunction with row damming or furrow diking. Both row damming and furrow diking control runoff from heavy rainfall incidents, which characterize precipitation patterns in the Plains and Western States.

Table 5--Estimated average irrigation efficiency of selected irrigation systems

| System | Irrigation system efficiency | Water applied to meet an acre's water requirement |
|---|---|---|
| | Percent | Acre inches |
| Drip | 92 | 1.09 |
| Low-energy precision application | 92 | 1.09 |
| Sprinkler[1] | 75-85 | 1.18-1.33 |
| Improved gravity[2] | 75-85 | 1.18-1.33 |
| Gravity | 40-60 | 1.67-2.50 |

[1] Includes side roll, solid set, traveling gun, high- and low-pressure center pivot, and other mechanical move systems.

[2] Includes tail water recovery, surge flow systems, and precision land leveling.

Source: Sloggett and Dickason.

A recursive linear programming model has been used to analyze the present value and distribution of net returns, changes in resource use, and the sustainability of irrigated agriculture over a 40-year period (1980-2020) for the several technologies outlined above (Ellis, Lacewell, and Reneau). The analysis showed that the adoption of limited tillage, improved furrow, and LEPA reduce per acre irrigation water requirements and increases delivery efficiency. Total water use per year and over time, however, would change very little because of increases in irrigated acreage. Acreage increases of 1-4 percent would increase aggregate net returns by 9-28 percent. The use of advanced technologies increases in importance as water supplies decline, and results of the study suggest that the use of improved technology can aid in sustaining irrigated agriculture in the arid plains portion of northwestern Texas.

## Reducing Total Water Use

Ground water supply developments and water conservation techniques may enable irrigators to continue the same cropping pattern in the early phases of declining ground water. When the water supply becomes severely limited because the decline in saturated aquifer thickness has reduced the quantity of water pumped per unit of time, supply development and water conservation cannot compensate for the large reductions that occur in the availability of water or mitigate the effects of the decline in the water supply. When this point is reached, water use can be reduced by altering the crop mix, reducing the number of irrigated acres, or limiting water applications to critical periods of crop growth.

Irrigated cropland acreage is expected to decline and shift to dryland production as the availability of water declines to low levels. Changes in cropland use in two groups of five Texas High Plains counties were compared to examine the effect of severe reductions in water availability on cropland use. Counties in group 1 had the highest average saturated aquifer thickness in 1980, while group 2 had the lowest average thickness (table 6).

Total cropland use increased in both group 1 and group 2 counties between 1964 and 1982. Irrigated and nonirrigated cropland in group 1 counties grew by 42 and 10 percent between 1964 and 1982, with an overall expansion of 23 percent in cropland acres. Irrigated cropland increased rapidly during the 5-year period between 1964 and 1969 in these counties, with a small decline in nonirrigated acres. This rapid development in irrigation was followed by steady growth from 1969 to 1979. Rising commodity prices during 1974-79 supported irrigation expansion. Between 1979 and 1982, however, rising energy prices and falling commodity prices apparently had adversely affected irrigation in the group 1 counties. Irrigated acres declined there by over one-fourth, while little irrigated acreage was shifted to dryland farming.

The pattern of changes in cropland use in group 2 counties was quite different from changes in group 1 counties. Irrigated cropland declined there by 44 percent between 1964 and 1982, except for the period of high commodity prices between 1974 and 1979. The decline in irrigated cropland was offset by a 115-percent increase in nonirrigated cropland. The net effect of cropland changes in group 2 was a 30-percent increase in total cropland. A large increase in nonirrigated acres and a decline in irrigated acres occurred. Total cropland changes were similar, with increases of 23 and 30 percent for groups 1 and 2.

Major differences occurred in irrigated cropland, with a 42-percent growth in irrigated acres for group 1, the water-abundant counties, and a decline of 44 percent for group 2, the water-scarce counties. Both groups 1 and 2 reduced irrigated acres during the 1979-82 period, when energy prices were increasing and commodity prices were falling.

The crop mix can be altered to reduce total water use by substituting crops with low water requirements for crops with high water requirements. The proportions of various crops in both groups 1 and 2 changed only slightly during the 1964-82 period. For group 1 counties, sorghum and wheat increased in about the

Table 6--Trends in irrigated and nonirrigated cropland use, selected counties, Texas High Plains

| Group and cropland use | 1964 | 1969 | 1974 | 1978 | 1982 | Percentage change 1964-82 |
|---|---|---|---|---|---|---|
| | 1,000 acres | | | | | Percent |
| Group 1:[1] | | | | | | |
| Irrigated | 260 | 451 | 463 | 506 | 368 | 42 |
| Nonirrigated | 373 | 329 | 430 | 229 | 412 | 10 |
| Total | 633 | 1,186 | 893 | 734 | 780 | 23 |
| Group 2:[2] | | | | | | |
| Irrigated | 419 | 408 | 383 | 389 | 233 | -44 |
| Nonirrigated | 369 | 618 | 341 | 622 | 792 | 115 |
| Total | 788 | 1,026 | 724 | 1,011 | 1,025 | 30 |

[1] Group 1 includes Roberts, Hansford, Sherman, Lipscomb, and Ochiltree Counties. These counties have the highest average saturated thickness of the Texas portion of the aquifer in 1980.

[2] Group 2 includes Lynn, Andrews, Cochran, Terry, and Randall Counties. These counties have the lowest average saturated thickness of the Texas portion of the aquifer in 1980.

Source: U.S. Department of Commerce, 1964-82.

same proportion, by 44 and 48 percent (table 7). Corn and hay acreages, which were small in 1969, expanded through 1979 and decreased between 1979 and 1982.

The group 2 counties experienced a large reduction in cotton (61 percent) and sorghum (39 percent) acreage, a small decrease in wheat acreage (6 percent), and some increases in corn and hay production. In comparison with group 1, the irrigators in group 2 counties made changes in their crop mix, with cotton acreage reduced proportionately more than sorghum and wheat acreage. Water use changes resulted partly from a large reduction in the acres of irrigated crops and adjustments in the proportion of acres in various crops.

Declining water levels affect profitability, depending on the rate of water pumping. Table 8 shows the results of a water-decline analysis that was designed to determine the most profit-preserving strategy for changing crop types produced and water use rates when water availability is gradually reduced over a hypothetical 25-year period, holding the number of wells constant. Results from the model indicate that application rates can be modified and the acres of dryland farming increased to reduce both per acre and total water use.

> "Competition for water during the 15-day critical season reduced all cotton irrigation from two to one postplant the fourth year. It was more profitable to apply water to grain sorghum post-three than cotton post-two. From the fourth year through the fourteenth, the amount of water decreased gradually, reducing sorghum postplant three to preplant irrigation with some dryland grain sorghum production added in the fifteenth year. In the fifteenth year, wheat with two postplant irrigations was reduced to preplant and dryland enterprises to 30 acres of preplant grain sorghum and 15 acres of postplant irrigated cotton." (Harman, Hughes, and Graves)

There was a steady increase in dryland or nonirrigated acreage between 1974 and 1978 in the 31 counties of Texas located in the Ogallala aquifer region of Texas (fig. 2). Part of this increase, especially after 1978, offset a sharp decline in irrigated acreage brought on by higher energy costs and falling commodity prices.

## Reverting to Dryland Farming

Dryland farming in semiarid climates is a well-established system of managing crops that is adapted to special soil and climatic conditions. Such climates exist in various parts of the Western States. The number of crops adapted to dryland farming and production under conditions of low precipitation is limited. Wheat, barley, sorghum, millets, pulses (for example, dry beans, dry peas, and lentils), safflowers, and sunflowers are commonly produced in these areas. Nonirrigated cotton is a major crop in the High Plains of Texas. The choice of a crop is further limited by certain climatic conditions such as seasonal

Table 7--Trends in irrigated cropland use for selected crops and counties, Texas High Plains[1]

| Group and crop | 1964 | | 1974 | | 1982 | | Percentage change 1964-82 |
|---|---|---|---|---|---|---|---|
| | 1,000 acres | Percent | 1,000 acres | Percent | 1,000 acres | ----- Percent | ----- |
| Group 1: | | | | | | | |
| Cotton | 1 | -- | 0 | -- | 0 | -- | -- |
| Sorghum | 105 | 40 | 170 | 37 | 152 | 41 | 44 |
| Wheat | 122 | 47 | 206 | 44 | 180 | 49 | 48 |
| Corn | 0 | -- | 36 | 8 | 13 | 4 | -- |
| Hay | 2 | -- | 8 | 2 | 10 | 3 | 344 |
| Other crops | 30 | 12 | 43 | 9 | 13 | 3 | -57 |
| Total | 260 | 94 | 463 | 100 | 368 | 100 | 42 |
| Group 2: | | | | | | | |
| Cotton | 242 | 58 | 225 | 59 | 120 | 52 | -61 |
| Sorghum | 108 | 26 | 84 | 22 | 66 | 28 | -39 |
| Wheat | 28 | 7 | 34 | 9 | 27 | 12 | -6 |
| Corn | 0 | -- | 4 | 1 | 0 | -- | -- |
| Hay | 2 | -- | 3 | 1 | 3 | 1 | -- |
| Other crops | 39 | 9 | 30 | 8 | 17 | 7 | -56 |
| Total | 419 | 100 | 383 | 100 | 233 | 100 | -44 |

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[1] See table 6 for counties in each group.

Source: U.S. Department of Commerce, 1964-82.

Table 8--Optimum cropping program and estimated return to land and management, water supply model II, High Plains of Texas, for a hypothetical 25-year period

| Year | Cotton | | | Grain sorghum | | | Wheat | | | | Return to land and management |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre-plant | Pre + 1 post | Pre + 2 post | Dry-land | Pre-plant | Pre + 3 post | Wheat grazing | Dry-land | Pre-plant | Pre + 2 post | |
| | Acres | | | | | | | | | | Dollars |
| 1 | -- | -- | 40 | -- | -- | 111 | 107 | -- | -- | 107 | 12,700 |
| 2 | -- | 3 | 37 | -- | -- | 111 | 107 | -- | -- | 107 | 12,518 |
| 3 | -- | 27 | 13 | -- | -- | 111 | 107 | -- | -- | 107 | 2,545 |
| 4 | -- | 40 | -- | -- | 7 | 104 | 109 | -- | -- | 107 | 2,236 |
| 5 | -- | 40 | -- | -- | 20 | 91 | 112 | -- | -- | 107 | 11,858 |
| 6 | -- | 40 | -- | -- | 31 | 80 | 115 | -- | -- | 107 | 12,686 |
| 7 | -- | 40 | -- | -- | 41 | 70 | 118 | -- | -- | 107 | 1,933 |
| 8 | -- | 40 | -- | -- | 51 | 60 | 120 | -- | -- | 107 | 1,281 |
| 9 | -- | 40 | -- | -- | 59 | 52 | 125 | -- | 6 | 101 | 1,016 |
| 10 | -- | 40 | -- | -- | 67 | 44 | 138 | -- | 36 | 71 | 9,458 |
| 11 | -- | 40 | -- | -- | 72 | 39 | 138 | -- | 59 | 48 | 8,294 |
| 12 | -- | 40 | -- | -- | 77 | 34 | 138 | -- | 77 | 30 | 7,805 |
| 13 | -- | 40 | -- | -- | 82 | 29 | 138 | 15 | 77 | 15 | 6,724 |
| 14 | -- | 40 | -- | -- | 86 | 25 | 138 | 27 | 77 | 3 | 6,275 |
| 15 | -- | 40 | -- | 29 | 63 | 19 | 138 | 45 | 62 | -- | 5,101 |
| 16 | -- | 40 | -- | 42 | 54 | 15 | 138 | 52 | 55 | -- | 4,549 |
| 17 | -- | 40 | -- | 53 | 46 | 12 | 138 | 57 | 50 | -- | 4,075 |
| 18 | -- | 40 | -- | 63 | 39 | 9 | 138 | 62 | 45 | -- | 3,665 |
| 19 | -- | 40 | -- | 70 | 34 | 7 | 138 | 107 | -- | -- | 3,195 |
| 20 | -- | 40 | -- | 75 | 30 | 6 | 138 | 107 | -- | -- | 3,009 |
| 21 | 25 | 15 | -- | 81 | 30 | -- | 138 | 107 | -- | -- | 1,684 |
| 22 | 26 | 14 | -- | 84 | 27 | -- | 138 | 107 | -- | -- | 1,587 |
| 23 | 26 | 13 | -- | 87 | 24 | -- | 138 | 107 | -- | -- | 1,496 |
| 24 | 27 | 13 | -- | 90 | 21 | -- | 138 | 107 | -- | -- | 1,496 |
| 25 | 28 | 12 | -- | 92 | 19 | -- | 138 | 107 | -- | -- | 1,496 |

-- = Not applicable.

Source: Harman, Hughes, and Graves.

distribution of precipitation, winter and summer temperatures, and length of growing season. The practice of limited irrigation can be used in dryland crop production to adjust to seasonal precipitation patterns which require irrigation during critical periods of crop growth or to cope with infrequent growing-season droughts.

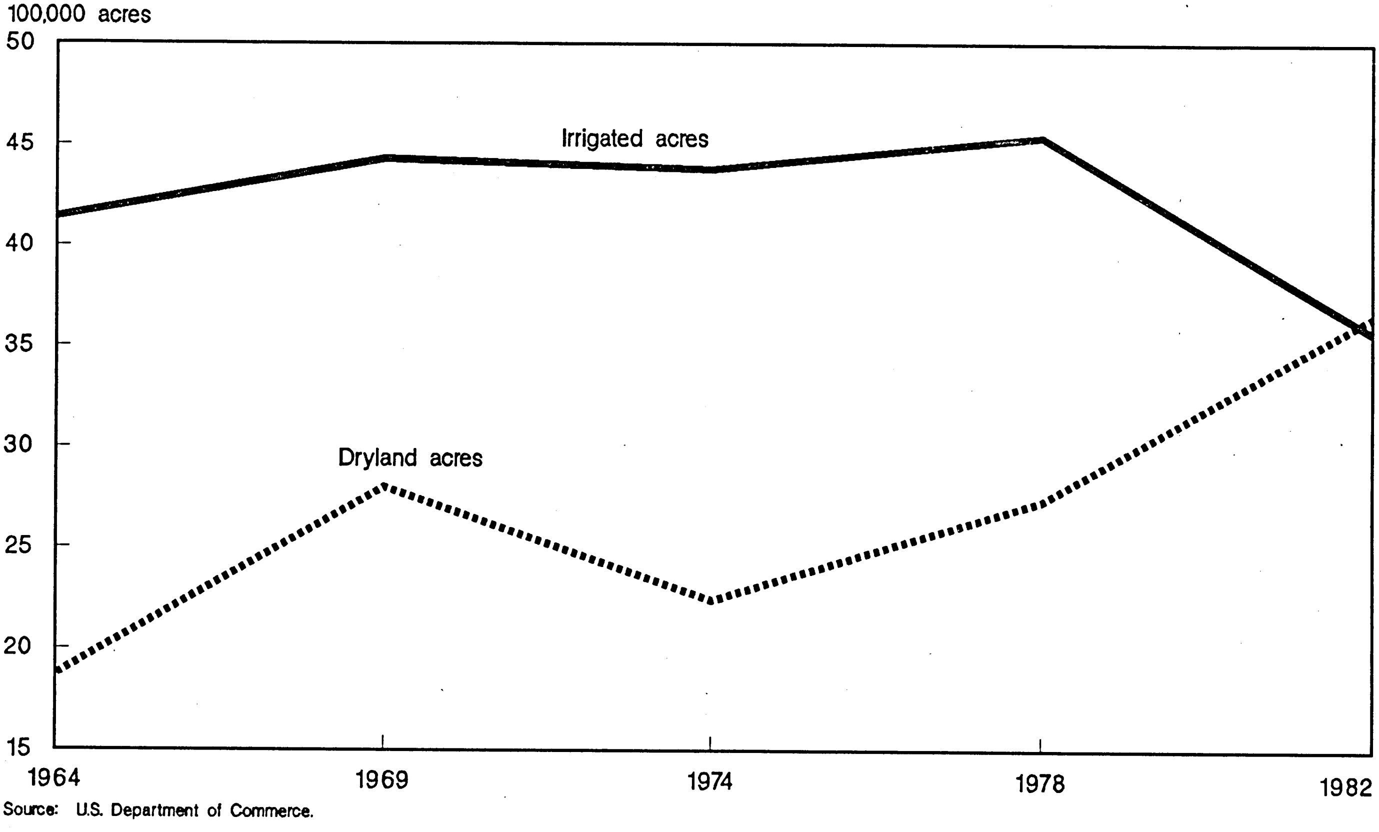
During the transition from irrigated to nonirrigated production, several irrigation practices or variations in practices are used to improve water use and stretch the economic life of the exhaustible underground water supplies that are at sufficiently shallow depths to make pumping feasible. Irrigation stabilizes yields and returns, and so, even with greater net returns per acre for nonirrigated crops, farmers may continue to irrigate in order to reduce yield and income variation and risk.

Many factors influence the economic life of an aquifer and the decision to revert to dryland farming.

> "The economic life of the aquifer is determined by the profitability of irrigation crop production. As the water level declines, pumping costs rise and, other things being equal, the profitability of irrigated production declines. When the declines in the water table are combined with rising energy costs, particularly in the price of natural gas in the Oklahoma Panhandle, profitability is further reduced.

Figure 2

**Irrigated and dry cropland acres, 31 Ogallala aquifer counties, Texas, 1964-82**



Source: U.S. Department of Commerce.

> Finally, when these factors are combined with low agricultural commodity prices, the profitability of irrigated crop production approaches that of dryland production. Once it is as profitable to produce crops under dryland conditions as under irrigated conditions, the economic life of the aquifer is exhausted. This concept of economic life is very important to agricultural producers and explains shifts in production patterns in many areas from irrigated to dryland activities." (Mapp)

In some water-mining locales of the United States (for example, southern Arizona, southern Idaho, and central Arkansas), the depth of the mined aquifer base is so great that economic exhaustion could occur for irrigation and yet leave considerable water for other, higher valued uses, such as municipal and industrial.

In the comparison of two groups of counties in the High Plains of Texas described above, counties with the highest saturated aquifer thickness experienced expansion phase with an increase in the number of irrigated farms and an ease in farms without irrigation between 1964 and 1982 (table 9). Counties with the lowest average saturated aquifer thickness experienced a consistent decline in the number of irrigated farms and an increase in farms without irrigated cropland between 1964 and 1982. Dryland crop acreage increased relatively faster in the group of water-scarce counties than in the group of water-abundant counties (fig. 3).

## Kansas Case Study

A Kansas locale was selected for an analysis of adjustment alternatives to declining ground water, namely Kansas Groundwater Management District Number Four (GWMD4). The purpose of the case study was to develop a better understanding of the alternative irrigation techniques available to farmers when adjusting to declining ground water supplies. The primary objective was to estimate differentials in irrigation costs for alternative irrigation technology options, and for selected crops, commodity prices, and energy sources.

The area studied, GWMD4, is located in the Ogallala aquifer region of Kansas. Water-bearing strata of the Ogallala are typically isolated from recharge sources, both surface and subsurface. GWMD4 is generally representative of ground water conditions existing in the large upper region of the Ogallala aquifer and includes Nebraska, eastern Colorado, and western Kansas. It includes portions of nine counties in northwest Kansas.

This district has experienced extensive declines in both water levels and saturated aquifer thickness. Average well yields have fallen from an initial rate of 800-900 gal./min. in 1950 to less than 500 gal./min in 1982, and some marginal wells have been

Table 9--Trends in the number of farms and the size of irrigated and nonirrigated farms, selected counties, Texas High Plains

| Group, farms, and cropland use[1] | 1964 | 1969 | 1974 | 1978 | 1982 | Percentage change 1964-82 |
|---|---|---|---|---|---|---|
| | Number | | | | | Percent |
| Group 1: | | | | | | |
| Irrigated farms | 512 | 729 | 667 | 696 | 559 | 9.2 |
| Nonirrigated farms | 666 | 761 | 617 | 463 | 542 | -18.6 |
| Total | 1,178 | 1,490 | 1,284 | 1,159 | 1,101 | -6.5 |
| Average number of acres of harvested cropland per farm | 1,236 | 796 | 695 | 633 | 709 | -42.6 |
| Group 2: | | | | | | |
| Irrigated farms | 1,792 | 1,667 | 1,296 | 1,280 | 754 | -57.2 |
| Nonirrigated farms | 477 | 725 | 449 | 615 | 963 | 102.0 |
| Total | 2,269 | 2,392 | 1,745 | 1,895 | 1,717 | -24.3 |
| Average number of acres of harvested cropland per farm | 348 | 419 | 415 | 533 | 597 | 71.3 |

[1] See table 6 for counties in each group.

Sources: U.S. Department of Commerce, 1964-82.

abandoned. Other changes in irrigated agriculture in this region since 1975 include the following:

(1) Irrigated corn acreage has fallen from over 100,000 acres to less than 25,000 acres, a decline of 75 percent;

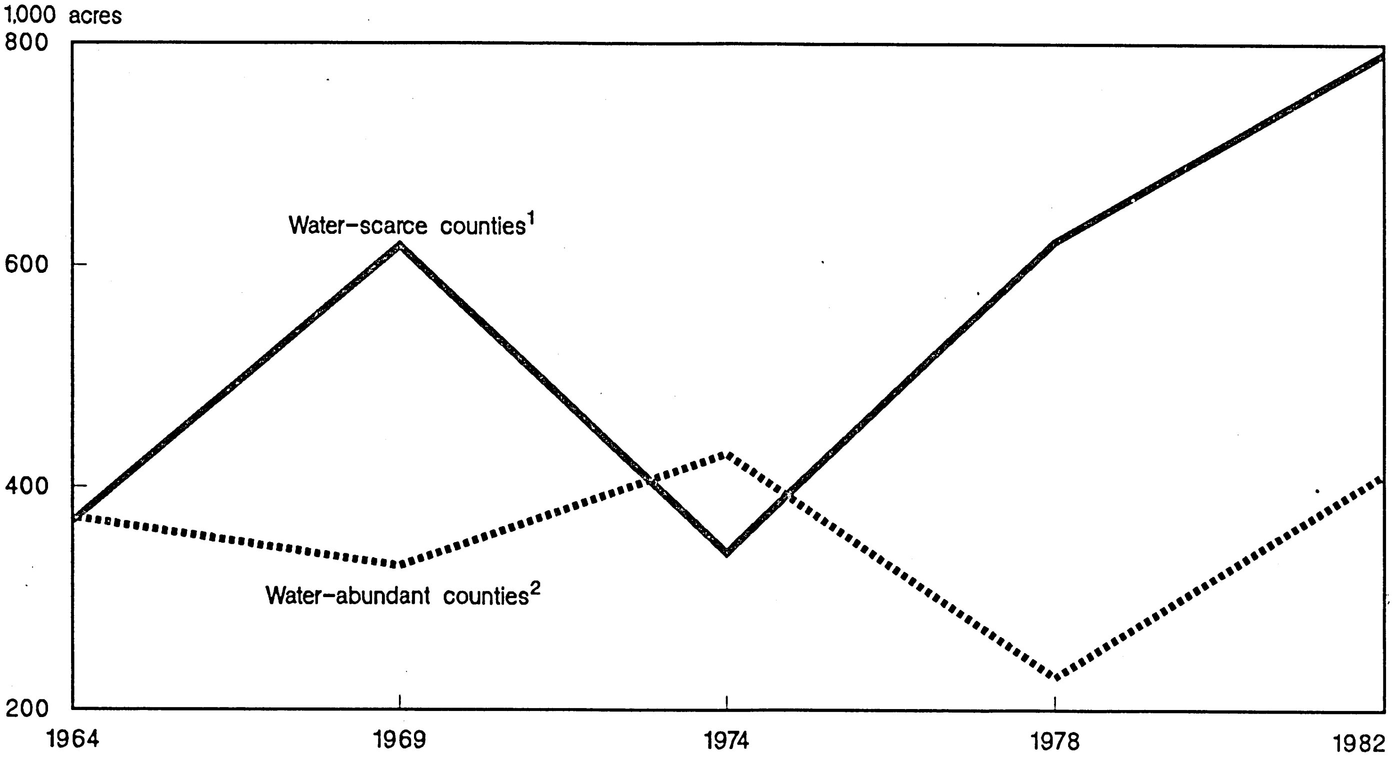
(2) Total acres irrigated in the nine-county area declined by almost 48,000 acres, a decline of 15 percent from 1978 to 1982; and

(3) The practice of limited watering of crops is increasing. Wheat and grain sorghum are irrigated before planting, with no subsequent watering during the growing period. Some grain sorghum may be watered once during the growing season, but this is not a widespread practice.

The number of irrigated farms in five counties in the district declined from 1,525 in 1978 to 1,160 in 1982 (table 10). A slight increase in the number of wells during the period may be partially explained by weather conditions, small changes in the irrigated crop mix, and commodity price changes. During wetter

Figure 3

**Dry cropland acreage in selected Texas counties**



1 Five most water-scarce counties are Hansford, Lipscomb, Ochiltree, Roberts, and Sherman.
2 Five most water-abundant counties are Andrews, Cochran, Lynn, Randall, and Terry.
Source: U.S. Department of Commerce.

Table 10--Irrigated farms, irrigated acres, and number of wells: Groundwater Management District Four, Kansas, 1978 and 1982

| County | Irrigated acres | | Farms with Irrigation | | Wells | |
|---|---|---|---|---|---|---|
| | 1978 | 1982 | 1978 | 1982 | 1978 | 1982 |
| | 1,000 acres | | Number | | | |
| Cheyenne | 62 | 45 | 380 | 185 | 540 | 590 |
| Rawlins | 32 | 18 | 200 | 150 | 250 | 207 |
| Sheridan | 91 | 83 | 295 | 325 | 630 | 696 |
| Sherman | 135 | 140 | 250 | 200 | 865 | 937 |
| Thomas | 110 | 100 | 400 | 300 | 900 | 855 |
| Total | 430 | 386 | 1,525 | 1,160 | 3,185 | 3,285 |

Source: Kansas Cooperative Extension Service, 1978 and 1982.

than normal seasons, crops such as wheat and grain sorghum typically require less irrigation water, while corn requires some irrigation during most seasons in this section of the country.

Data for GWMD4, obtained from the 1978 and 1982 Kansas Irrigation Survey, indicate that irrigated acreage in GWMD4 increased by over 10 percent between 1978 and 1982, with most of the increase occurring in the use of gated pipe systems (table 11). Only Sherman County produced fewer irrigated acres in 1982 than in 1978, a reduction of less than 5 percent in irrigated acres.

## Efficiency Rates

Seven irrigation systems were analyzed to determine the feasibility of their use in areas with declining ground water levels. Estimated investment costs of irrigation systems range from $55,380 for a high-pressure center pivot system to $22,800 for an open-ditch system (table 12). The higher cost estimate for center pivot systems does not include land-forming costs that may be required for surface systems and can increase the cost of a surface system to the same level as a center pivot system. Land preparation charges were not included because of the substantial variation in investment from site to site, ranging up to $350 an acre. The extent of required land preparation is the determining factor in the selection of a surface or overhead system. Center pivot and other sprinkler systems are the only feasible alternatives on many farms because of terrain features.

Escalating pumping costs due to increasing pumping lifts and declining well-yields in ground water decline areas have increased interest in the relative efficiency of irrigation systems. The efficiency of systems evaluated in this study varies from 50 to 85 percent. The efficiency of irrigation systems measures the proportion of irrigation water that is available to the plant. Systems that are 85-percent efficient require, under conditions of constant well yields, slightly more than half the pumping time of a 50-percent efficiency system.

The efficiency of center pivot systems varies from 60 to 90 percent, with 85 percent being a commonly used measure. The efficiency of gated pipe systems ranges from 60 to 85 percent, according to information obtained from the Cooperative Extension Service of Kansas State University. Gated pipe systems with efficiency rates above 70 percent require land leveling to design standards for the particular slope, length of run, and soil type. Farms in the study area require only partial leveling on most fields for adequate gravity water flows.

Surge flow systems represent a relatively new irrigation technology which has achieved efficiency levels of 80 percent (Sloggett and Dickason). The major advantage of surge flow in relation to standard gated pipe is improved efficiency and a lower cost averaging about $1,000 per unit. A surge flow system with an auxiliary pumping unit may have a cost that is only 10 percent as much as a tailwater recovery system. An 80-percent efficiency level was used in this analysis for the surge flow

Table 11 - Irrigated acres by type of system, Groundwater Management District Four counties, Kansas, 1978 and 1982

| | Open ditch | | Center pivot | | Gated pipe | | Tailwater pits | |
|---|---|---|---|---|---|---|---|---|
| County | 1978 | 1982 | 1978 | 1982 | 1978 | 1982 | 1978 | 1982 |
| | Acres | | | | | | Number | |
| Cheyenne | 0 | 0 | 12,000 | 18,600 | 26,400 | 38,600 | 127 | 110 |
| Rawlins | 0 | 0 | 3,500 | 10,000 | 13,500 | 12,000 | 7 | 5 |
| Sheridan | 800 | 880 | 12,548 | 13,800 | 66,389 | 73,000 | 110 | 121 |
| Sherman | 0 | 0 | 29,500 | 26,250 | 110,000 | 108,000 | 325 | 400 |
| Thomas | 0 | 0 | 50,000 | 43,000 | 50,000 | 66,000 | 200 | 200 |
| Total | 800 | 880 | 107,548 | 111,650 | 266,289 | 297,600 | 768 | 836 |

Source: Kansas Cooperative Extension Service, 1978 and 1982.

Table 12--Investment requirements and estimated efficiency of alternative irrigation systems, northwest Kansas, 1984

| System | Estimated investment cost | Maximum acres | Efficiency rate |
|---|---|---|---|
| | Dollars | Number | Percent |
| High-pressure center pivot | $55,380 | 130 | 85 |
| Low-pressure center pivot | 55,380 | 130 | 85 |
| Gated pipe with recovery pit | 36,800 | 100 | 85 |
| Gated pipe with surge flow | 28,800 | 100 | 80 |
| Gated pipe (design leveling) | 26,800 | 100 | 70 |
| Gated pipe (partial leveling) | 26,800 | 100 | 60 |
| Open ditch | 22,800 | 100 | 50 |

Source: Kansas Cooperative Extension Service, 1984.

system, although reported water savings of 40 percent by farmers in Oklahoma would make this system as efficient as those with tailwater pits. Surge flow systems, however, work best on tighter soils with low water intake and in fields with short irrigation runs.

## Irrigation Requirements

The irrigation systems listed in table 12 were evaluated for use with the five major crops in the area (corn, wheat, grain sorghum, limited-irrigation grain sorghum, and alfalfa). Limited watering of grain sorghum was reported to be increasing in the area studied. This practice included reducing the number of water applications and reducing seed and fertilizer levels. Irrigation water requirements for the commonly grown crops were computed using the Blaney-Criddle method, and data were supplied by the U.S. Geological Survey (USGS) (1982). Irrigation demands were modified by USGS by comparing computed values with estimates of the volume of water applied by farmers (U.S. Department of Interior). The modified irrigation requirement estimates are given in table 13. The efficiency estimates for various irrigation systems and irrigation demand estimates can be used to determine the irrigation water requirements of crops (table 14). Those data illustrate the importance of efficiency rates on water use. For example, an open-ditch system used in irrigating corn requires almost 70 percent more water to be pumped than a gated pipe system with tailwater recovery.

## Irrigation Costs

Irrigation costs were calculated for seven irrigation systems (table 15). Irrigation costs were separated into three categories: fixed costs, pumping costs, and repairs and maintenance. Depreciation charges, taxes, insurance, and items of this nature are included in fixed costs. Guidelines and data

Table 13--Estimated irrigation requirements and yields by crop (1-degree cell, lat. 39-40 deg., long. 101-102 deg.)

| Crop | Irrigation requirements |
|---|---|
| | Acre inches |
| Corn | 13.9 |
| Wheat | 7.1 |
| Grain sorghum | 8.2 |
| Grain sorghum[1] | 5.5 |
| Alfalfa | 16.2 |

[1] Limited irrigation.

Sources: U.S. Department of Commerce, 1984 and Kansas Cooperative Extension Service, 1984.

Table 14--Estimated irrigation water pumped by crop and irrigation system, Groundwater Management District Four, Kansas, 1984

| Crop | Gross irrigation by system | | | | | |
|---|---|---|---|---|---|---|
| | Center pivot[1] | Gated pipe | | | | Open ditch |
| | | With re-use | Surge flow | Design level | Partial level | |
| | Acre inches | | | | | |
| Corn | 16.4 | 16.4 | 17.4 | 19.8 | 23.2 | 27.8 |
| Wheat | 8.3 | 8.3 | 9.6 | 10.1 | 11.8 | 14.2 |
| Grain sorghum | 9.6 | 9.6 | 10.3 | 11.7 | 13.7 | 16.4 |
| Grain sorghum[2] | 6.5 | 6.5 | 6.9 | 7.9 | 9.2 | 11.0 |
| Alfalfa | 19.1 | 19.1 | 20.3 | 23.1 | 27.0 | 2.4 |

[1] Application rates for center pivots are assumed to be equivalent for both high- and low-pressure systems.
[2] Limited irrigation.

Source: U.S. Department of Commerce, 1979.

for estimating these costs were obtained from Farm Management Guides provided by Kansas State University (Kansas Cooperative Extension Service, 1985). Fixed costs were assumed to remain constant for the 10-year evaluation period used in this report. Pumping costs and, to a lesser extent, repairs and maintenance, however, are affected directly by increased lifts and reduced

Table 15- Estimated annual irrigation costs per acre for corn, assuming 130-bushel yield, by lift levels, Kansas, 1984

| System | Fixed costs | Pumping costs | | | Repairs and maintenance costs | | |
|---|---|---|---|---|---|---|---|
| | | 150 feet | 160 feet | 175 feet | 150 feet | 160 feet | 175 feet |
| | | | | Dollars per acre | | | |
| Center pivot: | | | | | | | |
| High | 76.68 | 31.56 | 32.38 | 33.69 | 21.32 | 22.37 | 23.82 |
| Low | 76.68 | 22.73 | 23.71 | 25.02 | 21.32 | 22.37 | 23.82 |
| Gated pipe with: | | | | | | | |
| Tailwater pit | 53.97 | 15.04 | 15.86 | 17.33 | 17.16 | 17.96 | 19.16 |
| Surge flow | 40.77 | 15.99 | 16.85 | 18.42 | 16.16 | 17.06 | 18.26 |
| Design leveling | 39.30 | 18.27 | 19.26 | 21.05 | 17.26 | 18.26 | 19.66 |
| Partial treatment | 39.30 | 21.31 | 22.47 | 24.56 | 19.26 | 20.36 | 22.06 |
| Open ditch | 34.91 | 23.25 | 24.74 | 27.24 | 21.16 | 22.56 | 24.56 |

Source: Kansas Cooperative Extension Service, 1984.

saturated thicknesses associated with declining ground water levels and are likely to vary over a 10-year period.

Information concerning pumping lifts, saturated thicknesses, and well yields was obtained from Wayne Bossert, Director of Groundwater Management District Four. While resource characteristics vary from well to well within the District, averages are considered reasonably good estimates for the areas as a whole. The base pumping costs and maintenance charges were determined using 150 feet of lift and well yields of 750 gal./min.

Energy costs of pumping a given quantity of water (in acre inches or acre feet) were determined from farm management guides published by Kansas State University for natural gas, electricity, diesel, and propane. Data from the Kansas Irrigation Survey (Kansas Cooperative Extension Service, 1978 and 1982) indicate that nearly 60 percent of the pumping units in the northwest area of Kansas are powered by natural gas. While most of the analysis for this report pertains to the use of natural gas, cost data were also developed for electricity and diesel (table 16). Natural gas is currently the most economical source of energy for pumping, and where it is available, it is the fuel of choice. There is a wide range of prices for natural gas, but GWMD4 personnel estimated that irrigators were paying an average of $3.00 per million cubic feet. Diesel prices averaged about 95 cents per gallon during the summer of 1984 and the rate for electric power was assumed at 8 cents per kilowatt hour.

## Effects of Declining Ground Water Levels

Data obtained from GWMD4 indicate that annual declines in the water table vary from less than half a foot to 2 feet. With continued development, these declines could be expected to range between 1 and 2.5 feet per year. Therefore, the cumulative range of decline over the next 10 years could vary between 10 and 25 feet. The latter would be more likely in the event there is continued irrigation development in the area.

Detailed cost estimates for irrigation water pumping were developed for irrigation systems at three lift levels: 150 feet, which represents the present condition; 160 feet, which assumes an average annual decline of 1 foot; and 175 feet, which represents an average annual decline of 2.5 feet (table 16).

Declining ground water tables increase irrigation costs in three ways: increased energy costs associated with greater lifts; decreasing well yields, which increases pumping time; and decreases in pump efficiency or the costs to modify the pumping unit to maintain the same efficiency.[3]

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[3] No attempt was made to evaluate this cost increase factor because data were not available concerning the age and capacities of pumping units within the area.

Well-yield reductions occur generally over time and annual changes may not be detected by most farmers. Given the physical properties of the wells in GWMD4 area, a 10-foot decline in ground water levels would reduce yields by a little over 7 percent; a 25-foot decline would drop the average well yield by about 18 percent (Kansas Cooperative Extension Service). The effect of these reductions, in most cases, would be to increase pumping time to compensate for reduced volume. An example of increased pumping time for irrigated corn is shown in table 4. The increases in pumping hours can be large for higher lifts, especially for crops that require large amounts of water in a limited time period. The magnitude of the cost effects of higher pumping lifts and lower well yields as water tables decline is shown in table 16 with estimates for three energy sources and selected systems at three lift levels. The variable costs of operating each of the systems as the lift level increases are clearly shown.

Table 16--Pumping costs per acre inch of water, selected lifts, 750 gal./min., 1984

| System and lift distance | Energy source | | |
|---|---|---|---|
| | Natural gas $3.00 per million cu.ft. | Diesel $0.95 per gallon | Electric $0.08 per kilowatt hr. |
| | Dollars per acre inch | | |
| 150-foot lift: | | | |
| Center pivot | | | |
| High | 1.93 | 3.47 | 3.61 |
| Low | 1.39 | 2.48 | 2.58 |
| Gated pipe | .92 | 1.64 | 1.70 |
| Open discharge | .84 | 1.49 | 1.55 |
| 160-foot lift: | | | |
| Center pivot | | | |
| High | 1.98 | 3.57 | 3.72 |
| Low | 1.45 | 2.58 | 2.68 |
| Gated pipe | .97 | 1.73 | 1.80 |
| Open discharge | .89 | 1.59 | 1.65 |
| 175-foot lift: | | | |
| Center pivot | | | |
| High | 2.06 | 3.72 | 3.87 |
| Low | 1.53 | 2.73 | 2.84 |
| Gated pipe | 1.06 | 1.88 | 1.96 |
| Open discharge | .98 | 1.74 | 1.81 |

Source: Adapted from <u>Farm Management Guides</u>, MF-578 and MF-585, Cooperative Extension Service, Kansas State University, Aug. 1984. Based on Nebraska Fuel Test Standards at 75-percent efficiency; center pivot pressures of 75 pounds (high pressure), and 35 pounds (low pressure).

How large are the increases in irrigation costs due to declining water levels? Variable irrigation cost increases for center pivot systems are similar since both the high- and low-pressure systems are assumed to have the same efficiency rates (table 17). Gated pipe systems, which have different rates of efficiency, have differing cost increases as a result of increased lift. A system with tailwater recovery would have an increased cost of $4.29 per acre, assuming a water level decline from 150 to 175 feet; a system with a surge flow setup, $4.53; a system with design leveling, $5.18; and partial leveling, $6.05. On a per foot decline basis, the cost increases range from 17 cents to 24 cents per foot per acre.

Based on the estimates in table 17, an irrigator with a basic gated pipe system could reduce variable costs by $8.37 per acre ($40.57-$32.20 at 150 feet lift) and $10.13 ($46.62-$36.49 at 175 feet lift) with the addition of a tailwater recovery system. With system costs about $100 an acre to install, as indicated earlier, there is little economic justification for adding this technology at current cost-price relationships. Addition of a surge flow system would reduce variable costs by $8.42 at the 150 feet level, and $9.94 at 175 feet. The lower investment cost for surge flow technology will become much more widespread, especially in areas where soils are well suited.

## Crop Mix

The crop mix has been and will continue to be affected by declining ground water levels. As has been noted, there have been large reductions in irrigated acreage of some high water requirement crops and increased acreage of low water requirement crops. Some of the decline in the acreage of high water requirement crops can be attributed to increasing costs

Table 17--Estimated variable irrigation costs per acre for irrigated corn, by lift levels, 1984[1]

| System | Feet of lift | | |
|---|---|---|---|
| | 150 | 160 | 175 |
| | | Dollars per acre | |
| Center pivot: | | | |
| High | 52.88 | 54.75 | 57.51 |
| Low | 44.05 | 46.08 | 48.84 |
| Gated pipe with: | | | |
| Tailwater recovery | 32.20 | 33.82 | 36.49 |
| Surge flow | 32.15 | 33.91 | 36.68 |
| Design leveling | 35.53 | 37.52 | 40.71 |
| Partial treatment | 40.57 | 42.83 | 46.62 |
| Open ditch | 44.51 | 47.30 | 51.80 |

[1] Irrigation pumping and maintenance cost. Corn yield of 130 bushels per acre and natural gas at $3.00 per million cubic feet.

associated with rising fuel prices and part can be attributed to reduced well yields.

The estimated variable cost per acre for irrigation systems is based on constant prices and an assumed rate of water level decline over a 10-year period. Comparative partial-budget cost data are shown for four irrigation systems (high- and low-pressure center pivot, and two gated pipe systems) (table 18). One of the gated pipe systems was designed with surge flow and the other had only partial treatment. The two gated pipe systems with the most favorable cost structures are included in the analysis.

Table 18--Partial production costs per unit of production by lift levels[1]

| Irrigation system and crop | Unit | Feet of lift | | | | | |
|---|---|---|---|---|---|---|---|
| | | 150 | 160 | 175 | 150 | 160 | 175 |
| | | Dollars per unit | | | | | |
| | | High pressure | | | Low pressure | | |
| Center pivot system: | | | | | | | |
| Corn | Bushel | 2.25 | 2.26 | 2.28 | 2.18 | 2.20 | 2.22 |
| Wheat | do. | 2.55 | 2.56 | 2.58 | 2.50 | 2.51 | 2.53 |
| Grain sorghum | do. | 1.70 | 1.71 | 1.72 | 1.66 | 1.67 | 1.69 |
| Grain sorghum[2] | do. | 2.20 | 2.21 | 2.22 | 2.16 | 2.17 | 2.18 |
| Alfalfa | Ton | 50.96 | 51.40 | 52.06 | 48.91 | 49.38 | 50.04 |
| | | With surge flow | | | With partial treatment | | |
| Gated pipe system: | | | | | | | |
| Corn | Bushel | 2.07 | 2.09 | 2.11 | 2.13 | 2.15 | 2.17 |
| Wheat | do. | 2.12 | 2.14 | 2.15 | 2.30 | 2.32 | 2.35 |
| Grain sorghum | do. | 1.51 | 1.52 | 1.53 | 1.59 | 1.60 | 1.62 |
| Grain sorghum[2] | do. | 1.95 | 1.96 | 1.97 | 2.06 | 2.07 | 2.09 |
| Alfalfa | Ton | 39.06 | 39.46 | 40.11 | 40.73 | 41.26 | 42.12 |

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[1] Non-irrigation production costs were derived from 1984 crop budgets developed for Kansas by the U.S. Department of Agriculture's Economic Research Service, and (for alfalfa) by Kansas State University. Charges for operator labor, returns to land (interest on land), and general farm overhead are excluded from production costs. Price of natural gas was assumed to be $3.00 per million cubic feet. Crop-yield levels employed are normalized yields for Groundwater Management District Four in the early 1980's. Slight increases in commodity price levels or decreases in pumping costs (fuel prices) would more than offset the effects of increased pumping lift. Higher energy costs would, of course, exacerbate the cost effects of water level declines.

[2] Limited irrigation.

Extension personnel report growing interest in low-pressure pivot systems on the part of many farmers. This interest results from the substantial fuel savings of low-pressure center pivot systems. Potential savings from converting to a low-pressure system are enhanced when energy costs rise. In the example noted in table 17, variable irrigation costs for corn are about $8.70 per acre lower with low-pressure systems. Conversion costs have been estimated at $4,000 for a 130-acre system. Based on this cost estimate, the average annual cost of conversion per acre would be between $3.00 and $4.00, depending on the interest rate and a 15-year useful life. Comparable cost differences for wheat and grain sorghum are estimated at about $4.50 and $5.20. Thus, there is some economic justification for conversion. Extension personnel indicate, however, that use of low-pressure pivots is not widespread because many of the soils in the area do not have moisture intake rates suitable for these systems. Runoff problems are common, and extension workers report that conservation tillage methods which improve infiltration rates may be needed to control runoff problems.

There appears to be a cost advantage for gated pipe systems for each crop included in this study even though land preparation charges required for gated pipe systems are excluded from the cost estimates. Center pivot systems require a higher initial investment as well as higher operating costs but require less labor and are easier to manage. Agricultural engineers at Kansas State University use a figure of $150 an acre as an average estimate in design leveled systems. The annual cost of leveling, therefore, could range between $9.00 and $15.00 per acre, depending on the discount rate.

Assuming the systems are in place, continued irrigation of all crops in the shortrun, except wheat, could be expected by those with gated pipe systems, corn providing perhaps the best alternative, followed by grain sorghum. Alfalfa has a favorable cost-price relationship but is produced only by operators that have an established market with a commercial feedlot in the area.

Acreage reduction in corn may be incurred by individual farmers whose well yields are significantly reduced by declining water levels; that is, only by irrigating fewer acres could an adequate amount of water be delivered to the crop at critical stages during the growing season.

Alternatives available to irrigators as ground water levels decline and operating costs increase include adopting water-saving technologies, switching to crops that require less irrigation water, reducing irrigated acreage, and returning to dryland agriculture. These alternatives have been used to some extent in some arid plains areas where ground water levels and well yields have been declining.

The Kansas case study results suggest that savings in operating costs are possible through adoption of water conserving technologies. The surge flow system appears to be the most economically viable technology for the area studied.

Existing systems will likely be used in a less intensive manner such as supplementing moisture requirements for grain sorghum and wheat which require less water than corn or alfalfa. The rationale for this practice lies in the fact that fixed costs have been incurred (sunk costs) and are not considered by the farmer in maximizing shortrun returns by equating price and marginal cost. The results obtained in this case study suggest that this would be true for each system and crop.

Several important limitations are inherent in the case study analysis. First, no attempt was made to incorporate complementary relationships which might be available through crop rotations and other agronomic practices. These effects can be very important in U.S. ground water mining irrigation. In the Texas Trans Pecos Region, for example, barley is sometimes grown merely for the agronomic benefits in rotation with cotton.

Second, there are instances where irrigators have expanded the number of acres irrigated by using existing systems for different crops at different times of the year. An example of this practice is irrigating wheat at fall planting times and grain sorghum during summer months. Expanding the acreage of a system from 100 to 150 or 180 acres can lower fixed costs per acre in a dramatic fashion. These are important considerations and should be included in future case studies relating to these issues.

Third, the effects of Government programs which influence profitability of certain crops and the rates of water use are not addressed.

## Study Implications

Implications regarding adjustments that irrigators make in response to declining ground water supplies are based upon several sources of information, including results of published studies, analysis of county data in selected ground water decline areas, and results of the Kansas case study. The cited information sources examined a range of water supply conditions that are applicable to situations that exist in numerous other locations in the United States.

One of the main implications that emerges from these analyses, viewed as a whole, is that in declining ground water areas, the rising cost of pumping water and the decline in the availability of water are the primary irrigation-related factors exerting pressure on irrigators to adopt water-conserving practices and modify cropping patterns. The increase in pumping cost is caused by changes associated with the decline in ground water levels and, at times, a rising price of energy. Changes in pumping lift and well yields occur slowly, typically with only small annual changes. Over an extended period of time, however, the small annual changes accumulate and result in large changes in pumping costs.

In some ground water mining areas, including large portions of the Great Plains, where ground water supplies 80 percent of irrigation water, there is limited surface water available to replace ground water use. It is in these areas that major changes in crop mix, widespread use of limited irrigation, and reversion to dryland farming have occurred. It is in these areas, also, that large changes in the structure of agriculture are occurring and the viability of rural areas is open to question. A recent study by Holmes and Petrulis indicates that ground water mining areas share the concern that declining ground water supplies tend to stifle growth of other local industries and impose hardships on important parts of their communities.

The higher risks and costs associated with developing and using irrigation water in areas with declining ground water supplies discourage new investments. A finite supply of ground water means that additional water will come only at increasingly high costs as pumping lifts increase and well yields decline. The useful life of wells is limited and unknown because the rate of change in the system depends not only on the current use rate but also on irrigation expansion or decline in the future periods. The common property aspects of ground water use discourage conservation in cases where the resource is unregulated and in cases where there is an exaggerated perception of the rather minor actual rates of lateral movement of water in the aquifer.

Adjustments on irrigated farms are influenced by the cost and availability of water. Many farms shift to dryland farming when the irrigation water supply is economically depleted for irrigated farming purposes.

In the area of public policy significance, one implication of this study is that irrigators' mining of ground water tends to cease at pumping depths associated with economic exhaustion for irrigation purposes. Therefore, quantities of water that may lie at greater depths would remain available to other, higher valued uses, such as industrial and domestic use.

This suggests that in certain deep-aquifer irrigation-mining locales, ground water would be preserved for higher valued uses even without any public measures aimed at conserving or regulating ground water use.

This study does not comment on the various types of policy levers that might deter irrigators from consuming mined ground water, except by implying that public measures that add to irrigators' costs tend to conserve ground water by resetting the economic exhaustion level of the aquifer's water surface at shallower depths than the depths that would be attained where water mining rates go unregulated.

Conversely, the study results imply that public measures, such as the U.S. Internal Revenue Code's ground water depletion allowance, which lower irrigators' costs, tend to make mining of aquifers more rewarding for irrigators and, thus, tend to thwart the water conservation objective.

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