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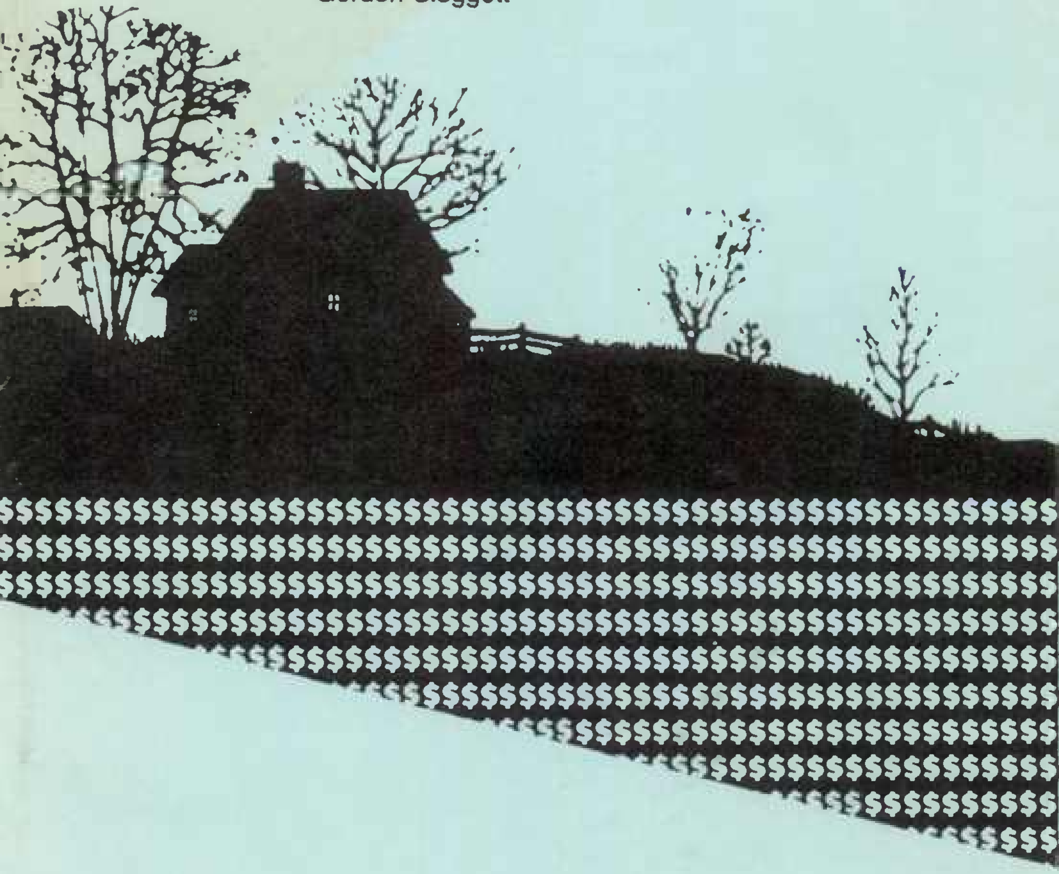
Prospects for Ground-Water Irrigation

Declining Levels and Rising Energy Costs

Gordon Sloggett



PROSPECTS FOR GROUND-WATER IRRIGATION: Declining Levels and Rising Energy Costs, by Gordon Sloggett, Natural Resource Economics Division, Economic Research Service, U.S. Department of Agriculture. Agricultural Economic Report No. 478

Abstract

Ground water, an irreplaceable resource tapped from underground reservoirs, is decreasing in 11 major irrigating States. Pumping from greater depths will add to irrigation fuel costs, but rising energy prices will likely be a more serious constraint to expanded ground-water irrigation. Declining ground-water levels may not significantly reduce the irrigated area in the United States until well into the next century.

Keywords: Ground water, irrigation, aquifer, energy.

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Summary

Ground-water levels are declining from a half foot to more than 6 feet under 15 million acres of irrigated land in the 11 major ground-water States reviewed in this report. Pumping from greater depths will add to irrigation fuel costs. However, rising energy prices could be an even more serious constraint to pump irrigators than the greater pumping depths. Farmers on the Texas High Plains saw electrical pump energy costs rise $4 per acre foot annually from 1973 to 1979. Dropping ground-water levels, averaging 2 feet per year, contributed only 20 cents to that annual increase.

Declining ground-water levels may not significantly reduce the irrigated area in the United States until well into the next century. Irrigated areas in the Texas High Plains, the largest contiguous area of ground-water decline in the Nation, are expected to decline by as much as 50 percent by the year 2020, largely because of a seriously depleted aquifer.

This report defines regions of ground-water decline, including areas and crops irrigated, rates of decline, and pumping lift. It also analyzes the effects of declining ground-water levels and increasing energy prices on pumping costs, and discusses possible implications for U.S. irrigated agriculture and agricultural production.

Crops grown in significant quantities in areas of ground-water decline include cotton, citrus, grapes, grain sorghum, and rice. Adjustments to current agricultural production of these crops must occur as irrigated acreage is lost. Some crops in the affected areas may be replaced with crops which do not need as much water. In some cases, nearby agricultural land can be expanded to continue growing the same crop. For example, rice production in Arkansas that relies on ground-water irrigation could be shifted to another rice growing part of the State, which contains sufficient land and water supplies.

Prospects for Ground-Water Irrigation

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Gordon Sloggett
agricultural economist

Introduction

Declining ground-water levels in 11 major irrigating States will likely hamper farming by the next century unless growers conserve the irreplaceable resource.

Water for irrigation in the United States comes from two sources—surface water and ground water. Surface water fills lakes, rivers, and streams and is annually replenished by melting snow, rainfall, and seepage from ground water. Ground water occurs in aquifers and it too is replenished by melting snow and rainfall but much more slowly than surface water.[1] Ground water, accumulated over millions of years, was not withdrawn in significant quantities until the development of high volume turbine water pumps about 50 years ago.

Land irrigated with ground water in the United States reached 32.3 million acres in 1977 *(5)*.[2] However, ground-water levels are in chronic decline for about 15 million of those acres.[3]

This report defines regions of ground-water decline, including areas and crops irrigated, rates of decline, and pumping lift. It also analyzes the effects of declining ground-water levels and increasing energy prices on pumping costs, and discusses possible implications for irrigated agriculture and agricultural production in the United States.

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[1]An aquifer is defined as earth sufficiently permeable to yield water to wells or springs. It may or may not be saturated with water. Further, an aquifer may be confined or unconfined. A confined aquifer is one in which water rises in a well drilled into the aquifer (artesian).

[2]Italicized numbers in parenthesis refer to items in the Bibliography.

[3]The Economic Development Administration (EDA) study of the Ogallala Aquifer in a six-State area of the central and southern High Plains is the latest and largest study of the economic depletion problem. Completion of that study is scheduled for 1982 at which time estimates will be available for when and how much economic depletion will occur in that area.

Prospects for Ground-Water Irrigation

The Problem

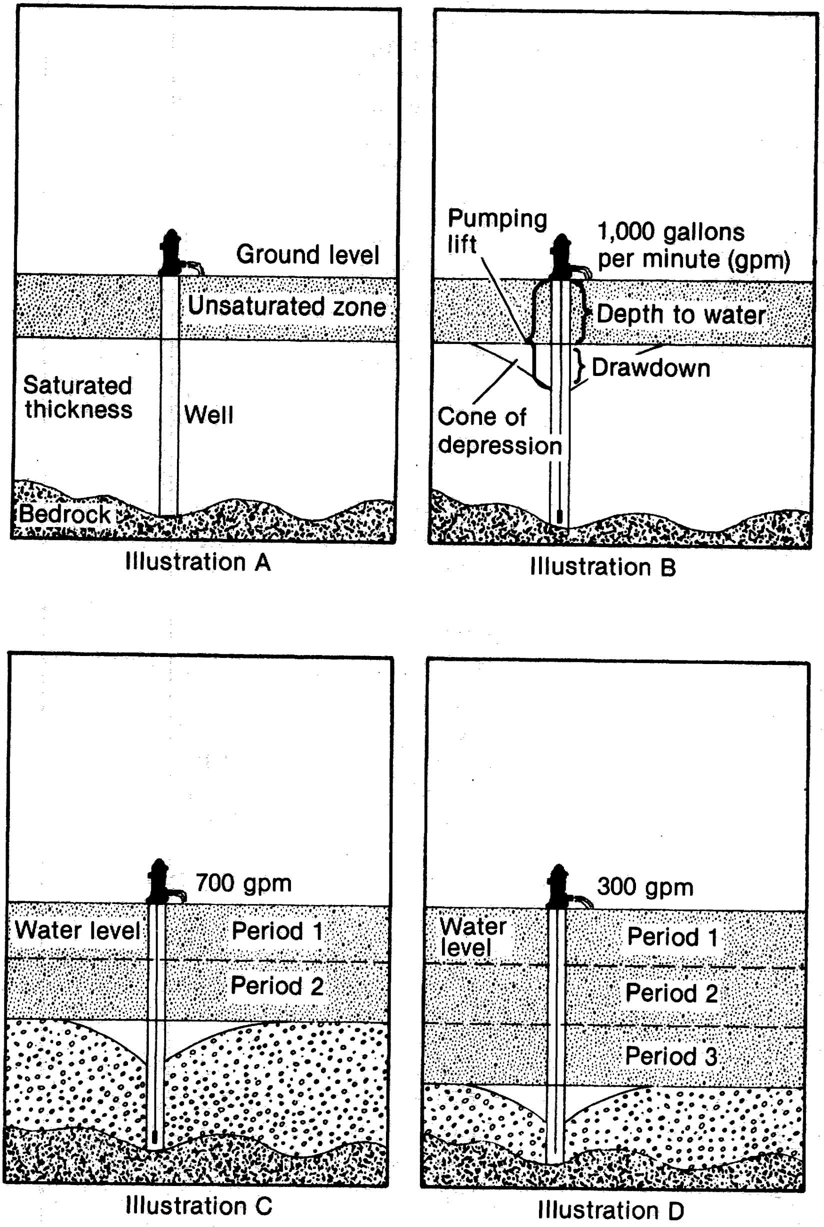
Ground water in areas of declining water levels is a stock resource—one which is not being replenished as fast as it is being withdrawn. Though some have argued that the irrigators should save that resource, the irrigators continue to use declining ground water because it is essentially a common resource. The irrigator's neighbors, who also irrigate, draw from the same resource, preventing a grower from saving a personal share. The irrigator seeking the highest possible income over time would have to control the quantity of ground water available in the future. Since individual irrigators cannot control their future ground-water supply, their best alternative is to earn as much as possible from year to year. Thus, little economic incentive exists for irrigators to cut back on ground-water use.

Declining ground-water levels may stop irrigation in two ways. First, receding ground-water supplies may dwindle until there is simply not enough water to meet crop water requirements. Second, irrigating with ground water may cease when increased pumping lifts render irrigation unprofitable; this possibility is enhanced as the cost of energy for pumping increases.

Factors that affect the cost of pumping ground water include the height the water must be raised (pumping lift), the quantity of water pumped, and the quantity of energy to operate the pump. Declining ground-water levels affect all three of these factors. Pumping lift increases as the water level falls. The well yields fewer gallons per minute (gpm) of water as the water level declines, making it necessary to pump longer to maintain the same quantity of water. Energy required for pumping an acre foot of water increases because of longer pumping times and increased pumping lift.

Figure 1 shows a cross section of the earth containing ground-water and a simplified version of what happens as water is withdrawn. Illustration A of figure 1 shows an unconfined aquifer, the unsaturated part of the aquifer, saturated thickness, and bedrock. The aquifer may consist of rock, sand, gravel, clay particles, or combinations thereof as well as other geologic materi-

Figure 1
Water Well Terminology and Declining Water Levels



als. The saturated thickness (that portion of the aquifer containing water) of an aquifer may range from less than a foot to thousands of feet. The thickness of the unsaturated zone and the depth to bedrock beneath it can vary significantly. Thus, depth to water and saturated thickness are generally inconsistent from well to well or aquifer to aquifer.

A well, motor, and pump are shown in illustration B (fig. 1). The cone of depression represents the surface of the water within the aquifer while the pump is operating. The well hole is encased with a pipe containing holes near the lower end. Water flows through the holes into the well casing. As water is pumped out of the casing, water in the aquifer nearest the well casing flows in first. The cone is formed because the water must flow around the sand, rock, and gravel in the aquifer. The size and shape of the cone of depression depend on the transmissive properties of the aquifer material and how the well was installed. An aquifer that is highly transmissive will generally have a very slight depression, while a poorly transmissive aquifer will have a large depression.

Illustrations C and D show a declining water level over time and its impact on well yield (fig. 1). Water flowing from the well in period 1 is 1,000 gpm. Well yield is reduced to 300 gpm in period 3. The water level in periods 2 and 3 depends upon length of time in each period and rate of decline. The rate of decline depends upon the quantity of water flowing into the aquifer (recharge), the quantity being discharged or pumped, and the physical properties of the aquifer.

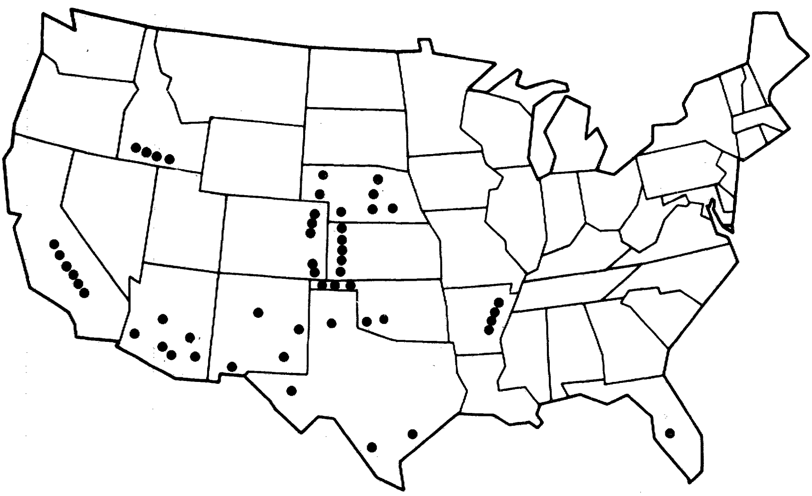
The declining well yields illustrated in figure 1 will eventually lead to insufficient water to meet crop water requirements. However, costs of pumping irrigation water may increase enough to make irrigation unprofitable before that time. The economic future of ground-water irrigation depends upon crop yields, energy and commodity prices, other production costs, and knowledge of individual aquifer characteristics. These are some of the variables being analyzed in the EDA High Plains study (see footnote 3). Only declining ground-water levels and energy prices and their relative effects on pumping costs are analyzed in this report.

Study Area and Data Sources

The U.S. Geological Survey (USGS) recently completed a survey of the Nation's ground-water resources *(8)*. That survey identified major areas of chronic ground-water level decline in 11 States, each of which irrigates more than 500,000 acres from ground water (fig. 2). Specific locations for each State are shown in appendix 1. These 11 States included 90 percent of the 32.3 million acres irrigated from ground water in 1977 *(5)*. Most States with fewer than 500,000 acres irrigated with ground water had no areas of chronic ground-water decline.[4]

[4]Washington and Oregon had some relatively small areas of ground-water decline *(8)*.

Figure 2
Major Ground Water Decline Areas in the United States



Prospects for Ground-Water Irrigation

The USGS national survey reported only very general data for ground-water decline areas. More specific information was obtained from reports by USDA, USGS, agricultural experiment stations, State and local water agencies, and personal communications with State irrigation specialists and hydrologists. Four items were estimated for each ground-water decline area in each of the 11 States: acreage irrigated, crops irrigated, pumping lift, and annual rate of decline.

Irrigated Decline Areas

Irrigated acres overlying ground-water decline areas are estimated in the appendix tables. Only areas where the average annual decline rate exceeds a half foot per year are included because of difficulties in defining areas with a smaller rate of decline. The process of estimating the land irrigated in ground-water decline areas differed considerably among the States. For example, nearly all of the ground-water irrigated area in the Texas and Oklahoma Panhandles, eastern Colorado, and western Kansas is experiencing a declining water level; thus, the estimates were not difficult to make. However, in Nebraska and California, surface water imported from plentiful ground-water sections into declining ground-water irrigation areas has stabilized the water level in some parts. Thus, areas of ground-water decline were intermingled with areas where levels were not declining.

Only those 11-State decline areas identified from published sources are included in this study. Areas not so identified were assumed to be either too small or their rate of decline too gradual to cause great concern.

Crops in Decline Areas

Very little irrigated crop data were available for specific ground-water decline areas. However, countywide irrigated crop data were available from USDA, State water agencies, or irrigation specialists. County irrigated crop distribution was assumed to be the same for the decline area within that county—an accurate assumption where ground-water levels are falling in an entire ground-water irrigated area such as western Kansas and the Texas and Oklahoma Panhandles. However, in areas containing only some ground-water level decline, or where surface water is also used for irrigation, the assumed crop distribution data may be subject to error.

Pumping Lift

Pumping lift is the static water level distance plus drawdown. Static water level in a well is the distance from ground level to water level when no water is being pumped. These measurements are taken annually by USGS and State and local water agencies. Drawdown is the difference between static water level and the water level in the well when it is being pumped (see fig. 1, illustration B). Pumping lift varies between, and within, the ground-water decline areas because of differences in static water levels and in drawdown. Drawdown may vary because of differences in the water bearing material (aquifer), well design, pumping rate, and other technical factors. Data on drawdown are not generally available. Therefore, unless otherwise noted in the appendix tables, drawdown was assumed to be 10 percent of the static water level.[5]

Annual Rate of Decline

Year-to-year differences in static water levels were used to estimate rates of decline. Many different data sources were used for these estimates, but the most recent 5-year period was used, when available, to estimate the annual rate of decline. Variations in decline rates between years and within areas is commonplace. Decline rates vary with rainfall each year; in wet years, irrigation requirements are usually less, and more water is available to recharge the aquifer (but not enough to overcome the long-term decline). The opposite, of course, is true for dry years. Also, decline rates vary within an area for several other reasons, including density of irrigation wells, structure of the aquifer and the permeability of the unsaturated zone overlying the aquifer

[5]Drawdown varies significantly from aquifer to aquifer, but a 10-percent drawdown is not unusual. The noted differences in the appendix tables were suggested by hydrologists.

which affects the recharge rate, and different water requirements among the crops irrigated. The annual rate of decline may also vary significantly between confined and unconfined aquifers (see app. table 6 as an example).

An average was calculated for pumping lift and for annual rate of decline for each of the study areas. Again, pumping lift and annual rate of decline can and do differ significantly within an area. However, considering the difficulty of finding and presenting such detail for this report, an average for each of the areas would be appropriate as a means of making general comparisons among decline areas.

Results

Ground-water levels are declining beneath more than 15 million acres of irrigated land at a rate of from a half foot to over 6 feet per year. Some ground-water irrigated land could revert to dryland production if irrigation becomes impractical. Other crops, however, require irrigation and would have to shift to other irrigated land.

Areas

A summary of the decline areas irrigated for the 11 major ground-water irrigation States is shown in table 1. The 28.9 million acres irrigated with ground water in those States represent nearly 90 percent of all land irrigated with ground water in the United States. Ground-water levels are declining beneath more than 15 million acres of irrigated land which is at least 53 percent of all the area irrigated with ground water in 1977. Ground-water decline areas, acres irrigated, crops irrigated, average feet of lift, and average annual decline in each area of each State in the study are shown in the appendix tables.

As more ground water is used for irrigation, and as the land irrigated with ground water expands, the decline area irrigated will also expand. Of course, at some point, declining ground water will force costs too high and the area irrigated with ground water will begin to decline, a process gradually beginning in the Texas High Plains *(2)*. Nonetheless, irrigation from ground water is currently expanding and areas where problems will occur can be identified *(5)*.

At least 65 percent of the ground-water irrigated area in Arizona, Kansas, New Mexico, Oklahoma, and Texas is suffering declining ground-water levels. A Texas High Plains study estimates that 57 percent of its available ground-water supply will be depleted by the year 2020 *(9)*. California is currently transferring surface water into some of its ground-water decline areas. An Arizona project is under construction to divert Colorado River water for irrigation and municipal use. Surface-water import plans have been made but not implemented in Texas and Oklahoma. Thus, the impact of declining ground-water levels will be reduced in parts of California and Arizona and perhaps in Texas and Oklahoma. However, declining ground-water levels will continue in those States because more ground water is being used than is being replenished.

Table 1—Area irrigated with declining ground-water supplies in 11 major ground-water irrigation States, 1977

State	Total ground-water irrigation [1]	Decline area irrigated [1]	Percentage of total acres irrigated by declining ground-water areas
	1,000 acres		*Percent*
Arkansas	1,400	407	29
Arizona	940	734	78
California	4,388	1,814	41
Colorado	1,650	570	35
Florida	1,076	250	23
Idaho	1,149	150	12
Kansas	3,083	1,995	65
Nebraska	5,855	1,842	32
New Mexico	760	560	75
Oklahoma	730	507	70
Texas	7,846	6,425	82
Total	28,877	15,254	53

[1]Only areas experiencing at least a half-foot average annual decline are included (see app. 1).

Source: Column 1 data from *(5)*.

Prospects for Ground-Water Irrigation

Crops

Declining ground-water levels will reduce some irrigated crop acreages in the areas affected. Individual crops irrigated in decline areas are compared to U.S. total harvested crop acreages in table 2. Harvested acreage of five crops—cotton, grain sorghum, rice, citrus, and grapes—in the affected areas exceeded 10 percent of the nationwide harvested acreage of each of those crops in 1978. Thus, some production adjustments in the affected crops will occur when irrigation is no longer feasible. The adjustments may be either growing the same crop under dryland conditions, or shifting to a different crop that can be grown with available natural moisture, or going out of crop production.

A feasible alternative to irrigated corn is dryland corn in much of Nebraska (table 3). The same alternative exists for irrigated cotton and grain sorghum in much of Texas. Irrigated wheat would likely go to dryland wheat in all but Arizona and California. Nearly all of the corn and alfalfa grown in ground-water irrigated States, except Nebraska, would not be grown at all

Table 2—Crops harvested in the United States and in areas of ground-water decline, 1978

Crop	Total U.S. acres harvested [1]	Acres harvested in decline areas [2]	Percentage of decline area from total acres harvested
	1,000 acres		*Percent*
Alfalfa	27,657	947	3.4
Barley	9,247	329	3.6
Cotton	12,370	2,572	20.8
Corn	12,370	2,572	20.8
Citrus	[3]1,262	200	15.8
Grapes	[3]712	206	28.9
Grain sorghum	15,800	2,191	13.9
Peanuts	1,511	52	3.4
Rice	2,970	425	14.3
Wheat	57,100	2,096	3.7

[1]Includes irrigated and nonirrigated acres, *Agricultural Statistics*, U.S. Dept Agr.
[2]See appendix tables.
[3]1974 Census of Agriculture.

Table 3—Crops irrigated in areas of ground-water decline in major ground-water irrigation States, 1978

State	Alfalfa	Barley	Cotton	Corn	Citrus	Grapes	Grain sorghum	Peanuts	Rice	Wheat	Other	Total
						1,000 acres						
Arizona	125	50	237	—	—	—	86	—	—	166	70	734
Arkansas	—	—	12	—	—	—	—	—	256	—	[1]139	407
California	248	227	490	61	—	206	—	—	—	163	419	1,814
Colorado	58	—	—	337	—	—	32	—	—	38	105	570
Florida	—	—	—	—	200	—	—	—	—	—	50	250
Idaho	—	29	—	—	—	—	—	—	—	53	68	150
Kansas	161	—	—	964	—	—	464	—	—	352	54	1,995
Nebraska	42	—	—	1,391	—	—	96	—	—	27	[2]286	1,842
New Mexico	108	23	102	60	—	—	112	—	—	86	69	560
Oklahoma	39	—	21	73	—	—	179	32	—	126	37	507
Texas	166	—	1,710	1,496	—	—	1,222	20	169	1,085	557	6,425
Total	947	329	2,572	4,382	200	206	2,191	52	425	2,096	1,854	15,254

— = no irrigated crops.
[1]Includes 117,000 acres of soybeans.
[2]Includes land that could be irrigated but may not have been in 1978.

Source: See app. tables.

without irrigation because rainfall is insufficient for dryland production (table 3). Much of the acreage devoted to irrigated corn and alfalfa in Colorado, Kansas, New Mexico, Oklahoma, and Texas would likely go into dryland grain sorghum or wheat.

Essentially no crops can be produced without irrigation in the desert areas of Arizona, California, and New Mexico. Rice in Arkansas and Texas, citrus in Florida, and grapes in California would not be grown because irrigation is essential to their production.

Crop production adjustments resulting from declining ground-water levels will occur very gradually. Adequate time exists to relocate crops to areas that will support production. For example, areas in California with adequate water supplies could pick up any lost grape and citrus production. Arkansas and Texas could transfer rice production, or other rice producing sections of the States could increase output. Grain crops could be transferred to other grain producing areas. The exact shifts in crop production caused by declining ground-water levels would require a knowledge of, among other things, when, where, and which crops would need to be shifted, and which cost/price relationships exist at that time.

Increasing Lifts

A summary of the ranges in average pumping lift and average annual decline is shown in table 4. The ranges are averages for each decline area in the State (see app. tables). For example, in Arkansas, average pumping lift in one decline area is 30 feet, while in another it is 75 feet. This does not mean that the average feet of lift is between 30 and 75. Average annual rates of decline should be interpreted the same way. Average pumping lifts range from 30 feet in Arkansas to 535 feet in Arizona, and annual rates of decline vary from a half foot in Arkansas and Nebraska to 6.6 feet in California.

Pumping Costs

Ground water will no longer be used for irrigation when total production costs, including pumping costs, exceed the returns from irrigation. Pumping cost increases due to declining ground-water levels have been less than those caused by rising energy prices. Since pump energy cost is a major portion of variable production costs, significant commodity price increases will be required to allow pump irrigators to cover their costs.

Energy Requirements

Energy requirements for pumping ground water for irrigation appear in table 5. The energy requirement for pumping a given quantity of water 500 feet is 10 times as great as for 50 feet. An average annual ground-water decline of 5 feet for 10 years would double energy use for the irrigator pumping water from 50 feet but would increase energy use by only 10 percent for the irrigator pumping from 500 feet. The absolute change in energy use

Table 4—Lift and rate of decline for areas of ground-water loss in major ground-water irrigated States, 1978[1]

State	Average pumping lift	Average annual rate of decline
	Feet	
Arkansas	30 to 75	0.5 to 1
Arizona,	75 to 535	2 to 3
California	75 to 300	2 to 5
Colorado	175 to 270	2
Florida	100	2.5
Idaho	50 to 400	2 to 5
Kansas	175 to 250	1 to 4
Nebraska	25 to 250	.5 to 2
New Mexico	75 to 225	1 to 2.5
Oklahoma	200 to 275	1 to 2.5
Texas	75 to 225	1 to 4

[1]The amount of lift and the annual rate of decline are the ranges of averages in the States. It does not indicate that the State average is between the two rates.

would be the same in both cases, but the irrigator whose energy use doubled would be more aware of the change. An average annual decline of a half foot per year for 10 years would be only a 10-percent change for the 50-foot lift and 1 percent for the 500-foot lift. This small rate of change in energy use in the latter case would hardly be noticed by most irrigators.

Figure 3 displays changes in pump energy cost per acre foot for two average annual rates of ground-water decline. At the high rate of decline, the added pump energy cost per acre foot each year would be 35 cents for electricity and 22 cents for natural gas. At the lower rate of decline, the added cost would be 3.5 cents and 0.02 cent annually for electricity and natural gas, respectively.

Energy Prices

Pump energy cost changes due to declining water levels were calculated using constant 1977 prices (fig. 3). However, energy prices have risen sharply since 1973 (table 6). Natural gas prices have quadrupled, and other energy prices have more than doubled.

Figure 4 displays changes in pump energy cost per acre foot due to price changes from 1973-79, assuming 100 feet of lift. Energy

Table 5—Energy requirements for pumping 1 acre foot of water for selected feet of lift [1]

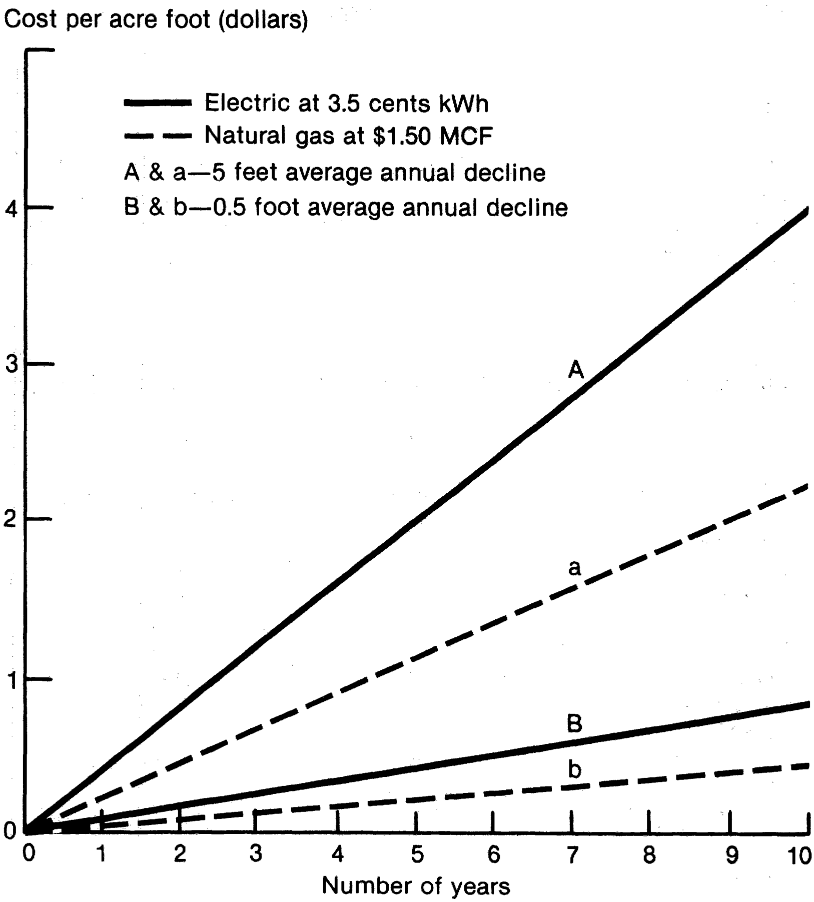
Energy	Unit	Feet of lift [2]			
		50	100	250	500
Electricity	kWh	100	199	498	995
Natural gas	MCF[3]	1.5	3	7.5	15
Diesel	gal.	9.5	19	47.5	95

[1]An acre foot is 1 foot of water covering 1 acre of land.
[2]A 60-percent pump efficiency is assumed.
[3]MCF=1,000 cubic feet.

Source: *(5)*.

costs for pumping 1 acre foot increased from $4.58 to $9.95 for electricity and from $1.50 to $6.00 for natural gas during the period. Average annual increases were 89 cents and 75 cents for electricity and natural gas, respectively. Energy price changes at constant water levels triggered these higher pump energy costs.

Figure 3
Annual Energy Cost Changes Per Acre Foot Due to Declining Water Levels, 1977 Prices



Energy prices have been the largest contributor to increased pump energy costs. A typical ground-water decline rate of 2 feet per year would result in an annual pump energy cost increase of only 14 cents per acre foot with electricity prices at 3.5 cents per kWh (table 4). Electric pump energy cost from 1973-79 increased 89 cents per acre foot annually. The contrast for other energy sources is similar to electricity. Since 1973, increased energy prices have spurred pumping costs more than have increased pumping lifts due to declining ground-water levels.

Cost of Production

To determine the effect that declining water levels and increasing energy prices have on production costs in irrigated agriculture, it is necessary to look at the cost of producing some selected irrigated crops. Variable costs with and without pump energy costs for producing wheat and grain sorghum in Arizona and Texas are shown in table 7.

A typical average annual rate of decline for ground-water irrigators is 2 feet in Texas and 3 feet in Arizona. Using 1977 prices,

Table 6—Selected energy prices in the United States

Item	Unit	1973	1975	1977	1979	Change 1973-79
		Dollars				*Percent*
Electricity	kWh	0.023	0.030	0.035	0.05	117
Natural gas	MCF	.50	1.00	1.50	2.00	300
Diesel	gal.	.23	.39	.45	.72	213
Gasoline	do.	.33	.52	.58	.83	152
Liquified petroleum gas	do.	.20	.30	.39	.44	120

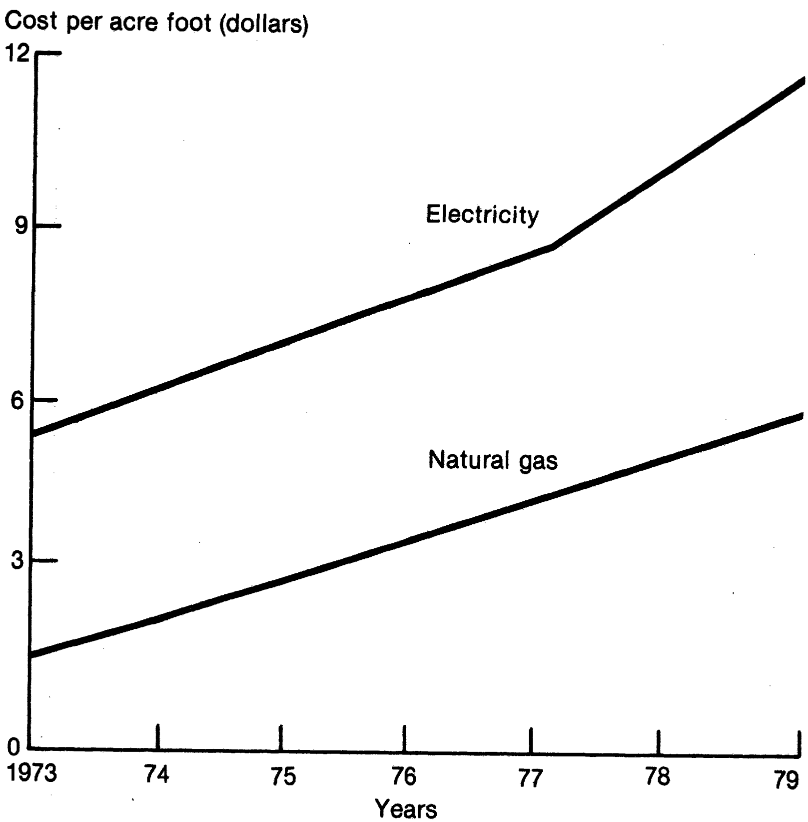
Source: *(6)* and private communication with electric and natural gas suppliers.

1-year electric energy pumping costs to irrigate grain sorghum increase by 23 cents per acre in Texas and 67 cents per acre in Arizona due to declining ground-water levels.[6] The same calculation for natural gas shows increases of 14 cents per acre for Texas and 43 cents per acre for Arizona. Such a small change in

[6]This was determined by dividing pumping energy cost by feet of lift and multiplying by average annual decline (table 4). For example, Arizona grain sorghum would be ($163-$107)÷250×3=67 cents.

Figure 4

Energy Cost for Pumping 1 Acre Foot of Water 100 Feet, 1973-79 Prices



year-to-year production costs caused by typical ground-water decline rates in either State is not likely to change irrigation practices immediately.

The current effect of declining ground-water levels on production costs is rather small. Increasing energy prices have had the most significant impact on production costs. Pump energy cost changes from 1973 to 1979 for the 250-feet-of-lift examples in table 7 are shown in table 8. For example, the combined effect of declining ground-water levels and increased electric energy prices has resulted in an average annual increase of $8 in the cost of producing grain sorghum in Arizona.

Table 7—Variable costs of production per acre for selected irrigated crops and selected feet of lift in Texas and Arizona, 1977

State and crop	Water pump	Variable costs without pump energy	Variable costs with pump energy[1]	
			250-foot lift	500-foot lift
	Acre ft.	*Dollars*		
Grain sorghum:				
Arizona	3.2	107	163	219
			[2](143)	[2](179)
Texas	1.6	87	115	133
			[2](105)	[2](123)
Wheat:				
Arizona	3.3	110	168	225
			[2](147)	[2](185)
Texas	1.0	67	84	105
			[2] (79)	[2] (98)

[1]Cost of pump energy is determined by quantity of energy used per acre per foot of lift multiplied by cents per kWh for electricity and $1.50 per MCF for natural gas, and then multiplying by the acre feet of water pumped per acre.
[2]Variable costs using natural gas are shown in parentheses *(5)*.

Source: *(7)*.

Declining ground-water levels and increasing energy prices are likely to continue. Ground-water irrigation has been increasing in many areas, including some areas where water levels are falling and energy prices are rising. Analysts peg electric rates at 0.098 cent per kWh and natural gas prices at $12.25 per 1,000 cubic feet (MCF) for 1990 *(3,4)*. Projecting the data in table 8 to 1990 for wheat in Texas and grain sorghum in Arizona shows electric pump energy costs of $54 and $186, respectively. The projected $54 electric pump energy cost is a $29-increase from the 1979 pump energy cost. If the 1978 yield of 32 bushels per acre does not increase, price per bushel would have to rise by 91 cents just to cover increased pump energy costs *(7)*. The Arizona grain sorghum electric pump energy cost would increase by $105. If the 1978 yield of 78 bushels does not increase, the price per bushel would have to rise by $1.35 to cover the increased cost of electric pump energy *(7)*. Using similar calculations, Texas wheat would need to increase by $2.56 a bushel and Arizona grain sorghum by $3.21 a bushel to cover the added costs of pumping with natural gas by 1990.

Table 8—Pump energy costs per acre for selected crops in Texas and Arizona, 1973-79[1]

Crops	Electricity			Natural gas		
	1973	1979	Annual change	1973	1979	Annual change
			Dollars			
Grain sorghum:						
Arizona	35	81	8	11	49	6
Texas	17	41	4	6	24	3
Wheat:						
Arizona	36	84	8	12	51	7
Texas	10	25	3	4	16	2

[1]Pumping lift in Arizona was assumed to be 238 feet in 1973 and 256 feet in 1979. Texas lifts were 242 and 254 feet. Costs were calculated using energy prices from table 6 and energy use from table 5. All numbers are rounded to the nearest dollar.

Areas with lower pumping lifts and slower rates of decline would not require as large an increase in commodity prices to cover increased pumping costs. Substantial commodity price increases will still be necessary, however, to cover pump energy cost increases as well as cost increases of nearly all inputs.

Conclusions

Over 15 million acres of U.S. ground-water irrigated land are experiencing declining water levels above a half foot per year. Average annual rates of decline range up to 6.6 feet per year in the 11-State study area. Declining water levels lead to increased pumping costs and the eventual depletion of the ground-water resource. Only one major irrigated area (some counties in the Texas High Plains) is suffering from ground-water depletion, although some isolated smaller areas, such as West Central Kansas, have essentially depleted ground water. However, analysts see significant quantities of ground water available for irrigation beyond the year 2020, even in the Texas High Plains.

Experts are uncertain whether running out of sufficient quantities of water or high energy prices will force pumping halts. Both situations have stopped irrigation in the past. The decline in irrigation in the Texas High Plains was traced to ground-water depletion. Many pump irrigators in the Trans-Pecos region of Texas had to quit irrigating when their energy prices increased, although sufficient water was available.

Areas showing rapid rates of decline and high pumping lifts will likely be the next regions to lose irrigated acreage. Higher energy prices, rather than dwindling water supplies, will likely trigger the decline. Energy price rises have affected production costs more than declining ground-water levels. States containing significant areas of high pumping lifts (more than 200 feet) and rapid rates of decline (more than 3 feet) include parts of Arizona, California, Idaho, Kansas, Texas, and the Oklahoma Panhandle.

The most abundant crops grown in areas most likely to experience a decline in irrigated acreage include cotton, citrus, grapes, grain sorghum, and rice. Growers must adjust production to maintain current production levels. Some of the cotton and grain sorghum irrigated acreage will revert to dryland, and areas of comparative advantage may pick up the remaining shortfall. Citrus, grapes, and rice require irrigation, so a shift to other irrigated land will be necessary to save crops. These high value crops will probably displace some lower value irrigated crops.

Adjustments in U.S. agricultural production because of declining ground-water levels will not occur abruptly. Even the rapid rise in energy prices since 1973 has failed to stem production of ground-water irrigated crops. Ground-water irrigation has been increasing, despite declining water levels and increased energy prices.

Land taken out of irrigation has been offset by newly irrigated land. However, substantial commodity price increases will be necessary for this trend to continue.

Research is needed to address the following questions:

- What is the potential for adding more irrigated land, and at what cost?
- What cost/price relationships will be necessary to maintain a given level of irrigated agricultural production?
- What effect would increased irrigation and/or energy efficiency or increased yields have on extending the economic life of our aquifers?
- What effect would increased commodity prices have on the cultivation of marginal land now in pasture?

Bibliography

(1) Brantwood Publications. *Irrigation Journal*, annual survey issues, Nov.-Dec., 1975 and 1978. Elm Grove, Wisc.

(2) New, Leon. "High Plains Irrigation Survey." Annual survey through 1978. Agr. Ext. Serv., Texas A&M Univ.

(3) Sanders, Bernard. "Availability and Price of Various Power Sources for Irrigation, Diesel." Paper presented at the 1980 Western Irrigation Forum, Tri-State Generation and Transmission Association, Inc., Denver, Colo., Jan. 1980.

(4) Selby, James. "Availability and Price of Various Power Sources for Irrigation, Electric." Paper presented at the 1980 Western Irrigation Forum, Tri-State Generation and Transmission Association, Inc., Denver, Colo., Jan. 1980.

(5) Sloggett, Gordon. *Energy and U.S. Agriculture: Irrigation Pumping 1974-77*. AER-436. U.S. Dept. Agr., Econ. Stat. Coop. Serv., Sept. 1979.

(6) U.S. Department of Agriculture, Economics, Statistics, and Cooperatives Service. *Agricultural Prices*. 1973-79.

(7) ________, Economics, Statistics, and Cooperatives Service. "Firm Enterprise Data System." Cooperatives, Oklahoma State Univ., 1977.

(8) U.S. Department of Interior, U.S. Geological Survey. "Summary Appraisals of the Nation's Groundwater Resources." Professional Paper Series 813-A-S, 1974-79.

(9) Wyatt, A.W. *TWDB High Plains Study*. Texas Water Development Board, Austin, Tex., Sept. 1974.

(10) *Arizona*

Denis, E.E. *Maps Showing Groundwater Conditions in the Harquahala Plains Area, Maricopa and Yuma Counties, AZ 1975.* WRI 76-33. U.S. Dept. Int., USGS, Tucson, Ariz. 1976.

Horner, Jerry. *Irrigation in Arizona and California.* Unpublished report. U.S. Dept. Agr., Econ. Stat. Coop. Serv., Davis, Calif., 1979.

Laney, R.L., and others. *Maps Showing Water Level Declines, Land Subsidence, and Earth Fissures in South Central Arizona.* WRI 78-33. U.S. Dept. Int., USGS. Tucson, Ariz., June 1978.

Stalik, R.S., and R.L. Laney. *Maps Showing Groundwater Conditions in Lower Hassayampa Area, Maricopa County, AZ-1975.* WRI 76-35. U.S. Dept. Int., USGS. Tucson, Ariz., Apr. 1976.

U.S. Department of Interior, U.S. Geological Survey. *Annual Summary of Groundwater in Arizona.* WRI 78-144. Tucson, Ariz., 1978.

Wilking, D.W., and W.C. Webb. *Maps Showing Groundwater Conditions in the Ranegras Plain Butler Valley Areas, Yuma County, AZ, 1974.* WRI 76-34. U.S. Dept. Int., USGS. Tucson, Ariz., Apr. 1976.

Wilson, R.P., and Natalie D. White. *Maps Showing Groundwater Conditions in the San-Simon Area, Cochise and Graham Counties, AZ and in Hidalgo County, N.M., 1975.* WRI 76-89. U.S. Dept. Int., USGS. Tucson, Ariz., July 1976.

(11) *Arkansas*

Halberg, H.N., and J.E. Reed. *Groundwater Resources of Eastern Arkansas in the Vicinity of U.S. Highway 70.* Water Supply Paper 1779-V. U.S. Dept. Int., USGS. 1964.

Plebuch, R.O. *Changes in Groundwater Levels in Deposits of Quarternary Age in Northeastern Arkansas.* Water Resources Summary No. 3. U.S. Dept. Int., USGS. 1962.

Shulstad, Robert N., and others. *Arkansas State Water Plan, Water and Related Land Resources.* Agriculture Experiment Station, Fayetteville, Ark., Appendix "B", Supplement "1", Special Report No. 61, Apr. 1978.

U.S. Department of Agriculture, Cooperative Extension Service. *Arkansas Irrigation Survey, 1975.* Univ. of Arkansas, 1975.

Wastefield, P.W. *Well Records, Water-Level Measurements, Logs of Test Holes, and Chemical Analysis in the Cache River Alluvial Aquifer-Stream System, Northeast Arkansas, 1946-1976.* OFR 77-402. U.S. Dept. Int., USGS. Little Rock, Ark. May 1977.

(12)*California*

California Department of Water Resources. *California's Ground Water.* Bulletin 118. Sept. 1975.

———. *Ground Water Basins in California.* Bulletin 118-80. Jan. 1980.

———. *The 1976-77 California Drought.* May 1978.

Knutson, G.D., and others. *Pumping Energy Requirements for Irrigation in California.* Spec. Pub. 3215. Div. Atr. Sci., Univ. of California. July 1977.

Stewart, J.E. *Irrigation in California.* Report to Land, Air and Water Resources, Univ. of California-Davis, June 1975.

U.S. Department of Interior, Bureau of Reclamation. *Special Task Force Report on San Luis Unit.* 1978.

(13) *Colorado*

Borman, R.G., and T.J. Major. *Water Level Changes in the Northern High Plains of Colorado 1964-76 and 1972-76.* WRI 77-42. And private communication, U.S. Dept. Int., USGS. Lakewood, Colo., Nov. 1977.

Hershey, L.A., and E.R. Hampton. *Geohydrology of Baca and Southern Prowers Counties, Southeastern Colorado.* WRI 16-74. U.S. Dept. Int., USGS. Aug. 1974.

Hofstra, W.E., and others. *Colorado Water Resources Basic Data Release.* No. 23, No. 28, No. 33. U.S. Dept. Int., USGS. In cooperation with the Colorado Water Conservation Board, 1973-75.

Konrad, Dwayne. Private communication. Ext. Serv., Colorado State Univ.

Luckey, R.R., and others. *Colorado Water Resources Circular.* No. 19, No. 24, No. 34. U.S. Dept. Int., USGS. In cooperation with the Colorado Water Conservation Board, 1973-75.

Major, Thomas. *Selected Water Level Changes in Colorado 1970-74, Basic Data Release No. 34.* Colorado Water Conservation Board, Denver, Colo., 1974.

(14) *Florida*

Healy, Henry G. *Water Levels in Artesian and Nonartesian Aquifers of Florida, 1975-76.* OFR 78-458. U.S. Dept. Int., USGS. May 1978.

Leach, S.D., and Henry G. Healy. *Estimated Water Use in Florida, 1977.* WRI 79-112. U.S. Dept. Int., USGS. Jan. 1980.

Mills, L.R., and C.P. Laughlin. *Potentiometric Surface of Floridan Aquifer, May 1975, and Charge of Potentiometric Surface 1969 to 1975, Southwest Management District and Adjacent Areas.* WRI 76-80. U.S. Dept. Int., USGS. 1976. .

Steward, J.W., and others. *Potentiometric Surface and Areas of Artesian Flow, May 1969, and Change of Potentiometric Surface 1964 to 1969, Floridan Aquifer, Southwest Florida Water Management District, Florida.* HA-440. U.S. Dept. Int., USGS. 1971.

(15) *Idaho*

Idaho Department of Water Resources. *County Water Related Land Use, 1975.* In cooperation with Pacific Northwest Regional Commission, Aug. 1978.

Idaho Department of Reclamation. *Goose Creek-Rock Creek Area of Idaho and Nevada.* Water Info. Bull. No. 9., Feb. 1969.

Idaho Department of Water Administration. *The Raft River Basin, Idaho-Utah.* Water Info. Bull. No. 19., Aug. 1979.

Idaho Department of Water Resources. County Land Use Maps, 1978.

_____ Critical Ground Water Area Maps.

_____ Water Level Records, 1972-79.

(16) *Kansas*

Hay, D. *1978 Kansas Irrigation Survey.* Engineering Newsletter. Extension Agricultural Engineering, Manhattan, Kans., 1979.

Pabst, M., and E. Jenkins. *Water-Level Changes in Northwestern Kansas.* Kansas Geological Survey Journal, Dec. 1976.

———. *Water-Level Changes in West Central Kansas.* Kansas Geological Survey Journal, Oct. 1977.

———. *Water-Level Changes in Southwestern Kansas.* Kansas Geological Survey Journal, May 1979.

(17) *Nebraska*

Conservation and Survey Division, Univ. of Nebraska. *Map-Location of Registered Irrigation Wells in Nebraska.* In cooperation with USGS. 1979.

———. *Map-Significant Rises and Declines in Nebraska Groundwater Levels, Fall 1978.* In cooperation with USGS. 1978.

Nebraska Agricultural Statistics, 1978. Nebraska Department of Agriculture. In cooperation with Econ. Stat. Coop. Serv., USDA. June 1979.

Pederson, D., and M. Johnson. *Groundwater Levels in Nebraska, 1978.* Nebraska Water Survey, Cons. Sur. Div. Paper 49, July 1979.

(18) *New Mexico*

Hudson, J.D. *Ground Water Levels in New Mexico, 1976.* Basic Data Report. U.S. Dept. Int., USGS. New Mexico State Engineer, Sante Fe, N.M., 1978.

Lansford, Robert, and others. *Sources of Irrigation Water and Irrigated and Dryland Acreages in New Mexico, by County, 1972-77.* Res. Rep. 377. New Mexico Agricultural Experiment Station, Las Cruces, N.M., July 1978.

Sorensen, Earl. *Water Use by Categories in New Mexico Counties and River Basins and Irrigated and Dryland Cropland Acreage in 1975.* Tech. Rep. 41, New Mexico State Engineer, Sante Fe, N.M., 1977.

(19) *Oklahoma*

Goemaat, Robert L. *Selected Water Level Records for Western Oklahoma, 1950-75.* ORF 77-73. U.S. Dept. Int., USGS. Jan. 1977.

Hart, D.L., and others. *Geohydrology of the Oklahoma Panhandle, Beaver, Cimarron, and Texas Counties.* WRI 25-75. U.S. Dept. Int., USGS. Apr. 1976.

Morton, Robert B. *Digital-Model Projection of Saturated Thickness and Recoverable Water in the Ogallala Aquifer, Texas County, Oklahoma.* OFR 79-565. U.S. Dept. Int., Jan. 1980.

Schwab, Delbert. *1979 Irrigation Survey.* Coop. Ext. Serv., Oklahoma State Univ., 1980.

(20) *Texas*

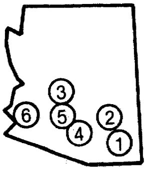
Texas Department of Water Resources. *County Water Level Measurements.* Unpublished computer printout data through 1978.

Texas Water Development Board. *Groundwater Resources of the Carrizo Aquifer in the Winter Garden Area of Texas,* Vols. 1 and 2., Sept. 1976 and Apr. 1977.

_____ *Inventories of Irrigation in Texas 1958-72.* Report 196, 1975.

Appendix I—Tables

Pages 5 through 8 of the text contain the source and method of determining the content of the material presented in the appendix. The numbers on the State maps refer to the numbered areas on the tables.



Arizona ground-water decline areas

Appendix table 1—Crops grown in areas of ground-water decline, Arizona, 1978

	County	Alfalfa	Barley	Cotton	Grain sorghum	Wheat	Other	Total
					1,000 acres			
1	Cochise	7	0	10	32	31	30	110
2	Graham	9	8	9	23	6	0	55
3	Maricopa	96	28	114	25	71	21	355
4	Pima	0	0	14	6	10	0	30
5	Pinal	13	14	86	0	48	19	180
6	Yuma	0	0	4	0	0	0	4
	Total	125	50	237	86	166	70	734

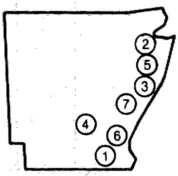
Source: Unpublished data supplied by Jerry Horner, USDA, ERS, Davis, Calif.

Appendix table 2—Size and characteristics of ground-water decline areas, Arizona

	County	Decline area irrigated	Lift	Average annual decline, 1973-78
		1,000 acres	---------------*Feet*---------------	
1	Cochise	110	375	2.5
2	Graham	[1]55	75	2
3	Maricopa	[1]355	275	3
4	Pima	30	350	3
5	Pinal	180	535	3
6	Yuma	4	375	2
	Total	734	NA	NA

NA=not applicable.
[1]Ground water and surface water are used conjunctively in two counties.

Source: *(10)*.



Arkansas ground-water decline areas

Appendix table 3—Crops grown in areas of ground-water decline, Arkansas, 1975

County	Cotton	Rice	Soybeans	Other	Total
			1,000 acres		
1 Arkansas	0	28	32	3	63
2 Craighead	3	20	20	3	46
3 Cross	1	42	18	4	65
4 Lonoke	7	28	20	5	60
5 Poinsett	0	70	4	12	86
6 Prairie	0	30	18	2	50
7 Woodruff	1	38	5	4	48
Total	12	256	117	33	418

Source: *(11)*.

Appendix table 4—Size and characteristics of ground-water decline areas, Arkansas, 1975

County	Decline area irrigated	Lift	Average annual decline
	1,000 acres	---------------*Feet*---------------	
1 Arkansas	63	60	0.5
2 Craighead	46	60	1
3 Cross	65	75	1
4 Lonoke	60	60	1
5 Poinsett	86	75	1
6 Prairie	50	30	1
7 Woodruff	48	30	.5
Total	418	NA	NA

NA=not applicable.

Source: *(11)*.

California ground-water decline areas

Appendix table 5—Crops grown in areas of ground-water decline, California, 1978

Area	Alfalfa	Barley	Corn	Cotton
	1,000 acres			
San Joaquin:				
1 East San Joaquin	22	13	31	0
2 Chowchilla	11	7	2	9
3 Madera	19	11	3	15
Tulare Basin:				
4 Kings	49	88	9	119
5 Tulare	28	45	4	81
6 Kaweah	21	11	3	37
7 Tule	25	13	4	44
8 Kern County	73	39	5	185
Total	248	227	61	490

Area	Grapes	Wheat	Other[1]	Total
	1,000 acres			
San Joaquin:				
1 East San Joaquin	22	16	76	180
2 Chowchilla	11	5	7	52
3 Madera	19	9	12	88
Tulare Basin:				
4 Kings	66	22	89	442
5 Tulare	2	38	15	213
6 Kaweah	19	18	53	162
7 Tule	23	21	60	190
8 Kern County	44	34	107	487
Total	206	163	419	1,814

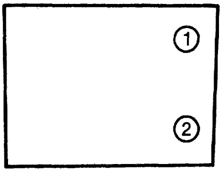
[1]Other includes crops that have less than 10 percent of the total acres irrigated.

Source: Unpublished data supplied by Jerry Horner, USDA, ERS, Davis, Calif.

Appendix table 6—Size and characteristics of ground-water decline areas, California, 1978

Area	Decline area irrigated	Lift[1]	Average annual decline[1]
	1,000 acres	*Feet*	
San Joaquin Basin:			
1 East San Joaquin	180	120	2.3
2 Chowchilla	[2]52	128	3.4
3 Madera	[2]88	128	2.7
Tulare Basin:			
4 Kings	442	98	2.1
5 Tulare	213	110 (unconfined)	2.6
		218 (confined)	6.6
6 Kaweah	162	96	1.1
7 Tule	190	128 (unconfined)	1.0
		221 (confined)	3.4
8 Kern County	[2]487	261	6.0
Total	1,814		NA

NA=not applicable.
[1]Data provided by private communication from Alex Williamson, USGS, Sacramento, Calif., Oct. 24, 1980. Feet of lift includes an average of 35 feet of drawdown.
[2]The Central Valley Project and the California Aqueduct are providing surface water to these critical areas. However, declining ground-water levels continue in these areas.



Colorado ground-water decline areas

Appendix 7—Crops grown in areas of ground-water decline, Colorado, 1978

Area	Alfalfa	Corn	Dry beans	Grain sorghum	Wheat	Other	Total
				1,000 acres			
1 Northern High Plains	32	318	20	7	24	74	475
2 Southern High Plains	26	19	0	25	14	11	95
Total	58	337	20	32	38	85	570

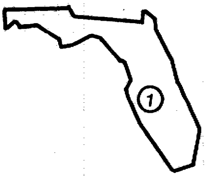
Source: Colorado 1978 Agricultural Statistics.

Appendix 8—Size and characteristics of ground-water decline areas, Colorado, 1978

Area	Decline area irrigated	Lift[1]	Average annual decline
	1,000 acres	---------------*Feet*---------------	
1 Northern High Plains	475	175	2
2 Southern High Plains	95	270	2
Total	570	NA	NA

NA=not applicable.
[1]Includes an average drawdown of 25 percent of static water levels. It may approach 80 percent in isolated areas. Communication with Dwayne Konrad, Crop Ext. Serv., Burlington, Colo., Oct. 28, 1980.

Source: *(13)*.



Florida ground-water decline areas

Appendix table 9—Crops grown in areas of ground-water decline, Florida, 1979

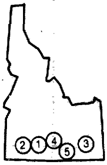
Area	Citrus	Pasture	Vegetables	Other	Total
			1,000 acres		
1 Southwest Florida Management District	200	20	20	10	250

Source: Unpublished data provided by the Southwest Florida Management District.

Appendix table 10—Size and characteristics of ground-water decline areas, Florida, 1979

Area	Decline area irrigated	Lift	Average annual decline, 1969-75
	1,000 acres	*Feet*	
1 Southwest Florida Management District	250	100	2.5

Source: *(14)*.



Idaho ground-water decline areas

Appendix table 11—Crops grown in areas of ground-water decline, Idaho, 1978

Area	Barley	Potatoes	Sugar beets	Wheat	Other	Total
			1,000 acres			
Critical areas[1]	29	21	29	53	18	150

[1]There were five critical ground-water areas identified: 1) Artesian City, 2) Blue Gulch, 3) Curlew Valley, 4) Oakley Kenyon, and 5) Raft River. Data sources did not allow for an individual listing of each area in the table.

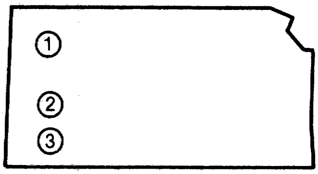
Source: *(5).*

Appendix table 12—Size and characteristics of ground-water decline areas, Idaho, 1978

Area	Decline area irrigated	Lift	Average annual decline
	1,000 acres	--------------*Feet*--------------	
Critical areas[1]	15	50 to 400	2 to 5

[1]There were five critical ground-water areas identified: 1) Artesian City, 2) Blue Gulch, 3) Curlew Valley, 4) Oakley Kenyon, and 5) Raft River. Data sources did not allow for an individual listing of each area in the table.

Source: *(15).*



Kansas ground-water decline areas

Appendix table 13—Crops irrigated in areas of ground-water decline, Kansas, 1978

Area	Alfalfa	Corn	Grain sorghum	Wheat	Other	Total
			1,000 acres			
1 Northwest	34	253	46	26	26	385
2 West Central	15	183	48	48	6	300
3 Southwest	112	528	370	278	22	1,310
Total	161	964	464	352	54	1,995

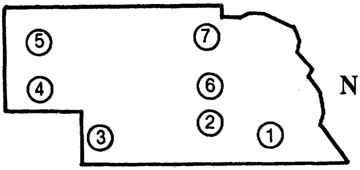
Source: Crop data supplied by DeLynn Hay, Coop. Ext. Serv., Kansas State Univ., Manhattan.

Appendix table 14—Size and characteristics of ground-water decline areas, Kansas, 1978

Area	Decline area irrigated	Lift	Average annual decline
	1,000 acres	*Feet*	
1 Northwest	385	200	1
2 West Central	300	175	2.5
3 Southwest	1,310	250	4
Total	1,995	NA	NA

NA = not applicable.

Source: *(16)*.



Nebraska ground-water decline areas

Appendix table 15—Crops irrigated in areas of ground-water decline, Nebraska, 1978

	Area	Alfalfa	Corn	Grain sorghum	Wheat	Other[1]	Total
				1,000 acres			
1	Southeast	10	803	93	10	114	1,030
2	East South Central	13	258	3	3	49	326
3	Southwest	3	192	0	6	58	259
4	West Central	3	6	0	3	7	19
5	Northwest	8	17	0	5	39	69
6	East Central	3	24	0	0	1	28
7	Northwest	2	91	0	0	18	111
	Total	42	1,391	96	27	286	1,842

[1]Includes land that could be irrigated but may not have been in 1978.

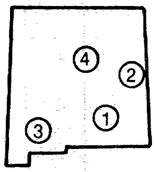
Source: 1980 Nebraska Agricultural Statistics.

Appendix table 16—Size and characteristics of ground-water decline areas, Nebraska, 1978

	Area	Decline area irrigated	Lift	Average annual decline
		1,000 acres	*Feet*	
1	Southeast	1,030	100	0.5
2	East South Central	326	25	.5
3	Southwest	259	150	1.5
4	West Central	19	250	2
5	Northwest	69	100	1
6	East Central	28	125	1
7	Northwest	111	50	1
	Total	1,842	NA	NA

NA = not applicable.

Source: *(17)*.



New Mexico ground-water decline areas

Appendix table 17—Crops irrigated in areas of ground-water decline, New Mexico, 1978

	County	Alfalfa	Barley	Cotton	Corn
		1,000 acres			
1	Chaves and Eddy	66	8	33	4
2	Curry, Roosevelt, and Lea	28	11	42	53
3	Luna	3	0	21	3
4	Torrance	11	4	6	0
	Total	108	23	102	60

	County	Grain sorghum	Wheat	Other	Total
		1,000 acres			
1	Chaves and Eddy	8	4	7	130
2	Curry, Roosevelt, and Lea	95	80	41	350
4	Luna	9	2	17	55
4	Torrance	0	0	4	25
	Total	112	86	69	560

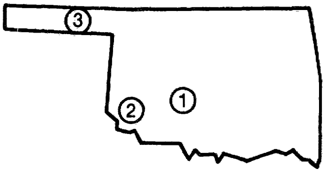
Source: *(18)*.

Appendix table 18—Size and characteristics of ground-water decline areas, New Mexico, 1978

County	Decline area irrigated	Lift	Average annual decline
	1,000 acres	---------------*Feet*---------------	
1 Chaves and Eddy:			
Shallow	54	75	2.5
Artesian	76	225	2.5
2 Curry, Roosevelt, and Lea	350	200	2
3 Luna	55	100	1
4 Torrance	25	100	1
Total	560	NA	NA

NA = not applicable.

Source: *(18)*.



Oklahoma ground-water decline areas

Appendix table 19—Crops irrigated in areas of ground-water decline, Oklahoma, 1978

Area	Alfalfa	Cotton	Corn	Grain sorghum
	1,000 acres			
1 Caddo County	15	7	1	10
2 Harmon County	0	14	0	1
3 Panhandle	24	0	72	168
Total	39	21	73	179
	Peanuts	Wheat	Other	Total
	1,000 acres			
1 Caddo County	32	10	5	80
2 Harmon County	0	4	8	27
3 Panhandle	0	112	24	400
Total	32	126	37	507

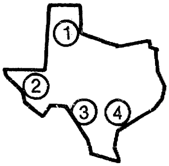
Source: *(9)*.

Appendix table 20—Size and characteristics of ground-water decline areas, Oklahoma, 1978

County	Decline area irrigated	Lift	Average annual decline
	1,000 acres	*Feet*	
1 Caddo County	80	100	1
2 Harmon County	27	100	2.5
3 Panhandle	400	275	2
Total	507	NA	NA

NA = not applicable.

Source: *(19)*.



Texas ground-water decline areas

Appendix table 21—Crops irrigated in areas of ground-water decline, Texas, 1978

Area	Hay and alfalfa	Cotton	Corn	Grain sorghum	Peanuts
	1,000 acres				
1 High Plains	129	1,667	1,475	1,200	0
2 Trans-Pecos	20	14	0	8	0
3 Winter Garden	17	29	21	14	20
4 Gulf coast					
Total	166	1,710	1,496	1,222	20

Area	Rice	Soybeans	Wheat	Other	Total
	1,000 acres				
1 High Plains	0	175	1,060	294	1,000
2 Trans-Pecos	0	0	15	53	110
3 Winter Garden	0	0	10	29	140
4 Gulf coast	169	0	0	6	175
Total	169	175	1,085	382	1,425

Source: *(20)*.

Appendix table 22—Size and characteristics of ground-water decline areas, Texas, 1978

County	Decline area irrigated	Lift	Average annual decline
	1,000 acres	---------------*Feet*---------------	
1 High Plains	6,000	200	2
2 Trans-Pecos	110	225	4
3 Winter Garden[1]	140	225	4
4 Gulf coast[2]	175	75	1
Total	6,425	NA	NA

NA = not applicable.

[1]Only Dimmit, Frio, and Zavala Counties included.

[2]Including Harris, Waller, Fort Bend, Wharton, Jackson, and Matagorda Counties.

Source: *(20)*.

Appendix II—Irrigation Specialists and Hydrologists

Arizona—Scott Hathorn Jr., Dept. of Agricultural Economics, University of Arizona, Tucson 85712.

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California—Alex Williamson, Water Resources Division, USGS, Federal Bldg., 2800 Cottage Way, Sacramento 94825. Jerry Knutson, Agricultural Engineering Extension, University of California, 3022 Bainer Hall, Davis 95619.

Colorado—Ron Borman, Water Resources Division, USGS, Box 25046, MS 423, Denver Federal Center, Denver 80226. Dwayne Konrad, Cooperative Extension Service, Colorado State University, Burlington 80807.

Florida—Henry Healy, Water Resources Division, USGS, 325 John Knox Road, Tallahassee 32303. Jerry Shaw, Regulatory Division, Southwest Florida Water Management District, 5060 Highway 41, South, Brooksville 33512.

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Kansas—DeLynn Hay, Extension Agricultural Engineering, Seaton Hall, Kansas State University, Manhattan 66506.

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