ECONOMY OF THE COLORADO HIGH PLAINS: DIRECT ECONOMIC-HYDROLOGIC IMPACT FORECASTS (1979-2020)

by

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ENERGY AND WATER SCARCITY AND THE IRRIGATED AGRICULTURAL ECONOMY OF THE COLORADO HIGH PLAINS:

DIRECT ECONOMIC AND HYDROLOGIC IMPACT FORECASTS (1979-2020)

by

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ABSTRACT

The Ogallala Aquifer is a water-bearing geological formation underlying portions of eight states in the High Plains region. Spurred by inexpensive energy, technological development in wells, pumps and irrigation equipment, irrigation spread acorss the semi-arid High Plains to the point that by 1980 more than one-fifth of all irrigated acreage in the U.S. was derived from this source. The water supply in the Ogallala, however, is only partially replenished by natural forces, so that exhaustion of this resource has already been experienced in some localities. Concern over this prospect and the rapidly escalating costs of energy for pumping was the impetus for a federally funded study of the future (to 2020) of the irrigation-based economy in the six states mostly affected. This report describes a portion of the Colorado part of the overall study, that dealing with direct agricultural economic and hydrologic impacts.

The projections were based on models of the water and land use decisions by typical profit-oriented farmers. Key factors in the forecasts were projected crop prices (derived from USDA national model estimates), energy costs, and irrigation and crop production technology. A digital computer simulation model was developed which provided forecasts through the forty year projection period of water use, as dependent on cost and physical availability, and remaining water supply. Future crop production, income, energy use, and employment were also estimated.

The projections were first made under assumptions reflecting no change in state or federal regulations affecting the situation and "best judgment" estimates of crop prices, energy costs, and technology. This was called the "Baseline scenario." A "pessimistic" baseline scenario was also examined,

which posited less favorable crop and energy prices and slower improvement in crop production technology. Other forecasts assumed modified water demand (via conservation techniques or regulations) and supply augmentation.

The expectation is that irrigation water use will eventually decline to a level close to the natural replenishment rate. Irrigated crop acreage at the end of the forecast period will drop to just above 60 percent of that in 1980, with most of the loss in the southern and central portions of Colorado's part of the aquifer. Direct employment in irrigated crop production is projected to fall some 45 percent to 750 man-years annually. Due to continuous small rises in both commodity prices and production per acre, total crop income is expected to rise, although irrigated crop income (in constant dollars) will fall somewhat by 2020. Irrigation water pumped will fall to less than 700,000 acre feet per year, 43 percent below 1979 levels. Nevertheless, these projections indicate only 40 percent of the economically recoverable water supplies will have been withdrawn by 2020.

The analysis of alternative policies to solve the problem indicated that water importation from outside of Colorado would cost some five times more than estimated farmer ability to pay. Large subsidies, accumulating to several billion dollars, would be required to accomplish such a solution. Stricter regulation of pumping also does not appear promising as a method of improved economic returns, although aquifer life would be extended. The most fruitful approach seems to be an emphasis on discovery and dissemination of methods for using water and energy more efficiently.

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CHAPTER I

INTRODUCTION

Extensive development of groundwater for crop irrigation has taken place on the western part of the Great Plains (the "High Plains") over the last 30 years. The source of water, the Ogallala aquifer, is a layer of porous, water-bearing sand and gravel up to several hundred feet thick which underlies a large portion of the Great Plains from western Nebraska and eastern Colorado south to the Texas Panhandle, including parts of Kansas, Oklahoma, and New Mexico. Some 14 million acres are irrigated from the Ogallala in the six-state region, more than 25 percent of all irrigated cropland in the U.S. Replenishment from natural sources is considerably less than the annual withdrawals in much of the region and water tables are declining.

Recent energy price increased combined with evidence of declining water supply have created concerns about the future viability of the irrigation-based economy of the High Plains. These concerns led the Congress in 1976 to fund an intensive study of the situation. The study is administered by the U.S. Economic Development Administration, advised by the High Plains Study Council, composed of representatives of each of the six states. The general contractor for the project is a consortium of consulting firms called the High Plains Associates, consisting of Camp, Dresser, and McKee, Inc., as the lead organization with Black and Veatch, Inc., providing agricultural and economic forecasts. In Colorado, as in other states, a significant portion of the research has been subcontracted to the state land grant universities and various state agencies. Direct agricultural and economic impacts, hydrologic impacts, and indirect regional economic impacts were studied at Colorado State University.

The regional investigation has produced forecasts of economic and hydrologic conditions for 40 years under each of several policy scenarios. The policy scenarios include a "Baseline" study, which assumes no new public policy initiatives, plus several alternative programs envisioning either water demand reduction or supply augmentation. A final scenario examines the impact under a set of more pessimistic assumptions regarding energy costs, crop prices, and technological improvements.

The general problem, as viewed by those who initiated the study, can be encapsulated in terms of four hypotheses and one broad policy inference. These are briefly stated as follows:

Hypothesis 1 - The Hydrologic Failure Hypothesis. This predicts that the water stored in the Ogallala is rapidly being exhausted, such that the recoverable supplies may be largely depleted in the next decade or two.

Hypothesis 2 - The Economic Failure Hypothesis. This proposition holds that the twin forces of increased energy prices and increased pumping lifts will soon inflate pumping costs to a degree that it will not be economical to continue to withdraw water for irrigation.

Hypothesis 3 - The Regional Economic and Social Impact Hypothesis. This assertion holds that there are strong linkages between the irrigated agriculture sector and the remainder of the regional economy such that occurrence of either the hydrologic or economic failure would have major detrimental economic and social repercussions on the region. These impacts would include reduced employment, inability to support public services, and the social decay associated with dying communities.

Hypothesis 4 - The National Agricultural Commodity Supply Hypothesis. This hypothesis contends that the Ogallala region accounts for a sufficiently large proportion of national production of food, feed, and fiber crops, that any significant decline in irrigation would adversely affect production, exports, and sharply drive up commodity prices.

Policy Inferences. The above four propositions taken together, imply that immediate public action at local, state, and national levels is required to alleviate and retard the economic and social impacts of the inevitable decline in the Ogallala groundwater supply. These public policies could include demand modification (such as technological improvement in irrigation, conservation efforts, or regulated withdrawals) or supply augmentation (primarily additional surface water supplies imported from in-state and distant sources).

This report is one of a series of studies which document the Colorado portion of the High Plains study. We focus here on the hydrologic and on-farm economic forecasts of the future of the irrigated area in the Colorado Ogallala High Plains. Other reports deal with indirect or regional economic impacts, energy supply issues, and rural community aspects. A non-technical summary of the study was published by the Colorado Department of Agriculture in November 1981.

Research Procedure and Organization of the Report

General Approach

The problem was conceptualized in terms of modeling how a rational, profit-oriented farmer would respond to changes in water availability, energy costs, crop prices, technological opportunities, and government policies. The solution technique involved combining a hydrologic model (which predicts depth to water and quantity of water remaining for each township), with a linear programming-farm management model which projects water and energy demands for expected water supply and crop production conditions. In general terms, the hydrologic model describes water availability and the linear programming model allocates the available water to various production activities so as to maximize the net returns to land, water, and management. The study forecasts water and energy consumption, crop production, and farm income for each of the years 1979, 1985, 1990, 2000, and 2020.

The remainder of this chapter provides a description of the study area, including climate, soils, irrigation development, and agricultural production trends and background. The next two chapters provide detailed descriptions of the assumptions and procedures of the economic and hydrologic portions of the analysis, while Chapter IV integrates this material to describe the computer simulation model. The succeeding six chapters summarize the model projections for each of the respective policy scenarios. The report concludes with a summary and policy implications. Detailed reports of the individual subarea projections are provided in extensive appendix tables.

Description of the Study Area

Location

This study is concerned with the portion of the Colorado High Plains that is underlain by the Ogallala Formation, where this formation is used as a source of groundwater for irrigation.

There are really two separate areas of concern in eastern Colorado. One can be called the Northern High Plains, which include all of Phillips, Yuma, and Kit Carson counties, southern Sedgwick county, eastern Washington county, eastern Cheyenne county, and small portions of Logan, Lincoln, Kiowa, and Prowers counties. This area lies between the valleys of the South Platte River and the Arkansas River.

The other portion of the study area will be called the Southern High Plains.

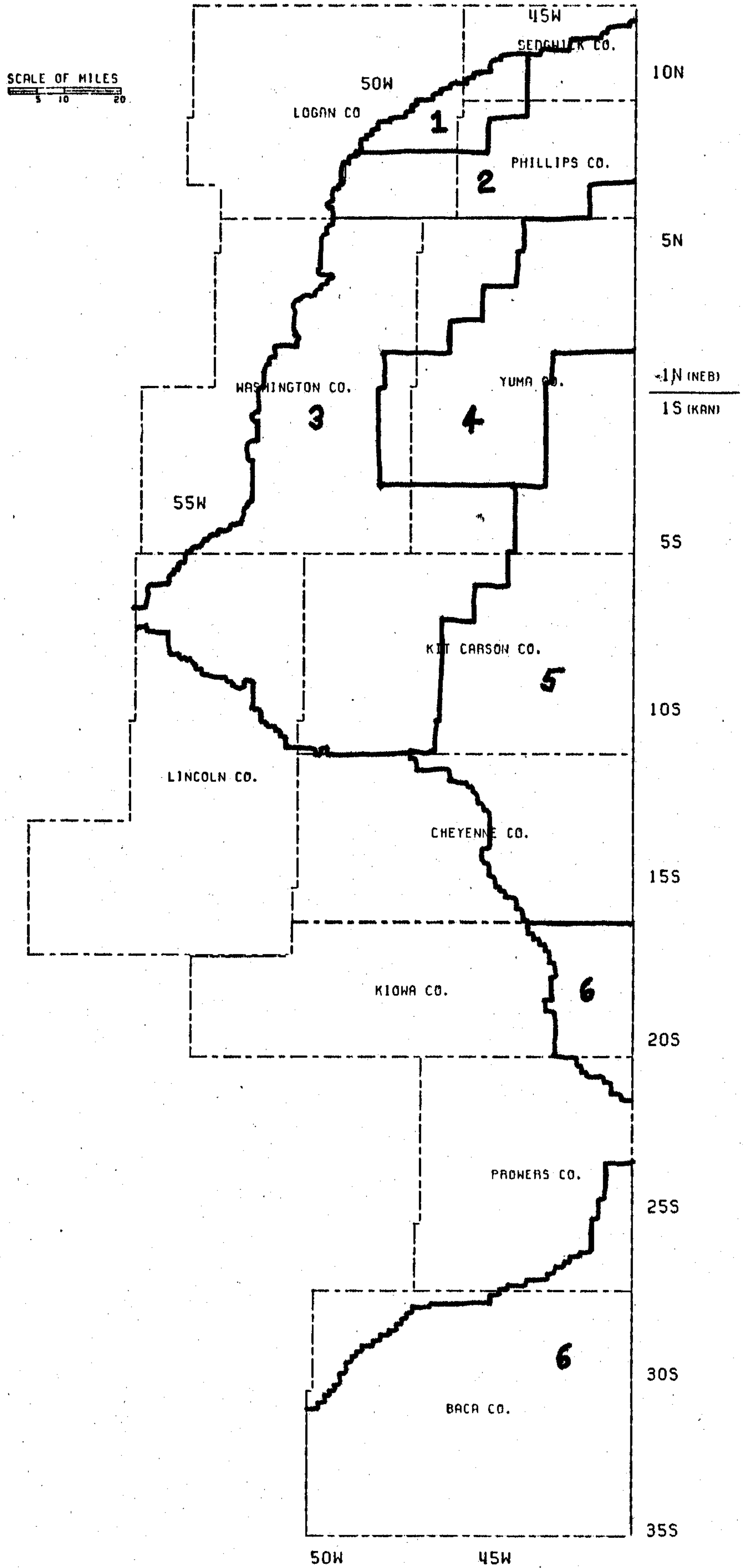

Figure 1.1. Ogallala Aquifer and Subareas, Eastern Colorado.

It lies south of the Arkansas River valley and includes most of Baca county and the southeastern corner of Prowers county.

Climate

In general, the climate in the study area becomes warmer (and the growing season longer) as one goes from north to south. However, southern areas receive less rainfall and have higher evapotranspiration rates, factors that tend to offset the advantages of a longer growing season. The entire area has low relative humidity and abundant sunshine. Table 1.1 shows the data on average growing seasons and annual rainfall for selected weather stations in the study area.

Table 1.1. Length of Growing Season and Average Annual Rainfall for Selected Weather Stations in the Study Area.

Weather Station	Average Length of Growing Season (days)	Average Annual Rainfall (inches)
Holyoke	145	17.8
Yuma	143	17.1
Wray	145	17.7
Burlington	151	16.2
Cheyenne Wells	151	15.4
Springfield	165	15.1

Source: County Information Service, Community Resource Development Project, Cooperative Extension Service, Colorado State University, Fort Collins, 1976.

A dominant feature of the weather is its variability. A large portion of total annual precipitation (usually 75 to 80 percent) falls during the growing season, but it is unreliable in terms of timing and amount. As an example, Table 1.2 shows how rainfall during the April through September period has varied over the last five years at Holyoke, in Phillips county.

Table 1.2. Variability of Growing Season Rainfall at Holyoke, Colorado, 1975-79.

	Rainfall in Inches				
Month	1975	1976	1977	1978	1979
April	1.2	1.7	4.1	0.8	1.3
May	5.0	3.0	4.3	2.8	3.2
June	2.5	1.1	2.1	1.4	4.4
July	2.7	1.9	2.5	1.6	2.7
August	0.9	1.4	3.8	1.2	2.9
September	0.5	0.5	1.2	0.1	0.2
Total	12.8	9.6	18.0	7.9	14.7

Source: "Climatological Data - Colorado," Environmental Data Service, U.S. Department of Commerce, Washington, D.C. (various annual issues)

Other aspects of weather variability include rapid temperature changes, windstorms severe enough to cause crop damage and erode base soils, and hailstorms that are severe and frequent enough many years to cause crop damage on about ten percent of the cropland.

Topography and Soils

Most of the famland in the study area has an elevation between 3500 and 4500 feet above sea level. Topography is nearly level or gently sloping in most of the irrigated areas, except in the sand hills north of Wray, where some of the land is sharply rolling.

The soils vary considerably within the study area, and six subareas were delineated on the basis of soil differences and their influence on irrigation development and cropping practices. These areas are described in the following paragraphs and were based on a special study performed by Deutsch and Heil [1980].

1. Haxtun area - The soils of this area are predominantly the sandy loams and loamy sands of the Haxtun-Julesburg Association. Most of the irrigated land

is devoted to corn and is irrigated by sprinklers. In general, the soils are too sandy to be suited for furrow irrigation. The soils are suited to dryland farming, however, and wheat is grown on most of the dry cropland.

2. Holyoke area - Most of the soils in this area are locally known as "hardlands." They are loams and silt loams of the Rago, Richfield, Platner, and Kuma series. Many of these soils have a silt loam or clay loam subsoil with a slow inflitration rate, which limits their suitability for low pressure sprinkler systems. The water supply situation is best on farms to the south and east of Holyoke, where a substantial portion of the land is devoted to corn, sugar beets, and pinto beans in rotation under surface irrigation. Center pivot sprinklers are also common in the subarea, with much of the land under them devoted to corn. Most of the land in the northeastern and western parts of this area is devoted to the dryland production of winter wheat.

3. Yuma-Arikaree area - Most of the soils in this area are loams and sandy loams of the Ascalon, Haxtun, and Platner series. Irrigation is mostly by center pivot sprinkler and the predominant crop is corn. Dryland wheat is also an important crop in this area.

4. Sand Hills area - In this area, the bulk of the soils are fine sand throughout the profile. Wind erosion is always a potentially serious problem on cultivated land in this area. Corn is practically the only irrigated crop here, grown with limited tillage under center pivot irrigation. Dryland farming is limited because of the wind erosion hazard, but is practiced on some of the loamier sands south and east of the town of Yuma.

5. Burlington area - Most of the soils of this area are loams and silt loams of the Keith, Richfield, Colby, Weld, and Adena series. Extensive irrigation began in the 1960s with surface irrigation on row crops. Center pivots

have been installed during the 1970s in areas where topography discouraged surface irrigation. In parts of this area, the cost of pumping water has dictated an increase in the acreage of crops that use less water than corn, such as small grains and pinto beans.

6. Kiowa-Baca area - A variety of soil types are irrigated in this area, silt loams and loams predominate, but there are some sandier soils. Physical limitations on the water supply and the cost of pumping overshadow the variation of soils in determining the economic feasibility of producing a given crop. Many farmers have recently stopped growing corn and now produce wheat and milo (grain sorghum) with their limited and expensive water. This lets them spread their demand for water and energy more evenly over the year since wheat is irrigated in the fall and spring and milo needs water in the summer. In addition to changing their crop mix, some farmers are summer-fallowing part of their irrigated land, producing a crop only every other year. In a few cases, land that was irrigated is now farmed as dryland.

Irrigation Development in the Study Area

There are several estimates available on the irrigated acreage for counties in the study area, but the figures vary widely. Table 1.3 presents data from the Census of Agriculture to show how both irrigated acreage and the number of farms with irrigated land have increased from 1949 to 1974 in those counties where the irrigated land is completely underlain by the Ogallala aquifer.

The Colorado Division of Property Taxation publishes the county assessors' estimates of irrigated acreage in each county on an annual basis. These figures are probably the most reliable figures available for 1979, but they may be a little low for some counties.

Table 1.3. Irrigated Development in Selected Counties in the Study Area.

County	1949	1959	1969	1974
A. Irrigated Farms				
Phillips	7	23	97	145
Yuma	33	106	312	438
Kit Carson	8	98	302	343
Baca	22	83	199	230
B. Irrigated Acreage				
Phillips	2,100	2,800	29,000	61,000
Yuma	1,600	11,100	89,200	173,100
Kit Carson	1,500	18,900	87,900	124,300
Baca	1,400	21,000	63,200	85,600

Source: U.S. Department of Commerce, Bureau of the Census, Census of Agriculture, (for years cited).

The figures reported by the Division of Property Taxation were used as a basis for estimating the irrigated acreage of each county. For Phillips, Baca, Cheyenne, Washington, and Sedgwick counties, the irrigated land figures were regarded as correct without modification. For the latter two counties, the total irrigated acreage was allocated as being inside or outside the study area on the basis of maps from the State Engineer's Office. The irrigated acreage for counties that had relatively small portions of their total area within the study area (Logan, Lincoln, Kiowa, and Prowers) was estimated entirely from these maps. During the field work, a check of the tax rolls was made to estimate the irrigated acreage in Kiowa county within the study area in 1979.

The estimates of irrigated acreage shown in Table 1.4 are higher than the figures reported by the Division of Property Taxation for Yuma and Kit Carson counties. After conversing with personnel in the State Engineer's Office, the U.S. Geological Survey, and county ASCS offices, it was concluded that the Division of Property Taxation estimates were a bit low. The differences are not

Table 1.4. Land Underlain by the Ogallala Aquifer, by County (1979).

County	Irrigated Land	Dry Cropland	Grazing Land	Other Land	All Land	Percent of County in Study Area
	(All land figures are in thousands of acres)					
Northern High Plains						
Logan	2	100	130	10	242	20
Sedgwick	22	115	40	12	189	54
Washington	30	490	380	58	958	60
Phillips	64	290	58	23	435	100
Yuma	230	377	847	63	1,517	100
Lincoln	0	112	265	32	409	25
Kit Carson	128	670	520	69	1,387	100
Cheyenne	20	225	265	24	534	47
Kiowa	2.5	135	85	11.5	234	20
Prowers	1.5	20	12	2.5	36	3
Total	500	2,534	2,602	305	5,941	
% of Total	8.4%	42.6%	43.8%	5.2%	100.0%	
Southern High Plains						
Prowers	14	60	40	14	128	12
Baca	86	764	530	90	1,470	90
Total	100	824	570	104	1,598	
% of Total	6.3%	51.6%	35.6%	6.5%	100.0%	
Grand Total	600	3,358	3,172	409	7,539	

large on a percentage basis, the estimates here being about 7 percent higher than the tax figures for each of the two counties.

In addition to irrigated acreage underlain by the Ogallala aquifer, Table 1.4 shows estimates of dry cropland, grazing land (which includes meadow hay land for counties which have that classification of land) and all land underlain by the aquifer in each county. The last column shows the portion of each county that is underlain by the aquifer.

"All land" figures were estimated from maps. For purposes of determining the land area underlain by the Ogallala aquifer, the boundaries of the Northern High Plains groundwater basin and the Southern High Plains groundwater basin were used. The figures for dry cropland and grazing land are based on figures published by the Division of Property Taxation, adjusted by the proportion of the county that overlies the aquifer. The figures for "other land" were needed to make the acreages sum correctly for each county.

Land was also classified on a subarea basis (see Table 1.5). Land in each classification was allocated to the subareas on the basis of proportions from the Important Farmlands Map prepared by the Soil Conservation Service and Colorado State University.

Table 1.5. Land Underlain by the Ogallala Aquifer, by Subarea (1979).

Subarea	Irrigated Land	Dry Cropland	Grazing Land	Other Land	All Land
	(All figures are in thousands of acres)				
Northern High Plains					
1. Haxtun	16	96	56	11	179
2. Holyoke	63	406	160	28	657
3. Yuma-Arikaree	110	1,105	895	137	2,247
4. Sand Hills	140	80	612	50	882
5. Burlington	167	692	782	65	1,706
6. Kiowa-Baca	4	155	97	14	270
NHP Totals	500	2,534	2,602	305	5,941
Southern High Plains					
6. Kiowa-Baca	100	824	570	104	1,598
Total	600	3,358	3,172	409	7,539

The total area underlain by the Ogallala aquifer (7,539,000 acres) is about 11 percent of the surface area of the state of Colorado. With regard to irrigated land, the study area contains about 20 percent of the state total.

Cropping Patterns and Trends

Table 1.6 shows the crop acreage distribution on irrigated land for the four counties in which all of the irrigated land is underlain by the Ogallala aquifer.

Table 1.6. Crop Distribution on Irrigated Land in Selected Counties in the Study Area.

	Phillips County			Yuma County		
Crop	1970	1974	1978	1970	1974	1978
	(Figures are percentages of irrigated acreage in county)					
Corn Grain	31	62	68	50	72	74
Corn Silage	6	3	4	8	4	4
Pinto Beans	21	14	9	4	3	4
Sugar Beets	25	9	6	16	7	3
Alfalfa Hay	14	7	9	16	9	9
Others	3	5	4	6	5	6
	Kit Carson County			**Baca County**		
Crop	1970	1974	1978	1970	1974	1978
	(Figures are percentages of irrigated acreage in county)					
Corn Grain	36	51	52	28	33	28
Corn Silage	12	12	13	10	7	6
Pinto Beans	7	5	5	0	0	0
Sugar Beets	26	13	5	3	1	0
Alfalfa Hay	7	4	5	5	6	6
Sorghum Grain	2	2	3	26	21	32
Winter Wheat	4	7	10	25	30	26
Others	6	6	7	3	2	2

Source: Figures in Colorado Agricultural Statistics, for years cited.

In the Northern High Plains, most of the irrigated land has come to be devoted to corn production. A small proportion of the corn (5 to 20 percent) is cut for silage, and the rest is harvested for grain. Corn acreage increased greatly during the 1970s, both in absolute numbers and relative to other crops, reaching nearly 75 percent of the irrigated acreage at present.

Pinto bean acreage has been increasing since 1970, but its relative position has been declining because of the tremendous increase in corn acreage. Sugar beet acreage has been declining, and its relative position in the crop acreage distribution has shrunk to about one-fifth of what it was in 1970.

Alfalfa hay acreage has not changed greatly during the 1970s. In spite of small increases in acreage, alfalfa was grown on a smaller percentage of the irrigated land in 1978 than in 1970.

In Kit Carson county (and in Cheyenne and Kiowa counties) an increasing proportion of the irrigated land is being devoted to irrigated winter wheat. This is a response to a decreasing water supply and increased pumping costs, since winter wheat requires less water than corn. In addition, it has a different irrigation season, which enables farmers pumping from wells whose capacity is failing to spread out their water demand over the year.

In the Southern High Plains, corn was grown on about 40 percent of the irrigated land in the early 1970s. Corn acreage has begun to decline, and will probably continue to do so as more farmers switch to milo and winter wheat, crops which require less water than corn and which complement each other with water demands in different seasons of the year. Irrigated hay is a minor crop in this area, and beets and beans are not grown.

Value of Agricultural Production Dependent Upon Irrigation

Crop Production. In order to estimate the volume of agricultural production in the study area that is dependent on irrigation, figures on irrigated acreage were combined with crop distribution figures to produce estimates of output. The fact that some counties have only part of their irrigated acreage in the study area provides some difficulties with this procedure, so a few assumptions were needed. The crop distribution in Phillips county was allowed to represent the irrigated areas in Logan and Sedgwick counties also. The irrigated crop distribution in Yuma county was also used for Washington county. The crop distribution in Baca county was used for all of Subarea 6. The irrigated crop acreage distributions used were based on figures reported in Colorado Agricultural Statistics for the last three years (1977-79), adjusted slightly to reflect the findings of the farm interview work that was done for this study in the fall of 1979. The percentages do not sum to 100 percent for all these areas because of rounding errors and acreages of minor crops that were not itemized. The estimates of irrigated crop production are presented in Table 1.7. The yields shown are averages of the figures reported by the Colorado Crop and Livestock Reporting Service for 1977-79, with some rounding done on the basis of farm survey results.

Corn production is estimated as if all of it were harvested for grain. Actually, some 5 to 20 percent would be cut for silage, depending on the subarea. The simplifying assumption of grain harvest overestimates corn grain production for the study area, but has little effect on the dollar value of all corn grown in the area. The crop production figures in Table 1.7 are used to generate the annual output figures in Table 1.8, where an estimate of the

Table 1.7. Estimated Irrigated Crop Production in Colorado Dependent Upon the Ogallala Aquifer.

County	Crops	Percent of Irrigated Land	Land in Irrigated Crops (1,000 Acres)	Average Yield Per Acre	Units	Estimated Annual Output (1,000 Units)
1. Phillips	Corn	74	65	130.0	Bu.	8,463
Sedgwick	Beans	10	9	17.0	Cwt.	150
Logan	Beets	6	5	19.0	Tons	101
	Hay	10	9	3.5	Tons	31
		100	88			
2. Yuma	Corn	80	208	130.0	Bu.	27,040
Washington	Beans	4	110	16.0	Cwt.	166
	Beets	3	8	17.0	Tons	138
	Hay	10	26	3.5	Tons	91
		97	260			
3. Kit Carson	Corn	65	96	120.0	Bu.	11,544
Cheyenne	Sorghum	3	4	70.0	Bu.	308
	Wheat	10	15	45.0	Bu.	666
	Beans	5	7	15.0	Cwt.	111
	Beets	5	7	17.0	Tons	126
	Hay	10	15	3.0	Tons	44
		98	148			
4. Baca	Corn	15	16	100.0	Bu.	1,560
Kiowa	Sorghum	45	47	70.0	Bu.	3,276
Prowers	Wheat	30	31	40.0	Bu.	1,248
	Hay	10	10	2.5	Tons	26
		100	104			

value of crop output is made. Based on the crop acreage distribution and typical yields for the past three years, and average prices for the 1979 crop, corn production dominates the crop production picture. Almost three-quarters of the total value of crop production is accounted for by corn. Sorghum, wheat, pinto beans, sugar beets, and hay each account for about 5 percent of the total value of crops.

According to the figures from the Colorado Crop and Livestock Reporting Service, the portion of Colorado underlain by the Ogallala aquifer produces about one-half of the corn grown in the state. About one-third of the state's

Table 1.8. Estimated Value of Crop Production in Colorado Dependent Upon the Ogallala Aquifer.

Crop	Annual Output	Approx. Price for 1979 Crop[a]	Value of Output	Percent of Total Value
Corn	48,607,000 Bu.	$ 2.60	$126,378,000	73
Sorghum	3,584,000 Bu.	2.20	7,885,000	4
Wheat	1,914,000 Bu.	3.50	6,699,000	4
Pinto Beans	427,000 Cwt.	24.00	10,248,000	6
Sugar Beets	360,000 Tons	28.00[b]	10,080,000	6
Hay	192,000 Tons	54.00	10,368,000	6
Other			1,500,000	1
Total			173,158,000	100

[a] **Source: Colorado Crop and Livestock Reporting Service, <u>1980 Colorado Agricultural Statistics</u>.**

[b] 1978 crop.

grain sorghum is grown on irrigated land in the area, along with one-quarter of the state's sugar beets and pinto beans. About 20 percent of the total value of crop production in the state has come from the aquifer area during **each of the last three years.**

<u>Livestock Production</u>. In addition to crop farming, there are several livestock enterprises in the study area, including rangeland cattle and sheep, cattle and hog feeding, and dairy. It was assumed that the rangeland activities are not dependent upon irrigation, while the feeding and dairy operations are dependent upon irrigation for forage and grain production.

The Colorado Crop and Livestock Reporting Service does an inventory of livestock each year. On January 1, 1979, there were approximately 125,000 head of cattle on feed in the aquifer area. On a state-wide basis, cattle marketings over a year's time are about three times the number of cattle reported to be on feed during the annual inventory. This factor of three reflects the intensive practices of several large feedlots outside the study area. Feeding in the aquifer area tends to be less intensive; there are some feedlots, but there are also a good number of farmers who will feed out a batch of animals over the winter but will devote the summer to field work. For the aquifer area, it was assumed that fed cattle marketings will typically be twice the number of animals on feed in the annual inventory. Assuming a typical market weight of 1,050 pounds per head would mean that 125,000 head x 2 x 1,050 lb./head = 262,500,000 pounds of liveweight beef are produced in the study area annually. This is about 8 percent of the total state output. With a season average price of $67.90/cwt. for 1979, this amount of beef production would be worth $178,237,500.

Hog production is another livestock activity in the study area that is dependent on a ready supply of grain for feeding. Colorado Agricultural Statistics report about 52,600 head of hogs and pigs in the study area on December 1, 1978. For the state, marketings are typically 1.5 times the inventory number, and market weight is typically 220 pounds. These numbers probably hold for the study area, and would indicate an output of 52,600 head x 1.5 x 220 lb./head = 17,358,000 pounds of liveweight pork are produced in the study area annually. This is about 16 percent of total state output. With a season average price of $42.30/cwt. for 1979, this amount of pork production would be worth $7,342,400.

There were about 5,250 head of dairy cattle in the study area on January 1, 1979. Assuming that the state-wide average of 12,000 pounds of milk per cow holds for the study area, milk production would be 63 million pounds or 630,000 cwt. This is about 7 percent of the total state output. With an average price of $12.80/cwt. in 1979, the total value of milk produced in the study area would be $8,064,000.

The figures indicate that livestock enterprises in the study area dependent upon irrigation are a small percentage of state totals but do have a total value of output of about $193.6 million. In addition, since about one-half of the corn produced in the state comes from the aquifer area, the complete loss of irrigation there would have a noticeable impact on livestock feeding throughout the state of Colorado, forcing a reduction in livestock feeding and/or imports of feedgrains from states to the east.

CHAPTER II

CHARACTERISTICS OF AGRICULTURAL PRODUCTION IN THE STUDY AREA

Primary Farm Management Data Collection

In order to assure the reliability of the farm production and cost data, it was decided to conduct a random sample survey of irrigated crop procedures in the study area.

Sampling Procedure

Interviews were conducted by L. R. Conklin and an assistant in November and December of 1979 with a randomly selected sample of farmers in the study area. Lists of well owners were obtained from groundwater management districts or county assessor's offices. From these lists a 5 percent sample was drawn. The names of people who lived outside the designated basins were not included among those eligible to be sampled, on the assumption that these people rented out their land and played only a limited management role and that the time and costs associated with contacting these people would be unwarranted. Even so, a number of people remained on the lists (and in the samples) who were renting out their land at the time of the survey. In each of these cases, an attempt was made to interview the person who was actually doing the farming.

A total of 86 interviews were conducted with farm managers who raised irrigated crops in 1979. Table 2.1 shows how the interviews were distributed over the study area. The distribution is similar to that for irrigated land in the study area.

In the farm survey, information was collected on crop acreages and yields for each farm. The sequence of field operations was noted in considerable detail, along with the level of input use associated with each crop. The

Table 2.1. Farm Interview Distribution by Subarea.

Subarea	No. of Interviews	Percent of Total	Percent of Irrigated Land in Study Area
1. Haxtun	4	4.6	2.6
2. Holyoke	7	8.2	10.3
3. Yuma-Arikaree	13	15.1	19.2
4. Sandhills	17	19.8	23.0
5. Burlington	32	37.2	27.4
6. Kiowa-Baca	13	15.1	17.0
TOTAL	86	100.0	100.0

irrigation facilities were described (farms with more than three wells could be accommodated on extra copies of the questionnaire's third page), as was the complement of field machinery on each farm. Brief descriptions of buildings and livestock operations were obtained, followed by estimates of labor use and overhead costs. The interviews closed with questions on where farmers sold their products and purchased their supplies. (A copy of the questionnaire is included as Appendix F.)

Data collected from the survey were summarized to describe a typical farm for each of the six subareas delineated for the study. These typical farms served as a basis for subsequent budgeting and linear programming operations.

Farm Size and Crop Mix

The data collected on crop acreages are summarized in Tables 2.2 and 2.3. The median irrigated and dryland crop acreages are shown for each subarea (the median is less influenced than the mean by the few very large farms found in most of the areas, and is more appropriate in this situation for describing a "typical" farm situation). The crop distribution is then shown in terms of percentage for both the irrigated and dry cropland.

Table 2.2. Median Farm Crop Acreage and Distribution of Crops on Irrigated Land.

Subarea	Irrigated Land (Acres)	Percent of Irrigated Land Devoted to						
		Corn Grain	Pinto Beans	Sugar Beets	Wheat	Milo	Alfalfa	Other
1	520	100	0	0	0	0	0	0
2	600	70	10	15	0	0	5	0
3	520	75	15	0	6	2	2	0
4	780	90	0	0	2	0	5	3
5	530	55	6	5	16	5	5	8
6	700	8	0	0	30	40	8	14
All	530	60	5	3	13	10	5	4

Table 2.3. Median Farm Crop Acreage and Distribution of Crops on Dryland.

Subarea	Total Dryland (Acres)	Percent of Harvested Dryland Devoted to			
		Wheat	Milo	Hay	Other
1	1,400	100	0	0	0
2	400	100	0	0	0
3	500	90	5	0	5
4	100	75	5	10	10
5	900	95	5	0	0
6	2,000	70	30	0	0
All	800	90	9	<1	<1

Table 2.2 shows that corn dominates the crop mix on irrigated land in the northern part of the study area (subareas 1 through 4), but that wheat and milo are more prevalent in the southern parts. This can be attributed to climatic differences and to water supply problems in the southern subareas.

In the study area, dryland crops are generally grown in a crop-fallow rotation. This means that one-half of the total cropland is fallow in a given year. The percentages in Table 2.3 refer to the harvested portion of the land, and show that wheat dominates the dryland crop mix throughout the study area, with some milo produced in the more southern areas. No dryland corn was raised by any of the farmers interviewed, but some is normally produced in subareas 1 and 2. Data from Colorado Agricultural Statistics indicate that about 5 percent of the harvested dry cropland is used to produce corn in this part of the study area.

In Table 2.2, the "other" category includes forage and silage crops, barley in subarea 5, and idle land (which was about 10 percent of the total in subarea 6). In Table 2.3, the "other" category includes millet and forage crops.

Enterprise Combinations

Most of the farmers interviewed combined irrigated crop farming with raising dryland crops. Only 14 did not, and 9 of these were located in the sand hills.

About 60 percent of the farmers interviewed combined a livestock enterprise with raising crops. This included a dairy, two hog operations, and three sheep herds, as well as 48 farms with beef cattle. The beef operations are detailed in Table 2.4. Ranching is the term used for an operation which a cow herd and/or one raising yearlings or "stocker" cattle on pasture or forage. Cattle feeding is used for grain feeding in confinement conditions, where the product sold is fat cattle. The numbers in the bottom two rows of the table indicate that the cow herds and feedlots on these mixed enterprise farms are fairly small.

Table 2.4. Beef Enterprises on Farms in the Field Survey.

	Subarea					
Enterprises	1	2	3	4	5	6
Crops Only	2	6	8	3	9	7
Crops and						
Ranching	1	1	5	12	17	5
Cattle Feeding	0	0	0	1	3	0
Both Ranching and Feeding	0	0	0	1	2	0
Median No. of Cows	30	100	85	150	100	150
Median No. of Cattle on Feed	0	0	0	200	800	0

Machinery Complements

The farm interview records were analyzed to determine the size of field machinery commonly used on farms in each subarea. The most frequently encountered machines were combined to form a typical machinery complement for each subarea.

The number and size of tractors used for field work appear in Table 2.5, along with the size of the tillage equipment typically used. Most farmers also had a sprayer they used with their disk to incorporate herbicide.

For row crops, eight-row planters and cultivators were the most common. With 30-inch row spacing, these machines would cover 20 feet with each pass through the field. Grain drills were typically double-hitched so as to plant about 27 feet with each pass.

As with planting equipment, harvesting equipment was also fairly standard in all of the subareas. Small grains were typically harvested with a grain platform 24 feet wide and corn was harvested with an 8-row header on a combine. Most farms had a 400-bushel grain cart.

Table 2.5. Tractors and Tillage Equipment Complements, by Subarea

Equipment	Subareas 1	2	3	4	5	6
	(Number)					
Tractors						
4WD, 180 HP	0	0	0	0	0	1
2WD, 150 HP	1	1	1	1	1	1
2WD, 125 HP	1	2	1	1	2	1
2WD, 100 HP	0	1	0	0	1	0
	(Size in Feet)					
Tillage						
Plow		6			6	
Ripper		10			10	
Chisel	18	18	18	18	18	24
Disk	20	20	20	20	20	25
Mulch-Treader				24		
Roller Harrow		15			15	
Plane or Float		14			14	
Bedder		20			20	20
Blades	28		28		28	33
Rodweeder	36	36	36		36	42
Springtooth	32	32	32		32	32

The typical farm truck had a nominal capacity of about 300 bushels, or about 9 tons. Farms with sugar beets typically had three such trucks; other farms had two.

Beet harvesting machinery was typically four-row. Beans were generally cut with an eight-row cutter, turned out of the ground with a ten-row bean rod and combined with two bean pickups (each one nine feet wide) on the front of the combine.

Irrigation Facilities

As part of the hydrologic research for this study, an inventory of irrigation wells operating in 1979 was taken from the records of those companies that provide power and fuel in the area. The distribution of wells by power or fuel source is shown in Table 2.6, on a percentage basis.

Table 2.6. Distribution of Irrigation Wells in the Study Area by Power Source, 1979.

		Percent of Wells Powered By		
Subarea	Total No. of Wells	Electricity	Natural Gas	Other Fuels
1	124	90	8	2
2	420	87	12	1
3	856	76	22	2
4	1,096	91	8	1
5	1,307	48	49	3
6	964	30	70[a]	
All	4,767	64	36[a]	

[a] includes other fuels.

The power company records were somewhat less complete on the distribution of wells by distribution system. The two common systems are gated pipe and center pivot sprinkler. There are a few open ditch and siphon-tube systems in subarea 2, but even here gated pipe is a much more common means of surface water distribution. Table 2.7 shows the distribution of wells by water distribution system. For subareas 1 through 5, the data are from records on electric powered wells only, but there is no reason to believe that the distribution for gas powered wells would be different. Subarea 6 figures are based on all wells.

Data on the number of tail pit pumps (which recycle drainage water back to the head of a field) are also shown in Table 2.7. These figures are for all surface systems, not just those with electric powered wells.

Table 2.7. Distribution of Irrigation Systems in the Study Area, 1979.

Subarea	Percent of Wells With Surface Irrigation	Percent of Wells With Sprinkler Irrigation	Percent of Surface Systems With Tail Pits	Percent of Center Pivots With Low Pressure (≤50 psi)
1	2	98	100	77
2	36	64	78	10
3	11	89	46	10
4	1	99	78	10
5	46	54	21	42
6	79	21	3	33

The only source of information on the distribution of high pressure (greater than 50 psi) and low pressure (50 psi or less) sprinkler systems was the farm survey. The distribution of low pressure systems is shown in the last column of Table 2.7. The low pressure systems require less energy per acre inch of water pumped, but are not suited to some soil and topography conditions since they apply water more rapidly on a given unit of land area. It appears that there is considerable room for conversion from high to low pressure in subareas 3 and 4, where the soils are quite sandy.

Development of Crop Enterprise Budgets

The Budget Generator

Information collected in the farm survey was summarized to determine typical cropping practices and levels of resource use for each subarea. This information was combined with price data obtained from farm supply dealers in the study area to produce budgets by means of the Oklahoma State University Budget Generator, as it is set up on the Colorado State University computer facilities.

The budget generator uses input data on the level of resource use and the price of each item to compute the variable costs associated with purchased inputs. Machinery costs are computed from data on fuel price, machinery sizes and prices, combined with standard coefficients which determine accomplishment rates, repair costs, depreciation, and other fixed costs. The fixed costs per acre are for a typical farm in each subarea.

An interest rate of 6 percent was used to compute interest costs in the budgets. This would seem unreasonably low in these times of 18 to 20 percent interest rates, but these high nominal rates have two components. One is a real return on capital, the other is a premium for inflation. Since all pure projections in this study are in constant dollars, (see the chapter on Baseline projections) the inflation premium is inappropriate. The appropriate interest rate for this study would reflect the real opportunity cost of capital, which has been in the neighborhood of 6 percent over the last few years.

Typical cropping practices and input use are described in the next section of this paper. Budgets for alternative crop and limited irrigation situations that are not presently found in a subarea, but which may be economically feasible, were computed on the basis of farmer experience in similar subareas and Extension Service information.

Since the budget generator has no particular facility for computing irrigation costs, these figures were developed separately. The procedures are described after the section on cropping practices and input use.

The results of the budgeting procedures (purchased input costs, machinery costs, irrigation costs, and receipts from crop sales), were used in a linear programming model to predict how crop output would change in response to changes in input and commodity prices. This model is described later in this report.

Cropping Practices and Input Use

The tillage and cultivation practices that are included in the enterprise budgets for each subarea are shown in Tables 2.8 and 2.9. On any farm, the sequence of field operation will vary with soil and weather conditions and with individual preferences, but the sequences described were encountered most frequently in the farm survey. It was assumed that sunflowers would require the same tillage sequence as sorghum.

Dryland farming is practiced only on some of the loamier sands in subarea 4. Some dryland wheat and grass hay were found on sample farms, but no dryland row crops. For this reason, dryland row crops are not considered an option for the farm model for subarea 4.

Table 2.8. Till[illegible]

Crop	Irrigation Method	Subarea	Tillage and Cultivation Practices
Corn	Flood	2,3,5,6	Disk, Plow, RH, Float, Bed or Furrow, Plant, RC, Ditch
	CP	1-6	Disk, Rip or Chisel, Disk or MT, Plant, RC
Sorghum & Sunflowers	Flood	2,3,5,6	Disk, Chisel, Disk, Bed, Plant, RC, Ditch
	CP	1-6	Disk, Chisel, Disk or MT, Plant, RC
Wheat	Flood	2,3,5,6	Disk 2x, Furrow, FC, Drill, Furrow
	CP	1-6	Disk 2x, FC, Drill
Beans	Flood	2,3,5	Disk, Plow, RH, Float, Bed, Plant, RC, Ditch
	CP	2,3,5	Disk, Chisel, Disk, Plant, RC
Beets	Flood	2,3,5	Disk, Plow, RH, Float 2x, Bed, Plant, Cult. 4x
	CP	2,3,5	Disk, Plow, Disk, FC, Plant, Cult. 4x
Alfalfa Seeding	Flood	2,3,5,6	Disk 2x, RH 2x, Float, Drill, Furrow
	CP	1-6	Disk 2x, Chisel, FC, Drill

Abbreviations: CP - Center Pivot; MT - Mulch Treader; RH - Roller Harrow; FC - Field Cultivator; RC - Rolling Cultivator; Cult. - Cultivate

Table 2.9. Tillage and Cultivation Practices for Dryland Crops.

Crop	Subarea	Tillage and Cultivation Practices
Corn	All (except 4)	Disk, Chisel, Disk w/ Herb., Plant, RC
Sorghum	All (except 4)	Disk, Chisel, Disk, Plant, RC
Sunflowers	All (except 4)	Disk, Chisel, Disk w/ Herb., Plant, RC
Wheat	1,3,4	Blade, Disk, Blade, Rodweed 2x, Drill
	2,5	Disk, Chisel, Rodweed 3x, Drill
	6	Blade 3x, Rodweed 2x, Drill
Beans	2,3,5	Disk, Chisel, Disk w/ Herb., Plant, RC

Typical seeding rates are shown in Table 2.10. The figures for corn, sorghum, and wheat are documented by farm survey information and the experience of agronomists in the study area. For sunflowers, the figures were derived from published reports in nearby states.[Bogle, 1978; Unger, et al., 1975]. For beans, the full irrigation seeding rate was established from farm survey data and the rest of the figures show the same proportionate decline as those for corn. It was considered likely that alfalfa seeding would take place only with full irrigation because inadequate moisture severely limits the possibility of getting a stand. Once the alfalfa is established, hay production can be carried out with the three irrigation levels assumed for all crops.

The details of sugar beet seeding rates are not shown. For sugar beets, seed size and price were coordinated to give a seed cost of about $12/acre in 1979.

Tables 2.11 and 2.12 show fertilizer application rates that are common in the study area. The fertilizer application level for full irrigation was established from farm survey data (except in the Southern High Plains, where it was assumed farmers were already irrigating at a level of two-thirds of full

Table 2.10. Seeding Rates, as Influenced by Irrigation Level.

Crop	Irrigation Level	Seeding Rate or Cost	
Corn	Full	28,000 seeds/acre (0.35 bags/acre)	
	Two-thirds	22,000 seeds/acre (0.28 bags/acre)	
	One-third	16,000 seeds/acre (0.20 bags/acre)	
	Dry	14,000 seeds/acre (0.18 bags/acre)	
Sorghum	Full	8 pounds/acre	
	Two-thirds	6 pounds/acre	
	One-third	4 pounds/acre	
	Dry	3 pounds/acre	
Sunflowers	Full	3 pounds/acre	
	Two-thirds	3 pounds/acre	
	One-third	2 1/2 pounds/acre	
	Dry	2 1/2 pounds/acre	
Wheat		Subareas 1-5	Subarea 6
	Full	60 pounds/acre	60 pounds/acre
	Two-thirds	50 pounds/acre	45 pounds/acre
	One-third	45 pounds/acre	30 pounds/acre
	Dry	45 pounds/acre	25 pounds/acre
Pinto Beans	Full	60 pounds/acre	
	Two-thirds	50 pounds/acre	
	One-third	35 pounds/acre	
	Dry	30 pounds/acre	
Sugar Beets	Full	$12/acre	
	Two-thirds	$ 9/acre	
	One-third	$ 6/acre	
Alfalfa Seeding	Full	Alfalfa, 12 pounds/acre Oats, 32 pounds/acre	

irrigation). For the limited irrigation situations, fertilizer use was scaled back roughly in proportion to yield.

Farmers use a wide variety of fertilizer products. Several different mixtures of nitrogen (N), phosphorus (P), and potash (K) are available in dry and liquid form. The various kinds of dry fertilizer can be blended to meet individual field conditions, as can the different liquid fertilizers.

Since anhydrous ammonia (NH_3) is the cheapest form of N, it is used as a major source of N on most crops. The blended dry or liquid fertilizers are

Table 2.11. Typical Fertilizer Application Rates for Irrigated Crops.

Crop	Subarea	Irrigation Level	Fertilizer Applied (Lb./Acre)		
			18-46-0	33-0-0	NH_3
Corn	All (except 4)	Full	150		200
		Two-thirds	135		180
		One-third	75		100
	4	Full	200		200
		Two-thirds	150		180
		One-third	100		100
Sorghum	All (except 4)	Full	100		100
		Two-thirds	90		90
		One-third	60		70
	4	Full	120		120
		Two-thirds	100		100
		One-third	60		70
Sunflowers	All (except 4)	Full			90
		Two-thirds			90
		One-third			60
	4	Full			120
		Two-thirds			120
		One-third			80
Wheat	All (except 4)	Full	50	50	60
		Two-thirds	50	50	60
		One-third	35	35	50
	4	Full	60	60	75
		Two-thirds	60	60	75
		One-third	35	35	60
Beans	2,3,5	Full	100		
		Two-thirds	90		
		One-third	50		
Beets	2,3,5	Full	200		120
		Two-thirds	180		110
		One-third	120		75
Alfalfa	All	Seeding	100		
		Hay:			
		Full	100		
		Two-thirds	70		
		One-third	40		

Table 2.12. Typical Fertilizer Application Rates for Dryland Crops.

Crop	Subarea	Fertilizer Applied (Lb./Acre) 18-46-0	33-0-0	NH_3
Corn	All (except 4)	50		50
Sorghum	All (except 4)			50
Sunflowers	All (except 4)			45
Wheat	All (except 4)			40
	4	60		40
Pinto Beans		50		
Grass Hay	1,4		50	

used mainly as sources of P and K and other plant nutrients such as sulfur and zinc.

In the survey, it was found that dry fertilizers are more widely used than the liquids. It was decided to let 18-46-0 with a blend of micronutrients (or trace elements) serve as the representative blended fertilizer in the budgets.

Table 2.13 shows the herbicide and insecticide costs commonly incurred by farmers in the study area. For those chemicals that are flown on by airplane, the cost figures include the flying service charge.

Irrigation Levels and Crop Yields

Consumptive water use and irrigation requirements for the crops included in the linear programming model were estimated from data provided with the evaluation of soils and crop yields performed by technicians from the Colorado State University Agronomy Department under the direction of Dr. Robert Heil. Yield response to reduced water application was estimated on the basis of agonomic research reports for Colorado and other High Plains states [Martin, et al., 1980; Blank, 1975].

Table 2.13. Typical Herbicide and Insecticide Costs.

Crop	Irrigated or Dry	Herbicide or Insecticide	Typical Cost ($/Ac.)	Application Method
Corn	I	H	10	Ground Spray
	I	I	8 6	Planter Air Spray
	D	H	6	Ground Spray
Sorghum	I	H	6	Ground Spray
	I	I	8	Air Spray
	D	H	2	Ground Spray
Sunflowers	I & D	H	7	Ground Spray
	I	I	24	Air Spray
	D	I	16	Air Spray
Pinto Beans	I & D	H	7	Ground Spray
	I	I	6	Air Spray
	I(CP)	Sulfate	9	Air Spray
Sugar Beets	I	H	15	Ground Spray
	I	Sulfate	9	Air Spray

Full irrigation water applications are shown in Table 2.14. Irrigation requirements are generally higher in subarea 6 because of higher temperatures and greater evaporation during the growing season.

Water application efficiency, the percentage of pumped water delivered to the root zone, varies by subarea and by irrigation system. Estimates of application efficiency were made after consultation with Extension agronomists familiar with the study area. An efficiency of 65 percent was assumed for gated pipe systems in subareas 2 and 5, where loam and silt loam soils predominate. In subarea 6, which includes a somewhat larger proportion of coarse-textured soils, an efficiency of 60 percent was assumed. For the sandy loam soils of subarea 3, an efficiency of 55 percent was used. Surface irrigation was not

Table 2.14. Full Irrigation Water Applications for Crops in the Study Area.

Application Efficiency	Amount of Water Delivered to Root Zone (inches)	Amount of Water Pumped (inches)				
		Gated Pipe			Center Pivot	
		55%	60%	65%	70%	75%
Subareas 1-5						
Alfalfa	24	44		37		32
Sugar Beets	21	38		32		28
Corn	17	31		26		23
Sorghum	13	24		20		17
Pinto Beans	12	22		18		16
Wheat	10	18		15		13
Sunflowers	9	16		14		12
Subarea 6						
Alfalfa	27		45		39	
Corn	20		33		28	
Sorghum	15		25		21	
Wheat	12		20		17	
Sunflowers	11		18		16	

considered a viable option in subareas 1 and 4 because of the sandiness of the soil.

For sprinkler systems, it was assumed that high and low pressure systems would have the same application efficiency. An application efficiency of 75 percent was used for sprinkler systems in all subareas except 6, where efficiency was set at 70 percent because of higher evaporation.

Full irrigation means the evapotranspiration requirements of the crop are satisfied throughout the growing season. In the case of grains, full irrigation may be suboptimal even if water is abundant, because a plant may use water in certain growth stages to produce vegetative matter without increasing grain yield. Mild moisture stress in the vegetative growth stage may promote root development, allowing the crop to produce a full yield with less irrigation water.

The monthly pumping requirements are shown in Tables 2.15 and 2.16. The data are based largely on monthly irrigation requirements presented in the Colorado Irrigation Guide, a Soil Conservation Service report.

Table 2.15. Monthly Pumping Requirements for Crops in Subareas 1 through 5. (Full Irrigation)

	Amount of Water Pumped (inches)						
Crop	Apr.	May	June	July	Aug.	Sept.	Total
Gated Pipe - 55% Appl. Efficiency							
Alfalfa	5.0	6.0	9.0	11.0	9.0	4.0	44
Sugar Beets	0	5.5	6.0	11.0	11.0	4.5	38
Corn	5.0	0	6.0	10.0	10.0	0	31
Sorghum	0	4.5	4.0	10.0	5.5	0	24
Pinto Beans	0	0	6.0	10.0	6.0	0	22
Wheat	0	6.0	6.0	0	0	6.0	18
Sunflowers	0	0	4.5	6.0	5.5	0	16
Gated Pipe - 65% Appl. Efficiency							
Alfalfa	4.5	5.0	8.0	9.5	7.0	3.0	37
Sugar Beets	0	4.5	5.0	9.5	9.5	3.5	32
Corn	4.0	0	5.0	9.0	8.0	0	26
Sorghum	0	3.5	3.0	9.0	4.5	0	20
Pinto Beans	0	0	4.5	9.0	4.5	0	18
Wheat	0	5.0	5.0	0	0	5.0	15
Sunflowers	0	0	4.0	5.0	5.0	0	14
Center Pivot- 75% Appl. Efficiency							
Alfalfa	4.2	4.2	7.0	8.5	6.1	2.0	32
Sugar Beets	0	4.2	4.2	8.5	8.5	2.6	28
Corn	3.5	0	4.5	8.0	7.0	0	23
Sorghum	0	3.0	2.0	8.0	4.0	0	17
Pinto Beans	0	0	4.0	8.0	4.0	0	16
Wheat	0	4.5	4.0	0	0	4.5	13
Sunflowers	0	0	3.0	4.5	4.5	0	12

Applications of less than three inches of water per irrigation were not considered feasible with gated pipe systems. With surface systems, the application of small amounts of water commonly results in wetting the upper end of the furrows but not the lower end. Three inches of water per irrigation was

Table 2.16. Monthly Pumping Requirements for Crops in Subarea 6.

Crop	Apr.	May	June	July	Aug.	Sept.	Total
	Amount of Water Pumped (inches)						
Gated Pipe - 60% Appl. Efficiency							
Alfalfa	5.0	7.0	10.0	11.0	9.0	3.0	45
Corn	6.0	0	7.0	10.0	10.0	0	33
Sorghum	0	5.0	6.0	8.0	6.0	0	25
Wheat	0	7.0	6.0	0	0	7.0	20
Sunflowers	0	0	5.0	6.5	6.5	0	18
Center Pivot - 70% Appl. Efficiency							
Alfalfa	4.0	6.0	9.0	10.0	7.0	3.0	39
Corn	5.0	0	5.0	9.0	9.0	0	28
Sorghum	0	4.0	5.0	7.0	5.0	0	21
Wheat	0	6.0	5.0	0	0	6.0	17
Sunflowers	0	0	4.0	6.0	6.0	0	16

considered the minimum required to produce an adequately uniform distribution of water over the field.

In addition to the full irrigation regime, in which the evapotranspiration requirements of the crop are satisfied throughout the growing season, two restricted levels of irrigation were considered: two-thirds of the full irrigation amount and one-third of the full irrigation amount. It was assumed that the farmers would be free to allocate the limited water so as to maximize yield for the growing season. Some crops have "critical periods" when water shortages can have a drastic effect on yields, while timing is less critical on other crops. Limited irrigation water was allocated according to an optimal irrigation decision model developed by H.G. Blank [1975] and the distribution of irrigation requirements presented in the Colorado Irrigation Guide. The results are shown in Tables 2.17, 2.18, and 2.19.

On corn, irrigation timing changes as water becomes more scarce, concentrating on the late vegetative and flowering stages of plant development. It

Table 2.17. Monthly Allocations of Limited Irrigation Water for Gated Pipe Systems in Subareas 2, 3, and 5.

Crop	Amount of Water Pumped (inches)						
	Apr.	May	June	July	Aug.	Sept.	Total
Subarea 3 - 55% Appl. Efficiency							
Alfalfa	3.0	4.0	6.0	8.0	6.0	3.0	30
	0	4.0	4.0	4.0	3.0	0	15
Sugar Beets	0	3.5	3.5	8.0	8.0	3.0	26
	0	3.0	3.0	3.0	4.0	0	13
Corn	3.0	0	4.0	8.0	5.0	0	20
	0	3.0	3.0	4.0	0	0	10
Sorghum	0	0	4.0	8.0	4.0	0	16
	0	0	4.0	4.0	0	0	8
Pinto Beans	0	0	3.0	8.0	3.0	0	14
	0	0	3.0	4.0	0	0	7
Wheat	0	3.5	3.5	0	0	5.0	12
	0	3.0	0	0	0	3.0	6
Sunflowers	0	0	3.0	4.0	3.0	0	10
	0	0	0	2.5	2.5	0	5
Subareas 2 & 5 - 65% Appl. Efficiency							
Alfalfa	3.0	3.0	5.0	7.0	6.0	0	24
	0	3.0	3.0	3.0	3.0	0	12
Sugar Beets	0	3.0	3.0	7.0	6.0	3.0	22
	0	3.0	3.0	5.0	0	0	11
Corn	3.0	0	4.0	7.0	4.0	0	18
	0	3.0	3.0	3.0	0	0	9
Sorghum	0	0	3.0	7.0	3.0	0	13
	0	0	3.5	3.5	0	0	7
Pinto Beans	0	0	3.0	6.0	3.0	0	12
	0	0	3.0	3.0	0	0	6
Wheat	0	3.0	3.0	0	0	4.0	10
	0	3.0	0	0	0	3.0	6
Sunflowers	0	0	3.0	3.0	3.0	0	9
	0	0	0	2.5	2.5	0	5

was assumed that this would also happen on sorghum, pinto beans, and sunflowers.

Alfalfa irrigation timing could remain the same as water supply decreases, but it was thought more reasonable to concentrate the water on two cuttings,

Table 2.18. Monthly Allocations of Limited Irrigation Water for Center Pivot Systems in Subareas 1 through 5.

	Amount of Water Pumped (inches)						
	Apr.	May	June	July	Aug.	Sept.	Total
Alfalfa	2.0	3.0	4.0	6.0	5.0	2.0	22
	0	1.0	4.0	4.0	2.0	0	11
Sugar Beets	0	2.0	3.0	6.0	5.0	2.0	18
	0	2.0	2.0	3.0	2.0	0	9
Corn	3.0	0	3.0	6.0	4.0	0	16
	0	2.0	2.0	4.0	0	0	8
Sorghum	0	0	3.0	6.0	3.0	0	12
	0	0	1.0	3.0	2.0	0	6
Pinto Beans	0	0	2.0	6.0	2.0	0	10
	0	0	1.0	3.0	1.0	0	5
Wheat	0	2.0	2.0	0	0	4.0	8
	0	2.0	0	0	0	2.0	4
Sunflowers	0	0	2.0	3.0	3.0	0	8
	0	0	0	2.0	2.0	0	4

rather than the usual three, when water went to the one-third of full irrigation level. With beets, the irrigation timing remained the same at the two-thirds water availability level. At the one-third level, the irrigation season was shortened slightly. This also was the procedure adopted for wheat.

The decision to not allow applications of less than three inches of water per irrigation under gated pipe systems created some problems with wheat and sunflowers. For example, an allowance of five inches of water would have to be applied all in one month, which is not very realistic and makes these crops appear relatively unattractive since the water supply constraints operate on a monthly basis. For sunflowers, it was decided to allow applications of less than three inches in as many as two consecutive months. This would imply an irrigation begun during the last days of one month and completed after the first of the next month. For winter wheat, however, the irrigations do not

Table 2.19. Monthly Allocations of Limited Irrigation Water, Subarea 6.

Crop	Apr.	May	June	July	Aug.	Sept.	Total
	Amount of Water Pumped (inches)						
Gated Pipe - 60% Appl. Efficiency							
Alfalfa	0	5.0	8.0	8.0	6.0	3.0	30
	0	3.0	4.0	5.0	3.0	0	15
Corn	3.0	0	5.0	8.0	6.0	0	22
	0	3.0	3.0	5.0	0	0	11
Sorghum	0	3.0	4.0	5.0	5.0	0	17
	0	0	0	4.0	4.0	0	8
Wheat	0	4.0	4.0	0	0	6.0	14
	0	3.0	0	0	0	4.0	7
Sunflowers	0	0	4.0	4.0	4.0	0	12
	0	0	0	3.0	3.0	0	6
Center Pivot - 70% Appl. Efficiency							
Alfalfa	0	4.0	7.0	7.0	6.0	2.0	26
	0	3.0	3.0	4.0	3.0	0	13
Corn	3.0	0	4.0	8.0	4.0	0	19
	0	2.0	3.0	4.0	0	0	9
Sorghum	0	3.0	3.0	4.0	4.0	0	14
	0	0	1.0	3.0	3.0	0	7
Wheat	0	4.0	3.0	0	0	4.0	11
	0	3.0	0	0	0	3.0	6
Sunflowers	0	0	3.0	4.0	3.0	0	11
	0	0	0	2.5	2.5	0	5

come on consecutive months. In the case of wheat it was decided to require a minimum of two irrigations, or six inches of water.

Of course, reducing the amount of irrigation water available has an adverse effect on yields. The effect on yields was computed in the form of a ratio of the yield under the limited irrigation regime (Y_L) to the yield under full irrigation (Y_{max}) for each crop. References employed to estimate crop yield response to limited irrigation include Blank [1975], Nicholson, et al., [1974], Martin, et al., [1980], Showcroft, et al., [1978], and Shipley and Regier [1975].

Table 2.20 shows the yield factors for selected crops under limited irrigation. Of course, the yield effect of limited irrigation depends mostly on soil moisture holding capacity and on the weather during a particular growing season. Further agronomic research will probably refine the data and computational procedures needed to relate water applications and crop yields, but the yield factors in Table 2.20 are thought to be reasonable as approximations for the study area.

Table 2.20. Yield Factors (Y_L/Y_{max}) for Selected Crops and Soil Types Under Limited Irrigation Conditions in the Study Area.

	Irrigation Level			
	2/3 of Full		1/3 of Full	
Crop	Loams	Sands	Loams	Sands
Alfalfa	.67	.60	.40	.33
Sugar Beets	.85	NG	.55	NG
Corn	.85	.75	.50	.35
Sorghum	.90	.80	.65	.55
Pinto Beans	.85	NG	.60	NG
Winter Wheat	.95	.80	.65	.55
Sunflowers	.90	.80	.65	.55

NG - Not grown because soil cover is likely to be inadequate.

The crop yields under full irrigation used in this study are shown in Table 2.21. The figures were chosen after analyzing the farm survey data, with consideration also given to yield figures from Colorado Agricultural Statistics and consultation with agronomists familiar with conditions in the study area.

It should be noted that the yields in Table 2.21 assume full irrigation. In most of the Northern High Plains, full irrigation is the typical practice. However, in the Southern High Plains water supply limitations have already

Table 2.21. Crop Yields in the Study Area.

	Subarea					
	1	2	3	4	5	6
<u>Irrigated Crops - Full Irrigation</u>						
Alfalfa (tons)	4.5	4.5	4.5	4.5	4.5	4.5
Sugar Beets (tons)		19.0	17.0		17.0	
Corn (bu.)	130.0	130.0	130.0	130.0	130.0	120.0
Sorghum (bu.)	60.0	60.0	60.0	60.0	75.0	90.0
Pinto Beans (cwt.)		17.0	16.0		16.0	
Winter Wheat (bu.)	50.0	50.0	50.0	50.0	50.0	50.0
Sunflowers (cwt.)	18.0	18.0	18.0	18.0	18.0	18.0
<u>Dryland Crops</u>						
Corn (bu.)	30.0	30.0	20.0	20.0	20.0	20.0
Sorghum (bu.)	20.0	20.0	20.0	20.0	20.0	20.0
Pinto Beans (cwt.)		3.0	3.0		3.0	
Winter Wheat (bu.)	32.0	32.0	25.0	22.0	22.0	18.0
Sunflowers (cwt.)	9.0	9.0	9.0	9.0	9.0	9.0

forced many farmers to cut water applications back to about two-thirds of full irrigation.

<u>Irrigation Costs</u>

<u>Power and Fuel Costs</u>. Two energy sources for pumping were considered in this study -- electricity and natural gas. In the five subareas in the Northern High Plains of Colorado, about 98 percent of the irrigation pumps were driven by one of these two power sources.

The electric power cost per acre inch of water pumped is computed using the equation

$$PC = \frac{1}{12} \frac{(1.025)(TDH)}{(PPE)} (ER) \tag{2.1}$$

where PC = the power cost, in dollars per acre inch of water pumped.

TDH = total dynamic head, in feet.

PPE = pumping plant efficiency (0.55 for gated pipe systems, 0.57 for sprinkler systems).

ER = electric rate, dollars per KWH.

The cost of natural gas per acre inch of water pumped is computed using the equation

$$NGC = \frac{1}{12}\,\frac{(0.00368)(TDH)}{(PPE)}\,(NGR) \qquad (2.2)$$

where NGC = the natural gas cost, in dollars per acre inch of water pumped.

TDH = total dynamic head, in feet.

PPE = pumping plant efficiency (0.10 for gated pipe systems, 0.11 for sprinkler systems).

NGR = natural gas rate (price), in dollars per MCF. (1 MCF = 1000 cubic feet)

Total dynamic head is the sum of lift, friction losses, and discharge head. Lift is the vertical distance from the pump discharge to the static water table, plus the drawdown that occurs when the pump is operating plus any vertical distance from the pump discharge to the water distribution system. The latter figure would be zero for most gated pipe systems and about 10 feet for center pivot systems. Drawdown is computed by dividing the well capacity (in gallons per minute or GPM) by the specific capacity of the aquifer (in GPM per foot of depth).

For all systems, there is some friction loss involved in lifting the water through the column to the surface and delivering it to the point of use. An average figure of 12 feet was included in computing TDH.

Discharge head is equal to the system operating pressure (in pounds per square inch or psi), times 2.31. Operating pressures were assumed to be 5 psi for gated pipe, 40 psi for low pressure sprinklers, and 75 psi for high pressure sprinklers.

Table 2.22 shows the components of total dynamic head for a representative well. The numbers are hypothetical and are presented to illustrate the procedure of calculating total dynamic head. Table 2.23 shows the energy costs of pumping for this representative well, based on equations (2.1) and (2.2) and typical 1979 energy prices.

Table 2.22. Total Dynamic Head (TDH) for a Representative Well. (All figures in feet)

Irrigation System[a]	Static Depth	Draw-down	Lift to Pipe	Friction Loss	Discharge Head (PSIx2.31)	TDH
HP	180	40	10	12	173	415
LP	180	40	10	12	92	334
GP	180	40	0	12	12	244

[a]HP - High pressure sprinkler (75 psi)
LP - Low pressure sprinkler (40 psi)
GP - Gated pipe (5 psi)

Table 2.23. Energy Costs for Irrigation Pumping with a Representative Well.[a]

TDH (Feet)	Electric Power Cost ($/Ac-In)	Natural Gas Cost ($/Ac-In)
415	3.11	2.31
334	2.50	1.86
244	1.89	1.50

[a]Electricity rate = 5¢/KWH
Natural gas rate = $2/MCF

Maintenance and Repair Costs. Maintenance and repair costs for irrigation facilities are presented in Tables 2.24 and 2.25. The figures are averages based on the farm survey data. Recognizing that maintenance and repair costs can vary widely among wells and among farm managers, the figures in the two tables are thought to be representative for the study area. The costs included are for parts and hired service; labor performed by the farm work force is included in irrigation labor.

Table 2.24. Pumping Plant Maintenance and Repair Costs.

	Natural Gas	Electric
Power Unit		
Routine Items:		
Oil and Filters	$150	
Tune-up Parts	100	
Batteries	75	
Other	75	$20
TOTAL	$400	$20
Amortization of Overhaul Costs	$500	$50
Pump		
Drip Oil	$30	$30
Amortization of Overhaul Costs	$250	$250
Annual M & R Costs: Total	$1180	$350
Per Acre (130 acres)	$9.10	$2.70
(150 acres)	$7.85	$2.35
Per Acre Inch (2860 ac. in.)	$0.41	$0.12
(3300 ac. in.)	$0.36	$0.11

The typical center pivot system irrigated 130 acres and the typical gated pipe system irrigated 150 acres. Average pumpage was reported to be about 22 inches of water per acre for corn. Based on these figures, the maintenance

Table 2.25. Irrigation Distribution System Maintenance and Repair Costs.

	Center Pivot	Gated Pipe
Annual M & R Costs: Total	$600	$180
Per Acre	$4.60 (130 ac.)	$1.20 (150 ac.)
Per Acre Inch	$0.21 (2860 ac. in.)	$0.05 (3300 ac. in.)

and repair costs per acre and acre inch are computed in Tables 2.25 and 2.26.

Some low pressure pivots operate without an end gun, so they only cover 120 acres per circle. It was assumed that the lower acreage would result in proportionately lower pumpage and repair costs, so that the maintenance and repair costs per acre would be the same for high and low pressure systems.

Irrigation Labor Costs. Twenty-eight farmers in the survey provided estimates of the time they spent on checking their center pivots each day. Their average reported amount of time, along with the time it takes a pivot to make a complete circle, allows computation of irrigation labor per acre per irrigation. The survey data show that a typical farmer spends about one hour per day per pivot, with the pivot covering a complete circle every three days. Under these conditions he would spend 3 hours ÷ 130 acres = 0.023 hours per acre per irrigation. A three-day circle commonly means that about one inch of water is being applied per acre, according to survey respondents. This means that irrigation labor is 0.023 hours per acre inch.

An additional 12 hours of maintenance work before or after the irrigation season would add 0.092 hours per acre for the season, or 0.004 hours per acre inch on corn (22 inches of water pumped). This figure would be somewhat lower on sugar beets and alfalfa, higher for other grains and pinto beans.

As an estimate of typical irrigation labor time with a center pivot, 0.030 hours per acre inch was selected.

Fourteen farmers with gated pipe systems were willing to take the time to work out a fairly detailed estimate of their irrigation labor time. This time, in hours per irrigation, is a function of the time spent with a head of water, the number of furrows irrigated, and the length of the furrows. The average, including the time to lay out the pipe in the spring and pick it up again in the fall, was 0.30 hours per acre per irrigation. About 4 inches of water were applied with each irrigation, so irrigation labor was 0.075 hours per acre inch of water applied.

Irrigation labor was valued at $4 per hour, which means that irrigation labor costs would be $0.12 per acre inch for a center pivot system; and $0.30 per acre inch for gated pipe.

CHAPTER III

GROUNDWATER HYDROLOGY, ADMINISTRATION, AND HYDROLOGIC MODEL DESIGN*

The part of eastern Colorado which is included within the boundaries of the six state Ogallala study is referred to as the High Plains. The Arkansas River eroded away the Ogallala Formation and thus divided the area into a northern and southern portion. Figure 1.1 illustrates the location and extent of the two areas.

This chapter contains a very brief description of the hydrology of the region and the hydrologic model. There are a number of references which describe in detail the hydrology and geology of the High Plains region. The U.S. Geological Survey initiated investigations of subareas in the region during the mid-1950s and data collection efforts have continued since that time.

A report prepared by Woodward, Clyde, Sherard, and Associates [1966] describes the Northern High Plains and provided the information required by the Colorado Groundwater Commission to designate the area. R. W. Beck and Associates [1967] describes the Southern High Plains and provided similar data needed by the Commission to designate that area. Both of these publications contain extensive bibliographies of all known reports describing these areas. The bibliography at the end of the present report contains references for some of the more important reports that describe the areas in detail.

The reader interested in more detail is referred to a companion report by Longenbaugh [1982] which provides further discussion of the hydrology,

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*This chapter prepared by Robert Longenbaugh.

geology, current administrative policies, municipal and industrial usage, groundwater quality, and contains extensive tables of the 1979 input data for the hydrologic and economic models.

Hydrologic Description

Northern High Plains

The Northern High Plains is a 9,000 square mile area including parts of nine counties. It is bounded on the north by the South Platte River drainage and on the south by the Arkansas River drainage. The eastern boundary is the state line with the adjacent states of Kansas and Nebraska. The topography slopes from west to east.

The major aquifer is the Ogallala Formation. In parts of Sedgwick, Logan, and Phillips counties, the Whiteriver Formation underlies the Ogallala and is in direct hydraulic connection with the Ogallala aquifer. In Cheyenne and Kiowa counties, there are some wells which take water from the deeper Dakota Sandstone.

The records of the Colorado Division of Water Resources show that approximately 4,350 irrigation wells have been drilled in the Northern High Plains. The power records for 1979 indicate about 3,830 were in operation that year [Longenbaugh, 1981]. The current administrative policies restrict the drilling of new wells to irrigate new lands throughout much of the area. It is estimated that another 200-250 wells may be permitted and most of those will be located in the under-developed areas which coincide with the sandhills in southern Phillips and Yuma counties.

The groundwater table also slopes from west to east. There is no surface or groundwater inflow into the area. The only source of water is precipitation that falls on the land surface. McGovern and Coffin [1963] of the U.S.

Geological Survey estimate the average annual recharge to be about three-fourths of an inch per year which amounts to 430,000 acre feet over the 9,000 square mile area. Recharge rates may exceed two inches per year in the sand-hills area and be near zero on some of the less permeable soils.

The saturated thickness is very small on the western edge of the area and increases eastward with a maximum of about 350 feet in northeast Yuma County. Much of the area had original saturated thicknesses of 100 to 150 feet.

Water levels have continued to decline since the major development period began in the early 1960s. Annual declines of three to five feet per year have been observed in many areas and especially in eastern Kit Carson county. Approximately 650 observation wells are measured annually. The U.S. Geological Survey has prepared maps of water level declines [Borman and Majors, 1977] and tabulated measurements of the depth to the water table [Boettcher, et al., 1969; Hofstra, et al., 1972; Hofstra and Majors, 1974; Borman, 1980; Borman and Meredith, 1981; Major, et al., 1975].

The density of wells and use of groundwater varies with the saturated thickness. The greatest declines have been occurring in areas with the largest combined pumping rates. The average decline is about 1.3 percent of the saturated thickness per year and this rate is increasing. The accelerated rate of decline is due to the continuously enlarging and intersecting of the cones of depression. Another reason is believed to be the reduction of specific yield that is occurring as water levels decline into aquifer zones with more cementation and tighter compaction. Specific yields are believed to average 15 percent in the upper part of the aquifer but may be less than 10 percent in the lower zones.

As the depletion of the aquifer occurs, the outflow to the east into Kansas and Nebraska will diminish. The natural recharge to the aquifer is expected to remain constant with time. With the reduced groundwater outflows, more of the natural recharge can be captured and used in Colorado. As the number of wells that are pumping decrease because of lack of saturated thickness or because of the rising costs of pumping, the total withdrawals from the aquifer will also decrease. It is expected that within the next 20 or 30 years, the rate of aquifer depletion will decrease and eventually reach an equilibrium state. At that steady state condition, there might still be 1,500 to 2,000 of the wells pumping but probably at a lower annual rate. The total pumpage under those conditions would equal that part of the natural recharge which can be captured for use. Some hydrologists estimate it could range from 250,000 to 300,000 acre feet annually.

Southern High Plains

The area encompassing approximately 2,500 square miles in the southeast portion of Prowers county and most of Baca county is referred to as the Southern High Plains. It is bounded on the north and northwest by the Arkansas River drainage. The irregular western boundary coincides with the intersection between the plains and mountains. The state lines with Kansas on the east and Oklahoma and New Mexico on the south nearly coincide with geologic boundaries for some of the aquifers that supply this area.

The geologic conditions in the Southern High Plains are complex. The Ogallala Formation overlies much of the area as a thin veneer and there are some thicker deposits in local areas coinciding with erosion channels into the underlying bedrock. Water in the Ogallala is unconfined, and the localized areas have sufficient saturated thickness to support irrigation wells. There are three underlying artesian, confined aquifers: the Dakota, Cheyenne, and Dockum Sandstones. These sandstone formations were under significant artesian pressure prior to the irrigation development which occurred in the early 1960s and, at that time, there were a number of flowing artesian wells.

Much of the irrigation development in this area occurred prior to the development of any administrative policies. Farmers were permitted to drill wells to any depth and most wells are completed in more than one aquifer. Historically, as water levels and artesian pressures were lowered in the upper aquifers, the farmer would deepen the well to the next formation. He would benefit from the artesian pressure of the lower formation for one or two years or until the development pumped off the artesian head. The drilling practices which interconnected the aquifers now allow drainage of water from the upper aquifers to the lower formations.

Records from the Colorado Division of Water Resources show that about 1,250 irrigation wells have been drilled in the Southern High Plains. Longenbaugh's [1981] examination of the power records reported that about 940 wells actually operated in 1979.

Water table elevations and piezometric heads have declined continuously in all the aquifers since development began. The reason for the declines is that pumping is exceeding recharge rates. The natural recharge to the Ogallala is small because the annual rainfall is only 12-15 inches. Because of the lower rainfall, higher evapotranspiration, and tighter soils, the average natural recharge rate is probably less than the three-fourths inch rate estimated for the Northern High Plains. Natural recharge to the sandstones occurs where they outcrop near the mountains to the west. The quantity of recharge in the Southern High Plains can only be guessed at but is assumed to be only a small fraction of the amount now being pumped from each aquifer. The sandstone formations also extend into Kansas and there is some groundwater outflow into Kansas. Because of the complexity caused by the inter-aquifer connections due to wells, the small amount of natural recharge, and the groundwater outflow, it is possible that no equilibrium level of water table would ever occur at a greatly reduced pumping rate. It appears that for most of the area the water levels and piezometric heads will continue to decline. Pumping levels in many of the irrigation wells now exceeds 400 feet, and the well capacity decreases significantly during the pumping season. Many of the wells drilled into the sandstones produce significant quantities of sand which causes excessive wear on pumps and other irrigation equipment. Sand pumping is common because of the drilling practices and either improper selection of perforated well screen or lack of any casing. A common practice during early development was to drill and set casing through the unconsolidated Ogallala and then continue to drill a slightly smaller open hole into the deeper sandstones without any casing.

Administration of Groundwater

Both the Northern and Southern High Plains areas were identified as designated groundwater basins by the Colorado Groundwater Commission pursuant to Colorado's statutes. On May 13, 1966, the Commission designated the Northern High Plains and since then eight Groundwater Management Districts, including most of the designated area, have been formed. The Commission designated the Southern High Plains on September 15, 1967, and a single management district for a portion of the area has since been formed. A map of the designated area and accompanying management districts is included in the report by Longenbaugh [1982].

The Groundwater Commission is responsible for developing policies for regulating the use of groundwater within any designated basin. The management districts can also promote local rules and regulations which could be more restrictive than the Commission policies. The Commission would incorporate the Districts' policies into their policies for the specified areas.

Soon after creation of the Northern High Plains Designated Basin, the Commission adopted policies to limit the number of wells and quantity of water that could be pumped so as to prolong the life of the aquifer. The decision was to limit pumping so that depletions would not exceed 40 percent in 25 years. They also required a half-mile spacing between wells and limited the annual withdrawals to 2.5 acre feet per acre irrigated. The Commission controls the number of well permits issued for construction of new wells and it monitors the acres irrigated to limit the amount pumped by each well. Prospective irrigators must obtain a permit from the Commission prior to constructing a well or pumping water for beneficial use.

There are some areas in Kit Carson county where development preceded the Commissions' control and depletions have exceeded the 40 percent depletion in 25 years. Except for the sandhills areas in Phillips and Yuma counties, the area is now fully developed and no new well permits are being granted.

In the Southern High Plains most of the irrigation development preceded the September 1967 date when the area was designated. The only policies implemented by the Commission were to enforce at least a half-mile spacing between wells for any new wells and to limit the annual withdrawals to three acre feet per acre for any new lands irrigated. Because of the rapidly declining water levels in that area, there has not been much interest in drilling any additional wells to irrigate new lands.

It has been the Commission's policy not to permit supplemental wells. Some replacement wells have been requested and permitted on the condition that the old well be plugged. Because of declining water levels the pumping rates have decreased in many wells. This is especially true where saturated thicknesses are 50 feet or less. Without supplemental wells and due to reduced pumping rates, it becomes more and more difficult to provide adequate water supplies for the original irrigated acres during peak consumptive use periods. This has forced many farmers to reduce their irrigated acres and/or to change cropping practices.

Hydrologic Model

It was necessary to develop a hydrologic model which would predict how, when, and where water levels would decline as pumping continues. As described in detail in Chapter IV, the hydrologic model was linked to an economic model which calculated the future agricultural production and water demand. Solutions were obtained in a leap-frog fashion where the economic model determines the types and acreages of each crop grown with its related water demands. Assuming the water demands are met by pumping, this information is fed into the hydrologic model which predicts how the water levels decline. The water level declines will result in increased pumping heads and costs as computed by equations 2.1 and 2.2.

The hydrologic model was developed using the basic continuity principle:

$$\text{Inflow} - \text{Outflow} = \text{Change in Storage} \tag{3.1}$$

This equation was developed for the specific groundwater system. To provide the capability for evaluating regional variations, the hydrologic model was developed for use on an area represented by one township, 36 square miles. The modelers felt this level of resolution was needed to provide a reasonable representation of the physical system. Selection of the township grid size was a compromise between the better resolution that might be expected with a smaller grid but much higher modeling costs versus the lack of sufficient detail that might be obtained using grids represented by a county. The data were also readily available on a township grid.

The saturated thickness, pumping depths, well density, and aquifer properties vary significantly throughout Colorado's High Plains. Data have been collected by the Colorado Division of Water Resources on most of the irrigation wells. Data include lithologic logs of the geology, depths to static water levels at the time of drilling, installed pump capacities, acres irrigated, date of first beneficial use, and values for specific capacity. These data coupled with annual measurement of the nearly 700 observation wells has permitted the development of several maps: water table contour maps, water table decline maps, saturated thickness and bedrock contour. Tables listing data by township [Longenbaugh, 1981] have also been prepared for values of: specific capacities; pump capacity; number of electric and internal combustion pumping plants, 1979; township acreage; and 1979 saturated thickness. Data to describe the areal variation in aquifer properties of porosity, specific yield, permeability, and transmissability have not been collected or developed. Natural recharge varies significantly from one location to another and is largely controlled by soil type where sandy soils may have annual rates of several inches per year and the tighter soils may have little, if any, recharge.

For the Northern High Plains hydrologic model it was assumed that the natural recharge was uniformly three-fourths of an inch per year. The specific yield or storage coefficient was assumed to be 15 percent over the entire area. Values for specific capacity were averaged for each township using data reported at the time the irrigation wells were drilled.

In the Southern High Plains, the wells are often completed in all three aquifers. This required that some weighted averages for pumping levels, static water level depths, saturated thickness, specific capacity, and pump capacity be developed. Because of this averaging process and the lack of detailed data describing each aquifer's properties, the hydrologic model is highly simplified. The model should accurately represent the trends, but the accuracy of the results will be less than that of the projections for the Northern High Plains. Natural recharge was estimated to be three-fourths of an inch per year and the storage coefficient of 15 percent was also selected.

For equation 3.1, the inflows to the groundwater system were considered to include groundwater underflow plus deep percolation to the water table of natural recharge, irrigation return flows, and any future artificial recharge. It was assumed that 15 percent of all water pumped for irrigation would percolate back to the water table. Natural recharge was assumed to be uniformly three-fourths of an inch per year over the entire area. The hydrologic model could have handled variable recharge rates, but data were lacking to document how rates varied areally. The computer code contains provisions for specifying artificial recharge rates by township, but all analyses reported in this publication were made with that rate set to zero.

Outflows included the groundwater inflow and withdrawals by pumping. It is assumed that there is no upward or downward leakage to underlying aquifers.

Pumping rates were summed for all wells within the township. The annual volume of water pumped within each township is computed from data obtained from the economic linear program analyses for the respective irrigated acreage in each township. The irrigated acreage per township may change for different time periods depending upon economic and hydrologic constraints. A further description of the cyclic operation of the hydrologic and linear programming model can be found in Chapter IV and is illustrated in Figure 4.1.

It was assumed that the groundwater underflows plus natural recharge into each township were equal to the underflows out of each township. This on first appearance appears to be a very crude assumption, but it was necessary to allow an independent solution to equation 3.1 for each time period for each township. In actuality, the water table elevations in the aquifer prior to irrigation development were considered to be steady state which implies the groundwater inflow plus natural recharge equaled groundwater outflow for a particular grid. As water levels decline both the groundwater inflow and outflow still decrease. If the groundwater outflow decreases faster than the groundwater inflows, it will be possible to capture more of the natural recharge. It is felt that the assumption that groundwater inflow plus natural recharge equals outflow for the 40-year projection period is reasonably realistic, because the water table will generally decline uniformly over a broad area. The rate of natural recharge is assumed to be constant with time, and thus the difference between groundwater inflow and outlfow in a particular grid are assumed to be time independent.

Computation of Water Level Changes

The changes in water table elevations, saturated thickness, and pumping levels are computed for each township. The static depth to the water table for the next time period is calculated as a function of the current static depth, storage coefficient, water consumption, natural recharge rate, artificial recharge rate, and deep percolation.

Natural recharge, artificial recharge, and deep percolation are expressed as inches per year and are considered to be average values for the township. The model is capable of including localized values for artificial recharge and deep percolation. These two parameters had zero values inserted for all the analyses reported here. Natural recharge was estimated as three-fourths of an inch per year.

The equations in word form are:

$$\text{STATIC DEPTH}_{i(t+1)j} = (\text{STATIC DEPTH} + \text{WATER LEVEL CHANGE})_{itj} \quad (3.2)$$

$$\text{SATURATED THICKNESS}_{i(t+1)j} = (\text{SATURATED THICKNESS} - \text{WATER LEVEL CHANGE})_{itj} \quad (3.3)$$

$$\text{WATER LEVEL CHANGE}_{itj} = \text{NET VOLUME WITHDRAWN}_{itj}/(\text{TOWNSHIP ACRES}_{ij} * \text{STORAGE COEFFICIENT}_{i}) \quad (3.4)$$

$$\text{WATER WITHDRAWN}_{itnj} = ((\text{LP WATER WITHDRAWN}_{itln}/\text{MODEL ACRES}_{i}) * \text{TOWNSHIP IRRIG. ACRES}_{itlnj}) \quad (3.5)$$

$$\text{NET VOLUME WITHDRAWN}_{itj} = ((\text{WATER WITHDRAWN}_{itnj} - (\text{NAT RECHG} + \text{ART RECHG} + \text{DEEP PERC}) * \text{TOWNSHIP ACRES}_{ij})) * \text{YEARS}/12 \quad (3.6)$$

where i is a subscript defining the subarea

j is a township within the subarea

t is the time period; t = 1:1979; t = 2:1985; t = 3:1990; t = 4:2000; t = 5:202

l is the power source; electric or natural gas

n is depth zone

YEARS is the length of time in years between the successive time periods.

LP WATER WITHDRAWN is expressed as acre inches and obtained from the linear program solution.

The discharge capacity of each well is expected to decrease when the saturated thickness becomes a limiting factor. The average capacity for 1979 conditions was estimated from well capacity data obtained from the Division of Water Resources and adjusted to reflect a weighted average considering the number of sprinkler pumps and open discharge pumps in each township. The capacity is computed as a function of saturated thickness and specific capacity using the following equation:

$$CAPACITY_{i(t+1)j} = MIN(AVERAGE\ CAPACITY_{i},\ 2/3 * SAT.\ THICKNESS_{i(t+1)j} * SPECIFIC\ CAPACITY_{ij}) \qquad (3.7)$$

If the saturated thickness falls below a critical lower bound, it was assumed that it become economically infeasible to continue with irrigated agriculture. A saturated thickness of 35 feet was selected as the critical level, and this would correspond to well discharges ranging from 150 to 300 gallons per minute. With this low discharge rate, it was felt the number of acres that could be irrigated with a single well would be so low that an individual farmer could not continue with irrigation. Computer logic was developed to adjust the number of remaining wells that would pump in future time periods when the saturated thickness dropped to the critical limit. If water levels rose due to artificial recharge or natural recharge then a provision was included so that the number of wells in a grid could be returned to the original number if it was economically feasible.

CHAPTER IV

PROJECTION MODEL

The basic form of the projection model is a computer simulation which models the combined hydrologic and economic interactions which govern the rate and profitability of water extraction. The hydrologic assumptions and procedures have been described in the preceding chapter, while the assumptions entered into the economic model are found in Chapter II.

The principal hypotheses by which the model was organized were:

1. Water demand at any given time period depends on the profitability of irrigation, and
2. Profitability of irrigation depends on (a) cost and supply of water, (b) productivity of water (how much an acre foot of water adds to crop production), (c) prices of commodities produced, (d) prices of resources used in production, particularly of energy resources, and (e) the general level of production technology available at each particular time period.

The general format of the model followed a pattern for projecting long term aquifer management consequences employing computer simulation developed by Martin, Burdak, and Young [1969] and Bredehoeft and Young [1970]. It employed a mathematical technique called linear programming to represent the profit-maximizing farm resource allocation decisions combined with a hydrologic model to forecast aquifer behavior. Linear programming was developed during World War II to help solve military allocation problems. Among its numerous applications have been the representation of farm decision problems and for use in projecting farmer choices in the face of changing price, technology or institutional conditions [Heady and Candler, 1958; Beneke and Winterboer, 1973].

The next section of this chapter describes the linear programming models employed as sub-routines in the simulation model. The concluding section of the chapter provides details of the format and computational process employed in the general simulations.

The Linear Programming Model

General Overview

A linear programming model was constructed for each subarea. The basic unit modeled was a four-well irrigation system on a "typical" section of land. The model for subarea 2 will be used for illustrative purposes since it is one of the largest, involving all of the crop and irrigation system options considered in the study. Table 4.1 shows the options considered in each sub-area.

Table 4.1. Crop and Irrigation System Options Included in the Linear Programming Model by Subarea.

	Subarea					
	1	2	3	4	5	6
Crops						
Corn	X	X	X	X	X	X
Sugar Beets		X	X		X	
Pinto Beans		X	X		X	
Wheat	X	X	X	X	X	X
Sorghum	X	X	X	X	X	X
Sunflowers	X	X	X	X	X	X
Alfalfa	X	X	X	X	X	X
Irrigation Systems						
Gated Pipe		X	X		X	X
Low Pressure Pivot	X	X	X	X	X	X
High Pressure Pivot		X			X	X

The linear program was set up to run on the Apex III linear programming software package from Control Data Corporation. Several computer storage files were created so that hydrologic and economic data in the linear programming matrix could be readily changed or updated to meet the assumptions of a variety of scenarios.

A solution to the linear programming problem allocated land and water among seven different crops, each of which could be watered by three different irrigation systems at three different levels of water application. These combinations created 63 crop activities. The irrigation levels were full irrigation, two-thirds of full irrigation, and one-third of full irrigation. In addition, all of the crops except sugar beets could be grown under dryland conditions.

The linear programming matrix, or tableau, for subarea 2 contained 59 rows and 103 columns (including right-hand side values). Since this would be rather cumbersome to present here, the explanations will be based on a generalized model, with blocks of similar rows and columns aggregated together. A complete list of row and column names, along with a brief explanation of each, can be found in Appendix G.

There are four types of rows in the linear programming matrix (Table 4.3). The objective function (a single row) computes net income, which is to be maximized. Net income in this case is the short-run return to land, irrigation facilities, overhead, and management. Next are balance equations, which balance crop activity input requirements with input purchase activities, and crop outputs with crop sales activities.

Another group of equations are constraint rows, by which the maximum available amount of fixed resources (water, land, and specific crop acreages) are stated. The water availability constraint was computed from the average well yield in the area under consideration. Land constraints were based on the average irrigated acres per well in the area, the distribution of soil types, and the historical crop mix (see Table 4.2).

Table 4.2. Land Constraints Used in Linear Programming Model.

Item	Constraint Direction	Constraint Acreage for Subarea 1	2	3	4	5	6
Irrigable Land Per Well	FIXED	129	150	128	128	128	107
Irrigable Land In Model	MAX	516	600	512	512	512	428
Land Irrigated By							
Gated Pipe System	MAX		300	100		300	428
Low Pressure Sprinkler	MAX	516	260	412	512	260	300
High Pressure Sprinkler	MIN		130			130	100
Land Devoted To							
Sugar Beets	MAX		60	30		30	
Pinto Beans	MAX		60	30		30	
Sunflowers	MAX	129	150	128	128	128	107
Sorghum	MAX						214
Alfalfa	MIN	48	48	36	48	36	36

For example, beets and beans, the most profitable crop, were constrained to their historical maxima. Although these crops are the most profitable, they involve a higher degree of management and risk than the others. In addition, beet acreage is limited by a contract with the processor. Sunflower acreage was constrained to one-quarter of the total acreage because a four-year rotation is recommended to control diseases of this crop. Alfalfa acreage was forced into the solution by a minimum constraint. This is a relatively low income crop that would never come into the solution otherwise. It is grown

Table 4.3. Generalized Linear Programming Tableau, Subarea 2.

	GP Pumping Cost	LP Pumping Cost	HP Pumping Cost	Energy Intensive Inputs	Non-Power Water Costs	Crop Sales	GP Irrig. Crops	LP Irrig. Crops	HP Irrig. Crops	Dryland Crops	Alf. Est.	Constraint Type	RHS
Number of Columns	6	6	6	4	1	7	21	21	21	6	3		
Objective Function (1 row)	-C1	-C2	-C3	-P1	-C4	+P2	-C5	-C6	-C7	-C8	-C9	N	MAX
Water Use -- GP (6 rows)	-1						W1				A1	E	0
Water Use -- LP Sprinkler (6 rows)		-1						W2			A2	E	0
Water Use -- HP Sprinkler (6 rows)			-1						W3		A3	E	0
Energy Intensive Inputs (4 rows)				-1			Q1	Q2	Q3	Q4	Q5	E	0
Non-Power Water Costs (1 row)					-1		ΣW1	ΣW2	ΣW3		ΣW4	E	0
Alfalfa Estab. (3 rows)							B	B	B		-1	E	0
Crop Yields (7 rows)						-1	Y1	Y2	Y3	Y4		E	0
Pumping Constraints (6 rows)	1	1	1									L	MW
Land Constraints (9 rows)							D1	D2	D3		D4	L or G	LV
Water Constraint for Season (1 row)							ΣW1	ΣW2	ΣW3		ΣW4	L	TW
Labor Accounting Row (1 row)							N1	N2	N3	N4	N5	G	0
Water Used, By Crop (7 rows)							ΣX1	ΣX2	ΣX3		ΣW4	L	WC
Dryland Net Income (1 row)										I		G	0

Constraint Types:

N - no constraint
E - equal to
L - less than or equal to
G - greater than or equal to

as a source of forage for cattle operations (relatively low income enterprises themselves lately), or as part of a rotation.

The final class of equations are "accounting rows" -- one for labor, one for net income on irrigable land farmed as dryland and seven for water use by crop. These rows are constrained, but the constraint levels were selected so that they would never be limiting. This allows these rows to simply count up and show the desired totals.

The labor accounting row includes the time required for machine operation, irrigation, and management. Machine operation times come from the budget generator discussed in Chapter II. Irrigation labor was computed as a product of the hours per acre inch developed previously, times the acre inches of water pumped. Management time was computed as one-third of total labor time for full irrigation for all crops except beets and beans, where it was assumed to be 40 percent of labor time. Management time did not decrease with irrigation water application, even though irrigation labor time did. This is because management of a limited amount of irrigation water would probably not require less time devoted to planning and management (and might well require more).

<u>Explanation of Symbols in the Generalized Linear Programming Tableau (Table 4.3)</u>

C1-C3	Vectors showing energy cost associated with pumping an acre inch of water (equal across months, but different for each irrigation system).
C4	Non-power costs of irrigation (includes labor and maintenance and repair costs), in dollars per acre inch. Different figures are used for electric and natural gas systems (electric systems = \$0.45/acre inch; natural gas systems = \$0.72/acre inch).
C5-C9	Vectors of crop production costs that are expected to remain constant in real terms over the next 40 years (this includes all costs that are not itemized as energy intensive inputs).

P1	Vector of energy-intensive input prices, which are expected to increase faster than the general level of inflation.
P2	Commodity price vector.
W1	Monthly water use matrix associated with gated pipe systems.
W2, W3	Monthly water use matrices associated with sprinkler systems (numerical values in W2 and W3 are the same).
ΣW1	Seasonal water use vector associated with gated pipe systems.
ΣW2, ΣW3	Seasonal water use vector associated with sprinkler systems (numerical values in ΣW2 and ΣW3 are the same).
ΣX1	Seasonal water use vector associated with gated pipe systems (one for each crop).
ΣX2, ΣX3	Seasonal water use vector associated with gated pipe systems (one for each crop -- numerical values in ΣX2 and ΣX3 are the same).
B	Alfalfa establishment vectors. For alfalfa activities, the entry is 0.2, reflecting the assumption that alfalfa is established once every 5 years. For other crops, the entry is 0.
A1-A3	Monthly water use vectors for alfalfa establishment. In the matrix, there is one column for each irrigation system. In each column, only one of these vectors has non-zero entries.
ΣW4	Seasonal water use vector associated with alfalfa establishment.
Q1	Matrix of energy intensive input quantities associated with gated pipe systems.
Q2, Q3	Matrix of energy intensive input quantities associated with sprinkler systems (numerical values in Q2 and Q3 are the same).
Q4	Matrix of energy intensive input quantities associated with dryland crops.
Q5	Matrix of energy intensive input quantities associated with alfalfa establishment.
Y1, Y2, Y3	Matrices of crop yields (assumed to be the same for all irrigation systems).

Y4	Matrix of crop yields for dryland conditions.
D1-D4	Land use matrices -- each entry is either one or zero, as appropriate. The individual rows and constraints are as follows:

Row	Constraint Type
Irrigable land	L
Gated pipe land	L
Low pressure sprinkler land	L
High pressure sprinkler land	G
Beet land	L
Bean land	L
Sunflower land	L
Alfalfa land	G
Irrigable land farmed as dryland	L

N1-N5	Labor input vectors.
I	Dryland net income vector.
MW	Vector of maximum water quantities available each month.
LV	Vector of land use acreage constraints.
TW	Maximum water quantity available for season.
WC	Vector of maximum water quantity available for each crop during the season (since this is an accounting row, each entry is equal to the value of TW).

The Combined Economic - Hydrologic Simulation Model

Basic Structure and Operation - One Time Period

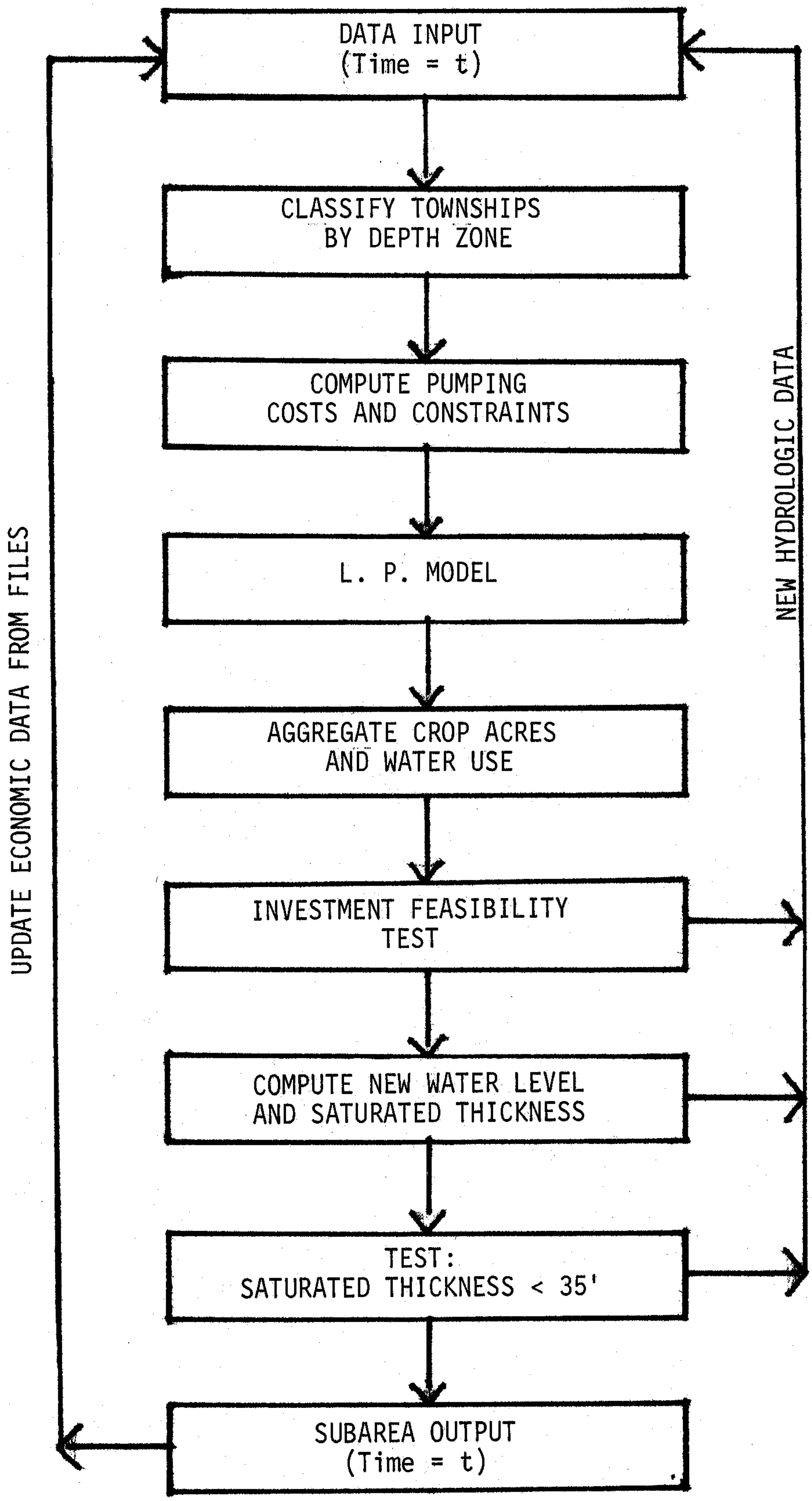
The simulation model is a combination of the linear programming model (discussed in the preceding section), and the hydrologic model (described in Chapter III). For each year of analysis, the linear programming model allocates land and water to cropping activities so as to maximize returns to land and management while the hydrologic model computes water withdrawn and the effects on pumping depth, the cost of pumping, and water availability. The years of analysis were 1979, 1985, 1990, 2000, and 2020. It was assumed that land allocations and water use established for a given year would hold until the next year of analysis.

Figure 4.1 is a flow chart diagram, which may help the reader follow the following discussions on the sequence of data processing steps carried out by the simulation model.

The initial (1979) data on depth to water, saturated thickness, and specific capacity of the aquifer were obtained from the State Engineer's office for each township or part township overlying the Ogallala aquifer in Colorado. For each township, a pumping level was computed as the static depth to water plus drawdown. Drawdown was calculated by dividing the well capacity (in GPM) by the specific capacity (in GPM per foot drawdown). On a basis of pumping level, each township was classified into one of four depth zones. (This step was undertaken since it would be too large a computing load to solve the allocation model for each township, and the effect on pumping cost estimates is small). Eighty foot intervals were selected for these depth zones with mean depths of 100, 180, 260, and 340 feet.

The second step was to compute average pumping costs and pumping constraints for each set of townships in a given depth zone. Pumping costs were computed separately for electric and natural gas powered pumps, operating for each of the three irrigation systems included in the model. Pumping costs were computed using the equation and parameters presented on pages 42 and 43 of this report. Pumping constraints, or the maximum amount of water available, were computed on a monthly basis. Well capacity was computed as two-thirds of saturated thickness times specific capacity, subject to a maximum value of 1000 GPM. The number of pumping days per month was set at 26, which allows for maintenance time when the pump is not operating. The maximum amount of water available in

Figure 4.1. Ogallala - High Plains Model Flow Chart (Run for t = 1979, 1985, 1990, 2000, and 2020)



a month of a system of four wells, each capable of pumping 1000 GPM would be,

$$4000 \text{ GPM} \times 60 \frac{\text{min.}}{\text{hour}} \times 24 \frac{\text{hours}}{\text{day}} \times 26 \frac{\text{days}}{\text{month}} = 149{,}760{,}000 \text{ gallons}$$

or 5,515 acre inches.

Pumping costs and constraints were then entered into the linear programming model sequentially so that a cropping activity allocation would be obtained for each power source in each depth zone for the time period under consideration. Since most subareas had four depth zones and two power sources, eight solutions were necessary to completely allocate land and water in a subarea for one time period. The results established relative crop proportions which were applied to all of the irrigated land in a depth zone for each power source. Depth zone crop acreages were obtained by summing over the two power sources, and subarea figures were obtained by summing over the four depth zones.

Cycling Through Time Periods

With land and water allocations set for a given time period total water withdrawal in each township was calculated and the appropriate adjustment in the pumping lift and saturated thickness data were made for the next time period. Total withdrawal for a time period was the amount withdrawn annually (as determined by the linear programming models), times the number of years in the time period. The hydrologic model was designed to account for recharge of the aquifer, either natural or artificial.

On the basis of the new data on pumping lifts and saturated thickness, townships were reclassified into depth zones and pumping costs and restraints again computed. Other budget information was updated from stored files, and the linear programming model again allocated land and water so as to maximize returns to land and management. The process of resource allocation and subsequent adjustment in water availability and cost continued until the results for the year 2020 were completed, and was performed separately for each of the six subareas for each of four scenarios.

Tests for Physical and Economic Exhaustion of the Aquifer

As the simulation model cycled from one time period to the next, two tests were applied in order to determine the maximum amount of land that would be producing irrigated crops during the next time period.

The test for physical exhaustion rested on an examination of the remaining saturated thickness in each township. If average saturated thickness in a township fell below 35 feet, all of the wells in that township were assumed to go out of use because of the physical difficulties of pumping adequate volumes of water for irrigation from such a thin saturated layer. Colorado law prohibits the drilling of supplemental wells near a failing well for the purpose of maintaining discharge volume by interconnecting several wells.

After being suspended because of physical depletion, 50 percent of the wells originally in a township could be returned to irrigation if recharge increased the saturated thickness to 50 feet or more. It was judged that at least 50 feet of water would be necessary to justify reinvestment in an irrigation facility.

The test for economic exhaustion involved calculating a return to land and water by deducting the capital costs for irrigation facilities and a management charge. If the resulting return to land and water was positive, reinvestment in irrigation was considered feasible and irrigated acreage was not reduced. In fact, if some wells had been suspended previously on economic grounds, a portion of them would be renewed.

On the other hand, if the return to land was negative, the number of wells in production was decreased for the next time period.

The rationale and procedure for this test were reasonably straightforward. The linear programming model allocated land and water so as to maximize annual returns to land (including irrigation facilities) and management, over and above annual variable costs and the investment costs associated with field machinery. It seemed reasonable to assume that farmers cropping decisions would hinge on these costs, at least for the first three time periods (ranging from five to ten years). However, in the longer run (which is implied by going from one time period to another), the cost of the irrigation system and a management charge must be paid out of crop revenues if irrigation is to continue.

We assumed a 20 year life for an irrigation facility. If irrigation investment were infeasible (the test was applied to each combination of depth zones and power sources for each time period), the number of wells in the given category of depth and power source was decreased by a factor equal to the number of years in the time period divided by 20. For example, a negative return in 1985 would mean a 25 percent reduction in the number of wells in use in 1990. A negative return in 2000 would mean that all wells would be out of production by 2020. This reflected the situation that not all wells would have to be replaced at any one year, since they were not all put in at a particular time.

The management charge was computed as 6 percent of the gross revenue from crop sales. Irrigation investment costs were figured by subarea for each type of irrigation system and power source included in the linear programming model. The weighted averages of amortized irrigation investment costs (amortized at 8 percent over a 20 year life) for each subarea are shown in Table 4.4.

Table 4.4. Weighted Averages of Irrigation Investment Costs, by Subarea.

Subarea	Average Annual Irrigation Investment Costs	
	Per Acre	Per 4-Well System
1,3,4,5	$50	$26,000
2	40	24,000
6	60	26,000

The reinvestment feasibility test can be summarized in symbolic notation as follows:

If LP Net Income - (MC + AIIC) > 0,

Then $W_1 = W_0 + (\frac{T}{20})W_s$, and

If LP Net Income - (MC + AIIC) $\leq$ 0,

Then $W_1 = (1 - \frac{T}{20})W_0$.

where LP Net Income = the net income which appears as the solution value of the objective function in the linear programming solution.

MC = the management charge.

AIIC = the annual irrigation investment cost.

W_0 = the number of wells in the present time period.

W_I = the number of wells in the subsequent time period.

W_s = the number of wells suspended for economic reasons in previous time period(s).

T = the number of years in the present time period.

In subarea 4, a positive result on the investment feasibility test allowed new wells to come into production. The Colorado State Engineer's office has estimated that about 200 more wells would be allowed in this area under current regulations. It was assumed that 25 percent of these would appear during the first time period of feasibility, then another 25 percent in the second period, and the final 50 percent in the third time period of feasibility.

If land dropped out of irrigation either because of inadequate saturated thickness or because of the finanacial infeasibility of reinvestment, it was assumed to revert to dry cropland (except in subarea 4, where it would be returned to grassland).

Reporting Crop Output and Resource Use

Crop output and resource use associated with irrigation in a subarea were calculated for each year of analysis by summing results over depth zones and power sources, as explained previously. Dryland crop output was also projected on the basis of some assumptions and an accounting of land that converted from irrigation to dryland production in each time period.

Wheat is generally the most profitable dryland crop in the study area, but for a variety of reasons, farmers grow small acreages of other crops. Budgeting anticipated future costs and returns showed that wheat would continue to be the most profitable crop, with increasing competition from sunflowers (if current processing and marketing problems can be solved for the sunflowers). It was assumed that future cropping patterns in the subareas would be similar to those found at present, with some adjustment for an increase in sunflower acreage. The proportions of harvested dry cropland allocated to various crops in each year is shown in Table 4.5. In most subareas, only crops that require tillage are considered. Subarea 4 is the exception, because of the importance of controlling wind erosion in the area.

For a given time period and subarea, the dryland acreage would be the initial acreage, plus any land that dropped out of irrigation for physical or economic reasons, plus any irrigable land that the linear programming model might allocate to dryland (which would happen if it became infeasible to irrigate any or all of the land served by a well before the water supply was

Table 4.5. **Projected Dryland Crop Acreage Distribution, by Subarea.**

Subarea	Crop	Percent of Harvested Dry Cropland Allocated to the Indicated Crop				
		1979	1985	1990	2000	2020
1 & 2	Wheat	95	95	95	90	90
	Corn	5	5	5	5	5
	Sunflowers	0	0	0	5	5
3 & 5	Wheat	95	95	95	95	90
	Sorghum	5	0	0	0	0
	Sunflowers	0	5	5	5	10
4	Wheat	90	80	80	80	80
	Hay	10	20	20	20	20
6	Wheat	70	65	65	65	65
	Sorghum	30	25	20	15	15
	Sunflowers	0	10	15	20	20

exhausted or the irrigation facilities were paid for). Once the dryland acreage was summed and allocated to crops, crop production and sales were computed using the yield and price data appropriate to the scenario under study.

The use of resources in dryland crop production was also computed. The projected levels of fertilizer use would be changed according to scenario assumptions. For all scenarios, fuel consumption was estimated at 2.5 gallons per acre per year for diesel and 0.4 gallons per acre per year for gasoline. The average labor requirement for dryland was 0.8 hours per acre per year.

Dryland net income per acre was computed for each subarea and time period by budgeting, and the figures were entered into a file so that the computer would calculate total dryland net income in each subarea.

Alternative Management Strategies

The plan of study mandated the analysis of several alternative scenarios for water management in the Ogallala region.

These scenarios, which will be described in more detail in the chapters that follow with the analytical results, were:

(0) Baseline

(1) Voluntary Water Demand Management (Improved Water Use Efficiency)

(2) Scenario 1 plus Mandatory Water Demand Management (Restrictions on Pumping)

(3) Scenario 2 plus Local Water Supply Augmentation

(4) Scenario 3 plus Intrastate Water Importation

(5) Scenario 4 plus Interstate Water Importation

Scenario 3 was not analyzed because there were no significant sources of water that were not being utilized in the Ogallala area of Colorado. Scenarios 4 and 5 were combined into Scenario 5 as a study of ability to pay for water regardless of from where it came. In addition, Scenario 6 was run as an alternative to the Baseline involving more pessimistic assumptions concerning crop yields and the prices of both crops and energy-intensive inputs.

CHAPTER V

BASELINE SCENARIO PROJECTIONS

The Baseline scenario assumed no change in public policy toward groundwater use and a continuation of current farm management trends. Each of the subsequent scenarios involve specific changes in certain assumptions, which will be detailed in the discussion of each individual scenario.

For each scenario, the tables showing subarea results will be found in the Appendix, along with summary tables for the six subareas together. Tables in the main body of the report will bring together the salient results with regard to crop output and resource use from the Appendix tables.

Projections of Prices and Crop Yields for the Simulation Model

All price projections are made in terms of 1979 dollars, or dollars that had the same purchasing power as a dollar in 1979. The meaning of this is probably best explained with an example. Let's say an item costs $10 in 1979 but will cost $20 in 2000. Let's further assume that the general rate of inflation from 1979 to 2000 will be 100 percent, so that a dollar in 2000 has a purchasing power equal to one-half dollar in 1979. Then, in terms of a constant value dollar, the price of the item did not change (the 1979 price is ten 1979 dollars, which is equal to twenty 2000 dollars; the 2000 price is $20, which is equal to ten 1979 dollars).

On the other hand, if the 2000 price of the item was $25 and the general rate of inflation was the same 100 percent, the price of $25 in 2000 dollars would be equivalent to $12.50 in 1979 dollars. In this case, the price of the item rose in real terms. Not all of the price rise is accounted for by the declining purchasing power of a dollar.

For this study, all prices were expressed in terms of 1979 dollars. This avoids the need to predict what the general level of inflation will do over the next 40 years. The problem then becomes to try to forecast whether the price of an item will rise at the same rate as general inflation, or faster. It was assumed that many farm input prices would rise at the same rate as general inflation, except for those that are energy intensive, such as fuel and fertilizer which would rise faster, and water, which is affected both by energy costs and increasing depth to water.

Energy Prices

Future energy prices were projected by Black and Veatch, Inc., an engineering consulting company and subcontractor on the study project. Their two-volume report, Regional Study Element B-8; Energy Price Projections, provided the basis for projected energy prices in Colorado. Their projections for gasoline and diesel fuel were used directly, but were indexed by means of the Producer Price Index to be in terms of 1979 dollars rather than the 1977 dollars shown in the report.

For natural gas and electricity, the 1979 price in the model was the average price for irrigation use in the study area during 1979. The price of natural gas in future years was based on the Black and Veatch report, but with slightly greater increases. We adopted the average of the indices used by the Kansas and Okalhoma study groups, rounded to the nearest tenth. A comparison of the indices can be found in Table 5.1.

Future electricity prices were projected using the index numbers implied by the Black and Veatch figures, adjusted to 1979 dollars.

Table 5.1. Natural Gas Price Indices, Baseline.

	Price Index (1979 Price = 1.0)			
Source	1985	1990	2000	2020
Black & Veatch	2.23	3.30	3.40	3.67
Kansas	2.53	3.74	3.87	4.17
Oklahoma	2.61	3.85	3.99	4.30
Colorado	2.60	3.80	4.00	4.20

Fertilizer price indices were developed by Arthur D. Little, Inc., another subcontractor on the study project, and provided to study participants in a memorandum dated June 20, 1980. The index for anhydrous ammonia was used directly. An index for other fertilizer was developed as a weighted combination of the anhydrous ammonia price index and the triple inperphosphate price index. The former was given a weight of one-third and the latter a weight of two-thirds, a weighting that approximates the ratio of nitrogen and phosphorus in 18-46-0 fertilizer, one of the most commonly used fertilizer blends in the study area.

The prices of energy and energy-intensive inputs used are shown in Table 5.2.

Table 5.2. Projected Energy and Energy-Related Prices, Baseline (1979 dollars).

Item	Unit	1979	1985	1990	2000	2020
Electricity	¢/KWH	5.00	6.20	6.90	8.70	9.70
Natural Gas	$/MCF	1.70	4.42	6.45	6.80	7.15
Diesel Fuel	$/Gal.	0.80	1.08	1.09	1.13	1.18
Gasoline	$/Gal.	0.90	1.10	1.12	1.14	1.18
Anhydrous Ammonia	$/Lb.	0.09	0.18	0.25	0.26	0.27
Other Fertilizer	$/Lb.	0.11	0.17	0.22	0.23	0.24

Commodity Prices

Future commodity prices were provided by Arthur D. Little, Inc., based on projections from the National Inter-Regional Agricultural Projections (NIRAP) system. The projections were for national prices in terms of 1977 dollars. These prices were adjusted for Colorado on the basis of historical relationships between national prices and Colorado prices, and were further adjusted by us to be in 1979 dollars.

The NIRAP model projected only a limited set of prices, including those for corn, sorghum, wheat, and soybeans. The prices of other crops (e.g., dry beans, sugar beets, hay, and sunflowers) were computed from these prices on the basis of historical relationships, specified in terms of equations established by linear regression.

The commodity prices used in the first two scenarios are shown in Table 5.3. The 1979 prices are the prices reported in Colorado Agricultural Statistics for 1979, the prices for other years are based on the projection procedure described above.

Table 5.3. Projected Commodity Prices, Baseline (1979 dollars).

Crop	Unit	1979	1985	1990	2000	2020
Corn	Bu.	$ 2.60	$ 3.07	$ 3.11	$ 3.32	$ 3.49
Sorghum	Bu.	2.20	2.59	2.63	2.82	2.95
Wheat	Bu.	3.50	3.26	3.29	3.36	3.66
Pinto Beans	Cwt.	24.00	24.40	24.70	26.00	28.00
Sunflowers	Cwt.	10.00	11.20	10.85	11.30	12.60
Sugar Beets	Ton	30.00	32.45	32.85	34.55	37.20
Hay	Ton	54.00	62.50	63.00	65.40	67.20

Crop Yields and Fertilizer Use

The crop yields used in the model for 1979 and future years are shown in Table 5.4. The 1979 figures have been explained earlier in this report (see page 41). For this project, the Nebraska study team took the lead on making yield projections [Hanway, et al., 1980]. The results for Nebraska's westernmost region were used for Colorado conditions, with some modifications based on trend lines from data in the appropriate Colorado counties.

Sunflower yield projections were made by Arthur D. Little, Inc., and by the Texas study team.

Sugar beet and pinto bean yields were not projected to increase very rapidly. This is based on trend lines for county yield data from the last 20 years.

Fertilizer applications were increased in proportion to yield increases. Table 5.5 shows the projected levels of anhydrous ammonia use, and Table 5.6 shows the projected applications of other fertilizer (mostly blends of nitrogen and phosphorus, as explained earlier).

It should be noted that for each irrigation level, the amount of water applied per acre is held constant over time. Therefore, as crop yields increase, the efficiency of water in producing crop output implicitly increases.

Results: Resource Use Projections

Table 5.7 summarizes the Baseline projections for cropland, irrigation water pumped, energy used for irrigation, and farm labor. The figures are aggregates for all subareas.

Between 1979 and 2020, irrigated cropland in the aquifer area is projected to decrease from 600,000 acres to 364,000 acres, a decline of almost 40 percent. Most of this decline is projected to occur in the central and southern parts.

Table 5.4. Projected Crop Yields in the Study Area, Baseline.

Crop	Subarea	Irrigation Level	Crop Yield 1979	1985	1990	2000	2020
Irrigated Crops							
Corn (Bu./Ac.)	1,2,3,5	Full	130.0	142.0	152.0	167.0	187.0
		Two-thirds	110.0	119.0	126.0	138.0	153.0
		One-third	65.0	71.0	76.0	83.0	93.0
	4	Full	130.0	142.0	152.0	167.0	187.0
		Two-thirds	97.0	106.0	113.0	125.0	140.0
		One-third	45.0	51.0	56.0	63.0	73.0
	6	Full	120.0	132.0	142.0	157.0	177.0
		Two-thirds	102.0	111.0	118.0	130.0	145.0
		One-third	60.0	66.0	71.0	78.0	88.0
Sorghum (Bu./Ac.)	1,2,3	Full	60.0	66.0	71.0	76.0	86.0
		Two-thirds	54.0	58.0	62.0	66.0	74.0
		One-third	39.0	42.0	44.0	47.0	53.0
	4	Full	60.0	66.0	71.0	76.0	86.0
		Two-thirds	48.0	52.0	56.0	60.0	68.0
		One-third	33.0	36.0	38.0	41.0	47.0
	5	Full	75.0	81.0	86.0	91.0	101.0
		Two-thirds	67.0	71.0	75.0	79.0	87.0
		One-third	49.0	52.0	54.0	57.0	63.0
	6	Full	90.0	96.0	101.0	106.0	116.0
		Two-thirds	81.0	85.0	89.0	93.0	101.0
		One-third	58.0	61.0	63.0	66.0	72.0
Wheat (Bu./Ac.)	1,2,3,5,6	Full	50.0	54.0	58.0	66.0	81.0
		Two-thirds	47.0	51.0	55.0	63.0	78.0
		One-third	32.0	36.0	39.0	45.0	57.0
	4	Full	50.0	54.0	58.0	66.0	81.0
		Two-thirds	40.0	44.0	48.0	56.0	71.0
		One-third	27.0	31.0	34.0	40.0	52.0
Pinto Beans (Cwt./Ac.)	2	Full	17.0	17.1	17.2	17.5	18.0
		Two-thirds	14.4	14.5	14.6	14.9	15.4
		One-third	10.2	10.3	10.4	10.7	11.2
	3,5	Full	16.0	16.1	16.2	16.5	17.0
		Two-thirds	13.6	13.7	13.8	14.1	14.6
		One-third	9.6	9.7	9.8	10.1	10.6
Sunflowers (Cwt./Ac.)	1,2,3,5,6	Full	18.0	21.0	24.0	27.0	33.0
		Two-thirds	16.2	18.6	21.5	23.5	27.5
		One-third	11.7	13.7	15.6	17.6	21.6
	4	Full	18.0	21.0	24.0	27.0	33.0
		Two-thirds	14.4	16.8	19.2	21.2	25.2
		One-third	9.9	11.5	13.2	15.2	19.2

(continued on following page)

Table 5.4. Projected Crop Yields in the Study Area (continued)

Crop	Subarea	Irrigation Level	Crop Yield 1979	1985	1990	2000	2020
Irrigated Crops (continued)							
Sugar Beets	2	Full	19.0	19.1	19.2	19.5	20.0
(Tons/Ac.)		Two-thirds	16.1	16.2	16.3	16.6	17.1
		One-third	10.4	10.5	10.6	10.9	11.4
	3,5	Full	17.0	17.1	17.2	17.5	18.0
		Two-thirds	14.4	14.5	14.6	14.9	15.4
		One-third	9.3	9.4	9.5	9.8	10.3
Alfalfa	1,2,3,5,6	Full	4.5	4.7	5.0	5.5	6.0
(Tons/Ac.)		Two-thirds	3.0	3.1	3.2	3.5	3.7
		One-third	1.8	1.8	1.8	1.8	1.8
	4	Full	4.5	4.7	5.0	5.5	6.0
		Two-thirds	2.7	2.8	2.9	3.2	3.4
		One-third	1.5	1.5	1.5	1.5	1.5
Dryland Crops							
Corn	1,2		30.0	32.0	34.0	36.5	41.5
	3,5,6		20.0	22.0	24.0	26.5	31.5
Sorghum	1,2,3,5,6		20.0	21.5	22.7	25.2	30.2
Wheat	1,2		32.0	35.0	37.5	41.5	46.5
	3		25.0	28.0	30.5	34.5	39.5
	4,5		22.0	25.0	27.5	31.5	36.5
	6		18.0	21.0	23.5	27.5	32.5
Sunflowers	1,2,3,5,6		9.0	10.0	11.0	12.0	14.0
Pinto Beans	2,3,5		3.0	3.0	3.0	3.0	3.0
Grass Hay	All		1.0	1.0	1.0	1.0	1.0

of the study area (see Table 5.8 and the maps, Figures 5.1 and 5.2). This difference in results among subareas follows from several factors, including the different time profiles for electricity and natural gas prices and variations in saturated thickness and depth to water (pumping lifts).

The price of natural gas is projected to rise more rapidly than the price of electricity. Electricity rates almost double over the 40 year period (even in constant dollars, with the effects of general inflation factored out). However, natural gas rates increase by a factor of two and one-half by 1985,

Table 5.5. Projected Use of Anhydrous Ammonia, Baseline.

Crop	Subarea	Irrigation Level	Application Level (Lb./Acre) 1979	1985	1990	2000	2020
Corn	All	Full	200	218	234	257	288
		Two-thirds	180	195	206	226	250
		One-third	100	109	117	128	143
	1,2,3,5,6	Dry	50	54	58	60	70
Sorghum	1,2,3,5,6	Full	100	110	118	127	143
		Two-thirds	90	97	103	110	123
		One-third	70	75	79	84	95
	4	Full	120	132	142	152	172
		Two-thirds	100	108	117	125	142
		One-third	70	76	81	87	100
	1,2,3,5,6	Dry	50	54	56	64	76
Sunflowers	1,2,3,5,6	Full	90	105	120	135	165
		Two-thirds	90	105	120	130	153
		One-third	60	70	80	90	111
	4	Full	120	140	160	180	220
		Two-thirds	120	140	160	177	210
		One-third	80	93	107	123	155
	1,2,3,5,6	Dry	45	48	54	58	68
Wheat	1,2,3,5,6	Full	60	65	70	80	100
		Two-thirds	60	65	70	80	100
		One-third	50	56	61	70	90
	4	Full	75	81	87	100	121
		Two-thirds	75	81	87	100	121
		One-third	60	69	75	89	115
	All	Dry	40	46	50	58	66
Sugar Beets	2,3,5	Full	120	120	121	123	126
		Two-thirds	110	110	111	113	116
		One-third	75	76	76	78	82

then increase by an additional 60 percent by 2020. Natural gas, under federal regulation, has historically enjoyed a cost advantage over electricity in irrigation pumping, but due to deregulation, this advantage is expected to disappear by 1985. This helps to explain why the number of natural gas powered pumps is projected to decline more rapidly than the number of electric powered

Table 5.6. Projected Use of Other Fertilizer, Baseline.

Crop	Subarea	Irrigation Level	Application Level (Lb./Acre) 1979	1985	1990	2000	2020
Corn	1,2,3,5,6	Full	150	164	175	193	216
		Two-thirds	135	146	155	169	188
		One-third	75	82	88	96	107
	4	Full	200	218	234	257	288
		Two-thirds	150	164	175	193	216
		One-third	100	109	117	128	143
	1,2,3,5,6	Dry	50	54	58	60	70
Sorghum	1,2,3,5,6	Full	100	110	118	127	143
		Two-thirds	90	97	103	110	123
		One-third	60	65	69	72	82
	4	Full	120	132	142	152	172
		Two-thirds	100	108	117	125	142
		One-third	60	65	69	75	85
Wheat	1,2,3,5,6	Full	100	108	116	132	164
		Two-thirds	100	108	116	132	164
		One-third	70	79	85	98	124
	4	Full	120	130	140	158	194
		Two-thirds	120	130	140	158	194
		One-third	70	80	88	104	130
		Dry	60	68	76	86	100
Pinto Beans	2,3,5	Full	100	100	101	103	106
		Two-thirds	90	90	91	93	96
		One-third	50	50	51	52	55
		Dry	25	25	25	25	25
Sugar Beets	2,3,5	Full	200	200	202	205	210
		Two-thirds	180	180	182	185	190
		One-third	120	120	122	125	132
Alfalfa Hay	All	Full	100	104	111	122	133
		Two-thirds	70	72	75	82	86
		One-third	40	40	40	40	40

pumps. The predicted number of natural gas powered pumps in operation in 2020 is only 27 percent of the number operating in 1979. The comparable figure for electric pumps is 78 percent.

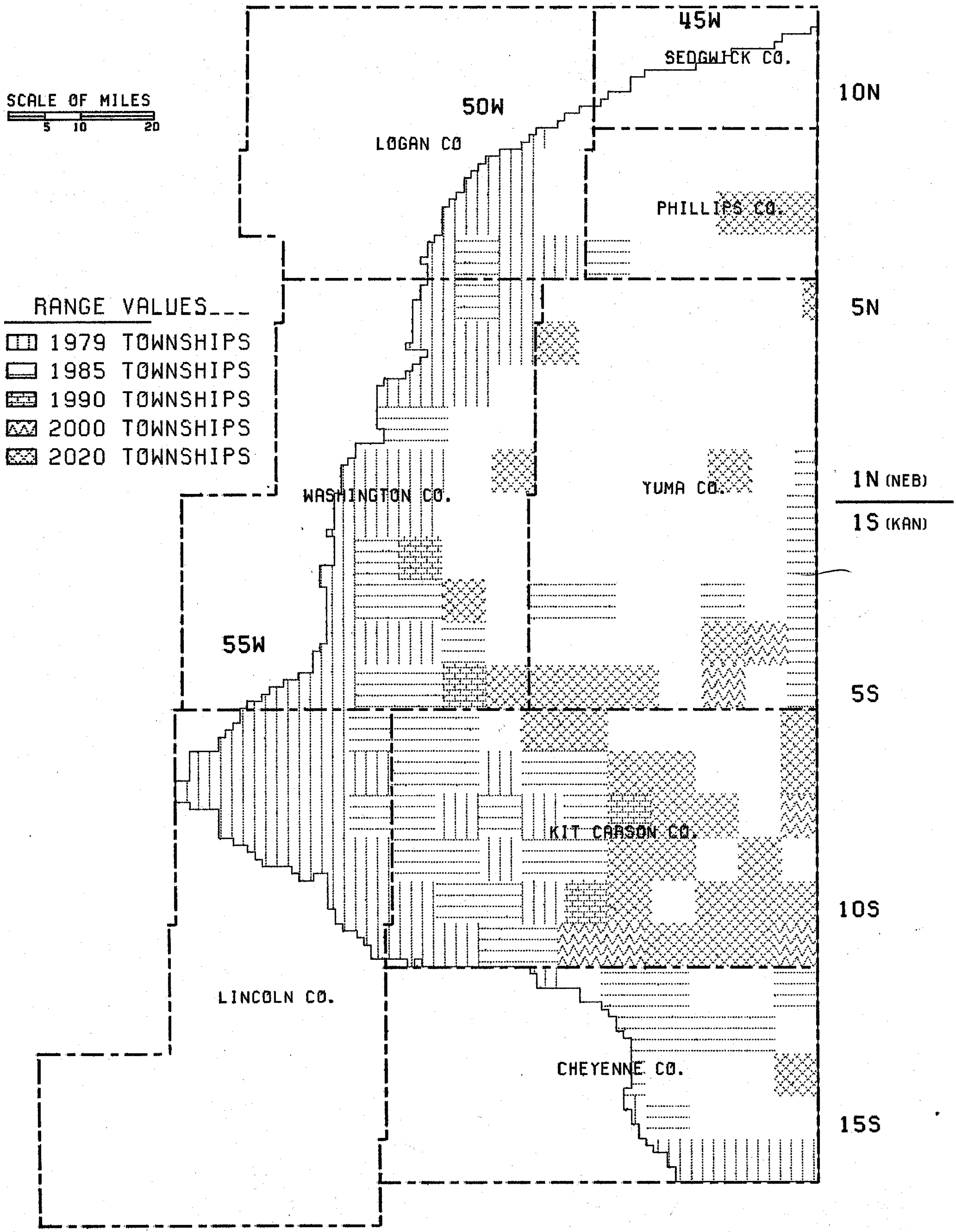
Energy prices are not the only factor, however. A large portion of the irrigated land in the northern subareas has an adequate amount of water for the

Table 5.7. Projected Resource Use, by Years, Colorado Ogallala Region, (Baseline).

	Time Period				
	1979	1985	1990	2000	2020
Irrigated Cropland (1,000 acres)	600	562	529	501	364
Dry Cropland Harvested (1,000 acres)	1,683	1,710	1,737	1,749	1,815
Irrigation Pumps, Electric	3,048	2,849	2,845	2,853	2,365
Irrigation Pumps, Natural Gas	1,719	1,606	1,466	1,078	465
Irrigation Water Pumped (1,000 acre feet)	1,148	1,076	1,005	965	656
Electricity Use for Irrigation (million KWH)	441	432	447	475	389
Natural Gas Use for Irrigation (1,000 MCF)	4,279	3,989	3,248	2,810	1,160
Crop Production Employment (man-years)					
Irrigated Farms	1,332	1,239	1,164	1,114	737
Non-irrigated Farms	1,344	1,361	1,376	1,393	1,445
Total	2,676	2,600	2,540	2,507	2,182

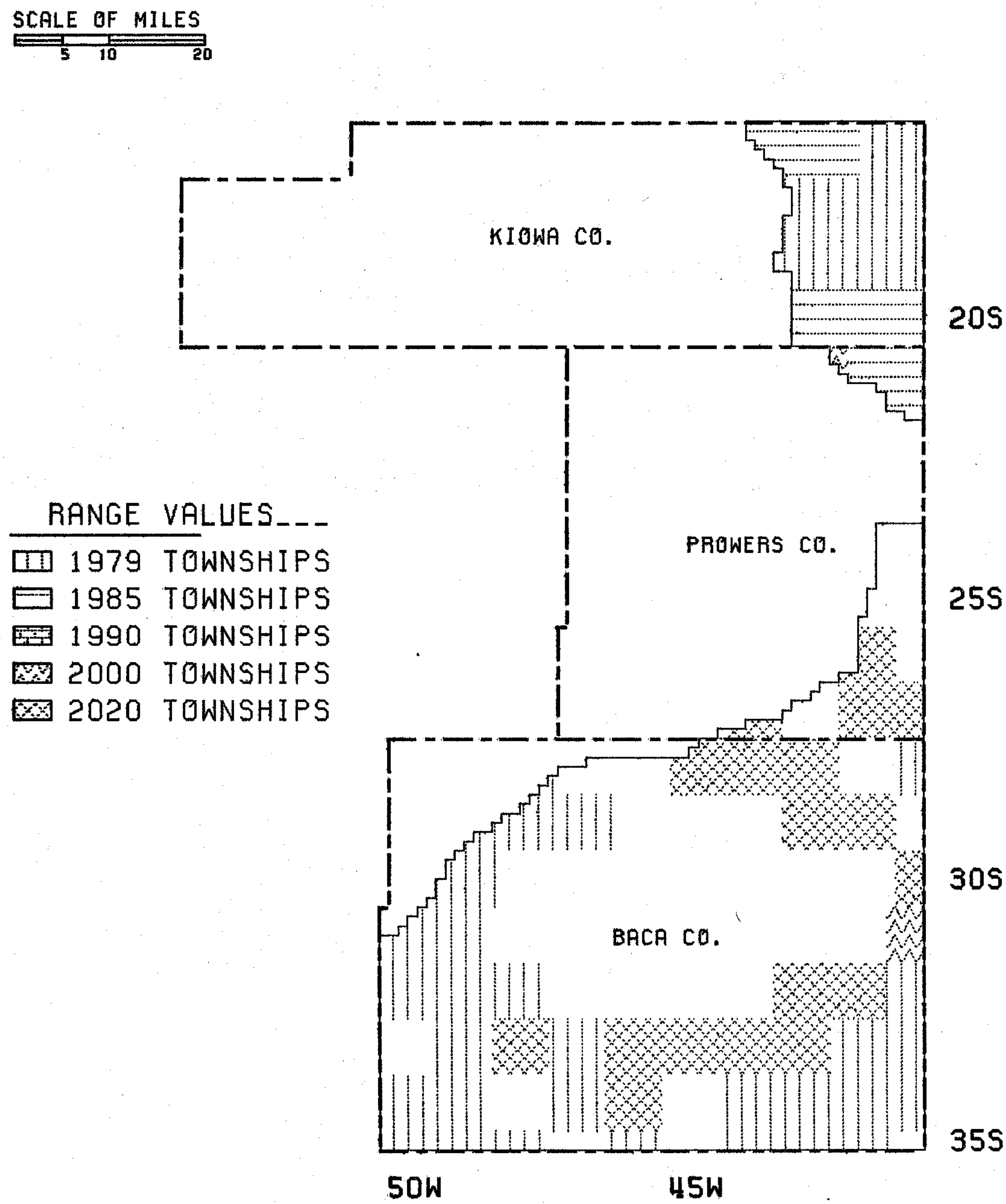
Table 5.8. Projected Irrigated Acreage in 1979, 2000, and 2020, (Baseline).

Location in Study Area	Subareas	Irrigated Land (1000 acrea)			Percent Change	
		1979	2000	2020	1979-2000	1979-2020
North	1,2,4	219.0	242.0	221.6	+11%	+1%
Central	3,5	277.0	212.0	118.7	-23%	-57%
South	6	104.0	47.2	24.1	-55%	-77%



OGALLALA AQUIFER, NORTH-EASTERN COLORADO
IRRIGATION REMOVED BY SIMULATION

Figure 5.1



OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
IRRIGATION REMOVED BY SIMULATION

Figure 5.2

next 40 years, with relatively small pumping lifts. Most (90 percent) of the pumps are powered by electricity. In subareas 3 and 5, most of the irrigated land that reverts to dryland does so because of inadequate saturated thickness. About 60 percent of the pumps in these subareas were powered by electricity in 1979. In subarea 6, the saturated thickness remains adequate in much of the area, but the pumping lifts and the rapidly escalating price of natural gas forces farmers to shut down the pumps for economic reasons. Seventy percent of the wells in subarea 6 were powered by natural gas in 1979. Table 5.9 shows the data on the number of irrigation pumps over time.

On the maps (Figures 5.1 and 5.2), the townships that actually had no wells in 1979 are shown by vertical lines. The townships that are projected to have no irrigation by 1985 are shown by horizontal lines and so on. Townships with no lines or hatching are projected to have at least some profitable wells after 2020. If a township drops out of irrigation because of inadequate saturated thickness, it does so all at once. On the other hand, the trend of wells dropping out for economic reasons represents a more gradual process, so that the number of wells in a township may decrease substantially before the map shows that irrigation has disappeared from the township.

Returning to Table 5.7, we see that dryland crop acreage increases as irrigated cropland decreases. The figures show the harvested dryland crop acreages, which for a given year will be one-half of the total of all crops except grass hay, since the remaining half is assumed to be fallowed.

By 2020, the amount of irrigation water pumped in a year is projected to decline to 656,000 acre feet, down from 1,148,000 acre feet in 1979. This is a decline of about 43 percent, somewhat more than the decline in irrigated acreage because of a projected shift to less water-intensive crops on the

Table 5.9. Projected Number of Irrigation Pumps in 1979, 2000, and 2020, (Baseline).

Location in Study Area	Subareas	Power Source	Number of Pumps 1979	2000	2020
North	1,2,4	Electricity	1,478	1,670	1,531
		Natural Gas	162	148	145
Central	3,5	Electricity	1,285	972	625
		Natural Gas	878	684	303
South	6	Electricity	285	211	209
		Natural Gas	679	214	17

remaining irrigated land.

Electricity use rises until 2000 because of new irrigation development in the sandhills (assumed to be with electric powered pumps) and because of increasing pumping lifts. The number of kilowatt hours used in pumping declines from 2000 to 2020 as new development is over and the reduction in the number of wells overshadows the effect of increasing lifts.

Natural gas use for irrigation is expected to decline steadily over the 40 year period to about one-quarter of its present level.

Employment in crop production is expected to decline gradually over the forecast period. A total of 494 farm jobs are lost over the 40 year period.

Projection of Crop Production

The details of crop production and the value of production changes are shown in Tables 5.10 and 5.11. Corn remains the dominant crop under irrigation in all time periods. Given the yield and price projections we used, sunflowers emerged as the principal water-conserving crop under irrigation. Whether or not a processing plant will be built and sunflower production really will boom is rather speculative right now, but our results indicate a strong potential

Table 5.10. **Projected Irrigated Crop Production and Value of Production, Baseline, Subareas 1-6.**

	1979	1985	1990	2000	2020
Crop Production					
Corn (mil. bu.)	56.0	60.3	63.5	68.4	48.5
Sorghum (mil. bu.)	2.7	3.5	1.7	1.8	0.2
Wheat (mil. bu.)	1.9	0	0	0	0.9
Sunflowers (th. cwt.)	0	418.6	403.1	301.8	1,963.8
Sugar Beets (th. tons)	390.0	156.9	120.4	108.5	0
Pinto Beans (th. cwt.)	366.6	342.5	327.2	180.8	34.0
Alfalfa (th. tons)	179.3	173.9	178.7	173.6	137.6
Value of Production (in millions of 1979 dollars)					
Corn	145.7	184.7	197.6	226.9	168.9
Sorghum	5.9	9.0	4.6	5.2	0.6
Wheat	6.8	0	0	0	3.2
Sunflowers	0	4.7	4.4	3.4	24.7
Sugar Beets	11.7	5.1	4.0	3.7	0
Pinto Beans	8.9	8.4	8.1	4.6	1.0
Alfalfa	9.8	10.9	11.3	11.4	9.3
Total	188.8	222.8	230.0	255.2	207.7
Returns to Land and Management	48.8	57.1	48.0	65.5	66.5

for sunflowers as an alternative crop in the area. If sunflower production does not take off, farmers facing water supply problems would probably turn to the traditional crops (wheat, sorghum, pinto beans) which use less water than corn.

Pinto bean and sugar beet production both decline considerably, largely because of the rather pessimistic yield increases projected relative to those made for other crops. If the research community can find ways to increase the yields for these crops more than past trends would indicate (or if the relative price improves), production of these crops would remain near current levels.

Table 5.11. Projected Dryland Crop Production and Value of Production, Baseline, Subareas 1-6.

	1979	1985	1990	2000	2020
Crop Production					
Wheat (mil. bu.)	35.0	39.3	43.1	49.1	63.6
Sorghum (mil. bu.)	3.8	2.7	2.3	2.0	2.4
Sunflowers (mil. cwt.)	0	1.0	1.3	1.9	3.0
Corn (th. bu.)	376.5	401.8	427.0	457.1	538.6
Hay (th. tons)	8.0	16.7	33.2	18.2	16.5
Value of Crop Production (in millions of 1979 dollars)					
Wheat	122.3	127.7	141.9	165.2	207.9
Sorghum	8.5	7.0	6.0	5.5	7.1
Sunflowers	0	10.7	14.5	22.0	38.3
Corn	1.0	1.2	1.3	1.5	1.9
Hay	0.4	1.0	2.1	1.2	1.1
Total	132.2	147.6	165.8	195.4	256.3
Returns to Land and Management	56.5	52.9	58.2	76.6	121.4

The value of total irrigation crop production peaks in 2000, then declines by 18 percent by 2020. It remains above its 1979 level, however, since increasing yields per irrigated acre more than offset the reduced acres. The value of dryland crop production is projected to rise steadily as projected yields and prices increase, and irrigated lands revert to non-irrigated status.

The last line in each table shows the net returns to land and management, which follow a generally upward trend over the 40 year period. This is a favorable conclusion that masks the economic dislocations that will be taking place in parts of the study area.

Aquifer Status Projections

It is difficult to cite a single statistic that describes the aquifer status over the study period. Maps are included in the Appendix to show the saturated thickness and depth to water zones across the study area for the years 1979, 2000, and 2020.

The rate of water table decline in a township depends on how many wells there are and how much water is pumped in the township. Since the hydrologic model does not allow for lateral flows among townships, annual recharge causes the water table to rise in townships with no wells. In addition, water table decline will be understated in townships with few wells and overstated for townships with many wells because lateral flows are not allowed for. In each subarea, representative townships were chosen from among those that were located completely within the subarea (the one or two with the number of wells nearest the median in 1979). The water table decline in each of these townships is shown in Table 5.12.

Table 5.12. Projected Water Level Declines in Representative Townships, Baseline Scenario.

Subarea	No. of Wells (1979)	Water Level Decline (feet)				Total Decline (feet)	Average Decline (ft./yr.)
		1979-1985	1985-1990	1990-2000	2000-2020		
1	26	9	7	15	30	61	1.5
2	15	5	4	9	17	35	0.9
3	18	5	4	9	18	36	0.9
	13	3	2	5	10	20	0.5
4	28	10	8	16	33	67	1.7
	31	11	11	24	59	105	2.6
5	24	8	7	12	25	52	1.3
6	19	3	3	6[a]	6[a]	18	0.5

[a] Five wells drop out in 1990, but are restored in 2000.

Recent experience has indicated an annual water table decline of one or two feet in most areas of pumping from the Ogallala on the Colorado High Plains. The figures in Table 5.12 indicate that this rate of decline will be a reasonable expectation for the future.

Table 5.13 shows the projections of water remaining in the aquifer under Baseline conditions. Figures are shown for both the total volume of water in storage and for the volume of water that is "recoverable," or available for irrigation pumping. The latter figure was computed with the following procedure:

1. Townships with 35 feet or less of saturated thickness were considered to have no recoverable water.
2. For townships with more than 35 feet of saturated thickness, the 35 feet were subtracted from the saturated thickness figure and the remaining volume of water was computed. The result was the volume of recoverable water in the township.
3. The results from step 2 were summed over all townships that had recoverable water.

Table 5.13. Projected Volumes of Water Remaining in the Ogallala Aquifer, Baseline Scenario. (millions of acre feet)

	1979	1985	1990	2000	2020
Total Water in Storage	94	89	86	81	71
Recoverable Water in Storage	61	57	53	46	36

By 2020, the volume of recoverable water in the aquifer declines by about 40 percent under Baseline conditions.

CHAPTER VI

SCENARIO 1 PROJECTIONS: IMPROVED EFFICIENCIES

The assumed policy changes underlying Scenario 1 are characterized by the term "voluntary water demand reduction." This was expected to be achieved by increasing the efficiency of irrigation pumping facilities and irrigation water application. The Baseline forecast had some improvements in efficiency built in, including improved crop production per unit of water, and the possibility of energy and water conservation in response to cost increases. The only ways that improved efficiency can be reflected is by changing efficiency assumptions in the water cost calculations or changing resource requirement coefficients in the linear programming matrix. No incremental cost to the producer was assumed for the changes made in Scenario 1; it was hypothesized that these could be adopted in the course of normal repair and maintenance activities, and/or would be the product of publicly financed research and extension programs.

It was assumed that significant differences from the Baseline conditions would not appear until 1990. The revised pumping plant efficiencies are shown in Table 6.1 (baseline pumping plant efficiencies were assumed constant at the values presented on pages 42 and 43).

Table 6.1. Pumping Plant Efficiencies Assumed for Scenario 1.

	Efficiency Coefficient	
Year	Electricity	Natural Gas
1990	0.58	0.13
2000	0.61	0.16
2020	0.65	0.18

It was also assumed that water application efficiency would improve over 1979 levels by 3 percent in 1990, by 7 percent in 2000, and by 12 percent in 2020. The effect of these assumptions was to reduce the amount of water and energy required to produce a given level of crop output.

Resource Use Projections

Table 6.2 summarizes the Scenario 1 projections for cropland, irrigation water and energy use, and farm labor in the study area.

Table 6.2. Projected Resource Use by Years, Colorado Ogallala Region (Scenario 1).

	1990	2000	2020
Irrigated Cropland (1000 acres)	567	528	472
Dry Cropland Harvested (1000 acres)	1,712	1,735	1,764
Irrigation Pumps, Electric	2,990	2,954	2,672
Irrigation Pumps, Natural Gas	1,507	1,174	1,085
Irrigation Water Pumped (1000 acre feet)	1,059	971	783
Electricity Use for Irrigation (million KWH)	442	423	351
Natural Gas Use for Irrigation (1000 MCF)	3,055	2,136	1,423
Crop Production Employment (man-years)			
Irrigated Farms	1,262	1,192	983
Non-irrigated Farms	1,359	1,381	1,403
Total	2,621	2,573	2,386

Note: Figures for 1979 and 1985 are the same as for the Baseline scenario.

Irrigated cropland in the area decreases to 472,000 acres, a decline of 21 percent from 1979. In other words, only about half as much land goes out of irrigation as under Baseline conditions. The solution to the simulation model is apparently quite sensitive to pumping plant and water application efficiency. The assumption of improved efficiencies was particularly effective in keeping natural gas powered pumps in operation -- 63 percent of the original (1979) number are projected to be pumping in 2020 (88 percent of the electric pumps remain in operation).

Maps were created (Figures 6.1 and 6.2) to show when irrigation ceases for townships in the study area. These maps were created by the same computerized procedure as was used to create the Baseline maps presented earlier.

The projections show an annual pumping rate of 783,000 acre feet by 2020. This is a decline of about 32 percent from 1979 pumpage, but is about 20 percent above the 656,000 acre feet projected by the Baseline scenario for 2020.

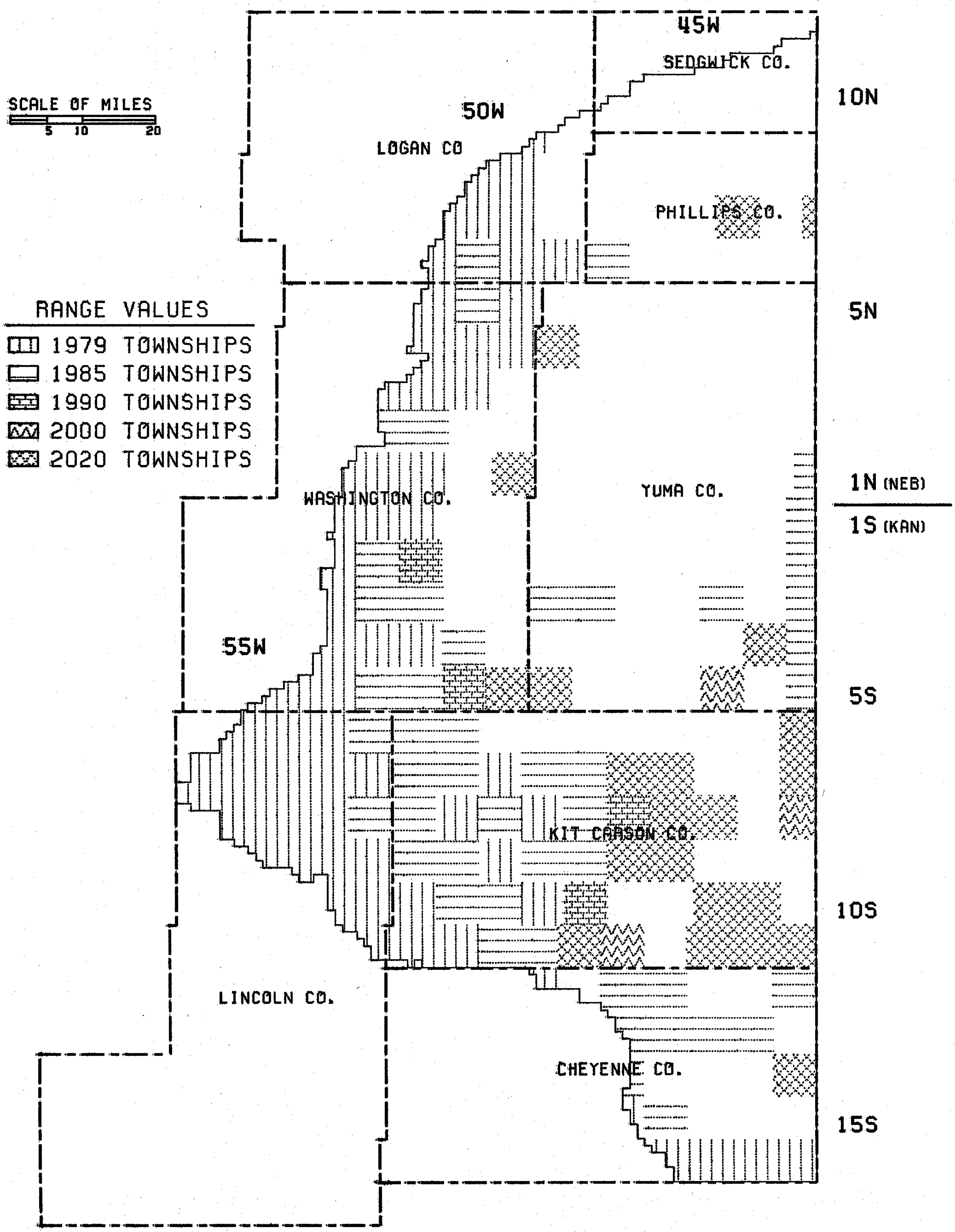
Under Scenario 1, electricity use for irrigation peaks in 1990 at 442 million KWH. This is one time period earlier than the peak under the Baseline conditions, and reflects the significant improvements in irrigation efficiencies in the later years. Natural gas use for irrigation declines steadily over the 40 year period to about one-third of its present level.

Employment in crop production is expected to decline gradually. A total of 290 farm jobs are lost over the forecast period.

Projection of Crop Production

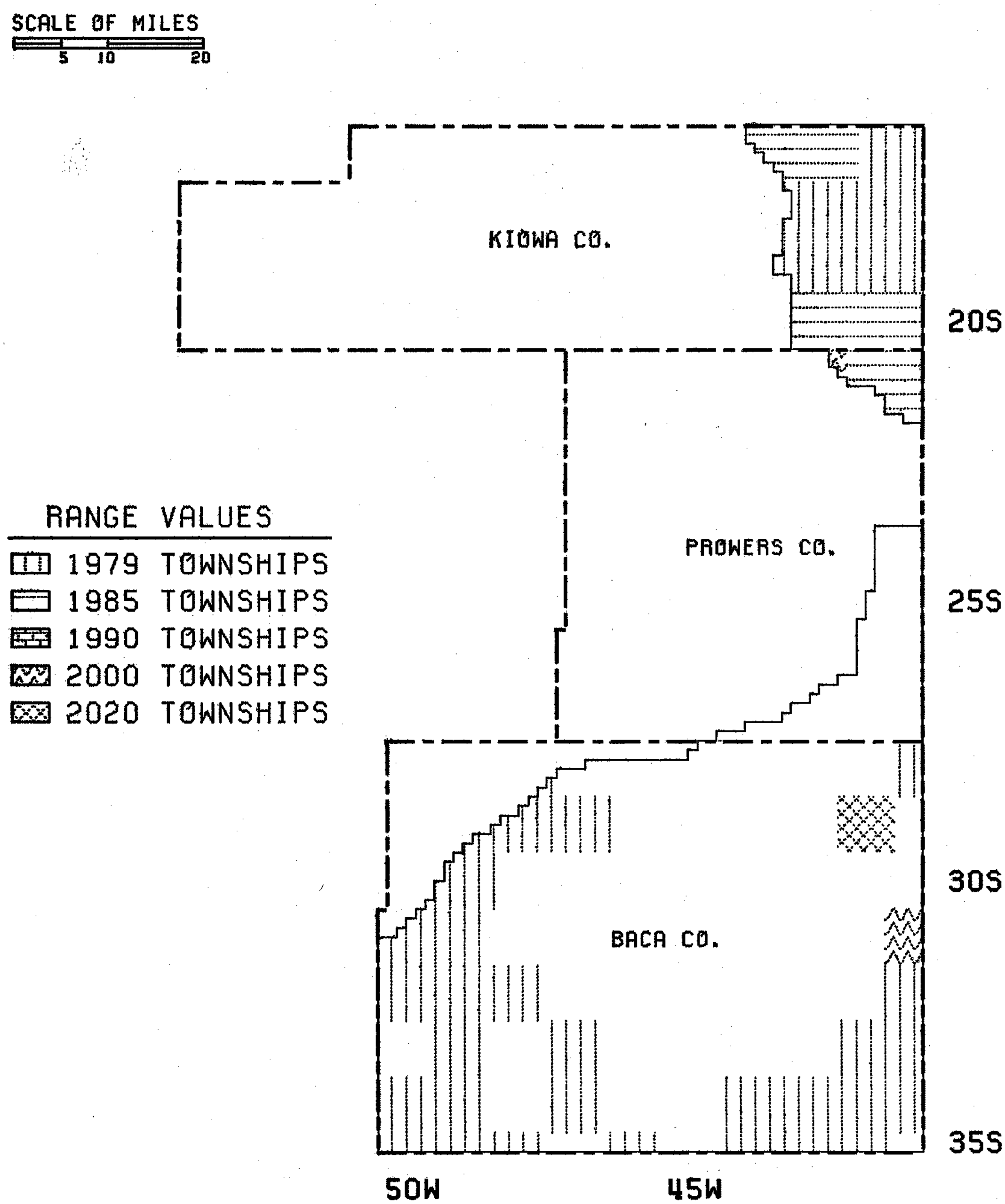
Tables 6.3 and 6.4 show crop production and value of production for Scenario 1. As in the Baseline, corn is the dominant crop under irrigation. Wheat competes strongly with sunflowers and pinto beans as a water conserving crop by 2020.

The value of total irrigated crop production levels off after 2000, with only about a 1 percent decline in 2020. The value of dryland crop production is projected to rise steadily over the forecast period, but not as much as in the Baseline scenario, due to the reduced abandonment of irrigation.



OGALLALA AQUIFER, NORTH-EASTERN COLORADO
IRRIGATION REMOVED BY SIMULATION 1

Figure 6.1



OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
IRRIGATION REMOVED BY SIMULATION 1

Figure 6.2

Table 6.3. Projected Irrigated Production and Value of Production, Scenario 1, Subareas 1-6.

	1990	2000	2020
Crop Production			
Corn (mil. bu.)	66.9	72.9	65.7
Sorghum (mil. bu.)	2.8	2.2	0.6
Wheat (mil. bu.)	0	0	3.3
Sunflowers (th. cwt.)	416.3	332.1	1,058.7
Sugar Beets (th. tons)	120.4	122.3	10.2
Pinto Beans (th. cwt.)	357.4	109.7	0
Alfalfa (th. tons)	192.0	195.3	193.2
Value of Production (in millions of 1979 dollars)			
Corn	208.2	242.1	229.2
Sorghum	7.4	6.1	1.9
Wheat	0	0	11.9
Sunflowers	4.5	3.8	13.4
Sugar Beets	4.0	4.2	0.4
Pinto Beans	8.8	2.9	0
Alfalfa	12.1	12.8	12.9
Total	245.0	271.9	269.7
Returns to Land and Management	57.1	83.6	101.9

As under the Baseline, returns to land and management show a generally rising trend in the aggregate. Returns are higher for irrigated farming because of the improved irrigation efficiencies and greater number of irrigated acres. Dryland returns are slightly lower because Scenario 1 involves less conversion of irrigated land to dryland.

In order to facilitate comparison between Scenario 1 results and those of the Baseline, Table 6.5 shows selected figures from Scenario 1 as a percentage of the corresponding Baseline figures. Irrigated cropland under Scenario 1 is greater than under Baseline conditions by 7, 6, and 30 percent

Table 6.4. Projected Dryland Production and Value of Production, Scenario 1, Subareas 1-6.

	1990	2000	2020
Crop Production			
Wheat (mil. bu.)	42.8	48.7	55.4
Sorghum (mil. bu.)	2.3	2.0	2.2
Sunflowers (mil. cwt.)	1.3	1.9	2.9
Corn (th. bu.)	427.0	457.1	531.5
Hay (th. ton)	19.5	16.2	16.6
Value of Crop Production (in millions of 1979 dollars)			
Wheat	140.8	163.8	202.8
Sorghum	6.0	5.5	6.7
Sunflowers	14.4	21.9	36.8
Corn	1.4	1.5	1.8
Hay	1.2	1.1	1.1
Total	163.8	193.8	249.2
Returns to Land and Management	57.7	76.1	118.3

in the three time periods, respectively. The value of irrigated crop production is greater by the same percentages.

Dryland crop acreage, the value of dryland crop output, and returns to land and management for dryland in Scenario 1 is slightly below that of the Baseline scenario (the small percentage change reflects the large base of dryland production in the area).

In comparison with the Baseline, Scenario 1 has more irrigation water pumped. This is partly because of the greater irrigated acreage and partly because the improved pumping plant efficiencies lower the cost of water. Less energy is used per acre under Scenario 1. In the case of electricity, less total energy is used in each time period. This is also true for natural gas in the first two time periods. In 2020, however, the increase in irrigated land

Table 6.5. Resource Use, Crop Production Values, and Net Income -- Scenario 1 Figures as a Percentage of Baseline Figures.

	1990	2000	2020
Irrigated Cropland	107	106	130
Dry Cropland Harvested	99	99	97
Irrigation Water Pumped	105	122	119
Electricity for Irrigation	94	76	123
Total Crop Production Employment	103	103	109
Value of Irrigated Crop Production	107	106	130
Value of Dryland Crop Production	99	99	97
Returns to Land and Management			
Irrigation	119	128	153
Dryland	99	99	97

served by natural gas powered pumps is so much greater under Scenario 1 that total natural gas use is also higher.

Total crop production employment does not show a very large percentage increase under Scenario 1; but irrigated net farm income does, because of the larger irrigated acreage and lower energy costs per acre foot of water.

Aquifer Status Projections

Table 6.6 shows the water table decline in each of the representative townships chosen for Table 5.12. Water table declines are not significantly different from Baseline conditions. Declines are slightly less in the northern areas because of increased water application efficiency. This efficiency improvement is overshadowed in subareas 5 and 6 by the retention of irrigated land, so water withdrawals and water table declines are slightly greater in these areas under Scenario 1.

Table 6.7 shows the projections of water remaining in the aquifer under Scenario 1. (The figures for 1979-1990 are the same as for the Baseline since the effect of changes introduced in 1990 do not show up until 2000.)

Table 6.6. Water Level Declines in Representative Townships, Scenario 1.

Subarea	Number of Wells (1979)	Water Level Decline (feet) 1979-1990[a]	1990-2000	2000-2020	Total Decline (feet)	Average Decline (ft./year)
1	26	16	14	28	58	1.4
2	15	9	8	15	32	0.8
3	18	9	8	16	33	0.8
	13	5	5	9	19	0.5
4	28	18	16	30	64	1.6
	31	22	24	54	100	2.5
5	24	15	13	25	53	1.3
6	19	6	6	13	25	0.6

[a] Same as Baseline.

Table 6.7. Projected Volumes of Water Remaining in the Ogallala Aquifer, Scenario 1. (millions of acre feet)

	1979	1985	1990	2000	2020
Total Water in Storage	94	89	86	80	70
Recoverable Water in Storage	61	57	53	46	35

Under Scenario 1, there is slightly less water remaining in the aquifer in both 2000 and 2020 than under Baseline conditions. This is because more land remains in irrigation under Scenario 1; the decrease in irrigation water use per acre is more than offset by the increase in the number of irrigated acres. The assumed efficiency improvements actually increase the rate at which the aquifer is depleted.

CHAPTER VII

SCENARIO 2 PROJECTIONS: TIGHTER REGULATIONS

Scenario 2 involved the same productivity assumptions as did Scenario 1, but with an added regulatory change requiring water conservation. This scenario was designed to evaluate the impacts of a potential state regulatory system to reduce water use below that which would occur without the program. Since Colorado has had an effective regulatory system limiting well numbers since 1965 (see Chapter III), Scenario 2 would of necessity imply a much more rigid set of regulations than exist elsewhere. Such regulations would require metering and enforcement. No institutional costs of this nature were accounted for in the forecasts, but would have to be recognized in any assessment of this type of program.

In the model, this scenario was effected by limiting monthly water availability to a certain percentage of that used in Scenario 1. These percentages are shown in Table 7.1.

Table 7.1. Water Availability in Scenario 2, as a Percentage of Water Use in Scenario 1.

Year	Water Availability Limit
1985	90%
1990	80%
2000	70%
2020	70%

In addition, crop prices were adjusted slightly for the years 1985-2000, in response to changes projected by the NIRAP model due to changed crop output in the six state Ogallala region. The prices used in Scenario 2 are shown in Table 7.2.

Table 7.2. Projected Commodity Prices, Scenario 2 (1979 dollars).

Crop	Unit	1985	1990	2000	2020
Corn	Bu.	$ 3.07	$ 3.14	$ 3.38	$ 3.53
Sorghum	Bu.	2.60	2.66	2.87	2.98
Wheat	Bu.	3.26	3.29	3.35	3.64
Pinto Beans	Cwt.	17.55	17.80	18.50	19.50
Sunflowers	Cwt.	11.20	10.85	11.30	12.60
Sugar Beets	Ton	32.45	32.95	34.55	37.45
Hay	Ton	62.50	63.30	66.10	67.80

Resource Use Projections

Table 7.3 shows the Scenario 2 projections for cropland, irrigation water and energy use, and farm labor in the study area.

Table 7.3. Projected Resource Use by Years, Colorado Ogallala Region, Scenario 2.

	1985	1990	2000	2020
Irrigated Cropland (1000 acres)	557	524	469	478
Dry Cropland Harvested (1000 acres)	1,714	1,743	1,745	1,750
Irrigation Pumps, Electric	2,925	2,858	2,798	2,786
Irrigation Pumps, Natural Gas	1,671	1,466	1,169	1,184
Irrigation Water Pumped (1000 acre feet)	968	815	656	584
Electricity Use for Irrigation (million KWH)	392	345	285	254
Natural Gas Use for Irrigation (1000 MCF)	3,659	2,406	1,503	1,200
Crop Production Employment (man-years)				
Irrigated Farms	1,174	1,065	969	841
Non-irrigated Farms	1,362	1,376	1,389	1,392
Total	2,536	2,441	2,358	2,233

Note: Figures for 1979 are the same as for the Baseline scenario.

Because of the pumpage constraint, irrigated acreage is less than under Baseline or Scenario 1 conditions in 1985, 1990, and 2000. However, the forced water conservation allows for a preservation of irrigated land from 2000 to 2020, when irrigated acreage is projected to be 478,000 acres. This is 6,000 acres more than would be irrigated under Scenario 1 and 114,000 acres more than would be irrigated under the Basline scenario.

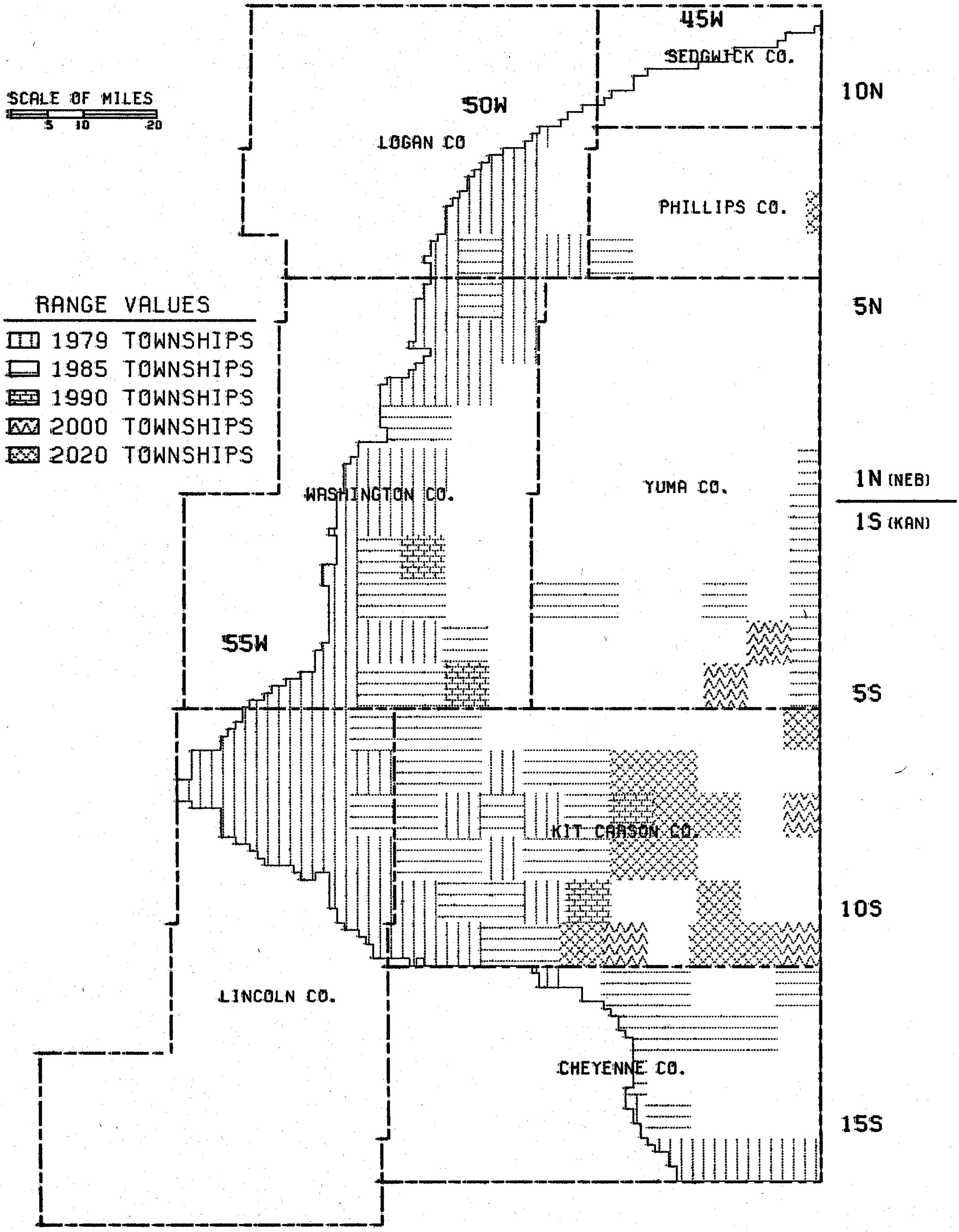
The projected number of electric-powered pumps in operation closely parallels the number found under the Baseline up to 2000. After 2000, this number falls substantially less under Scenario 2 as compared to the Baseline forecast. This pattern also holds for natural gas powered pumps. Under the Baseline, this number drops by almost 60 percent. Under Scenario 2, it rises slightly. In comparison with Scenario 1, the number of pumps in operation under Scenario 2 are slightly lower in 1990 and 2000 but somewhat higher in 2020.

Figures 7.1 and 7.2 are maps showing when irrigation ceases for townships in the study area under Scenario 2.

Because of the water use restrictions, pumpage is substantially lower under Scenario 2 than for either of the other two scenarios.

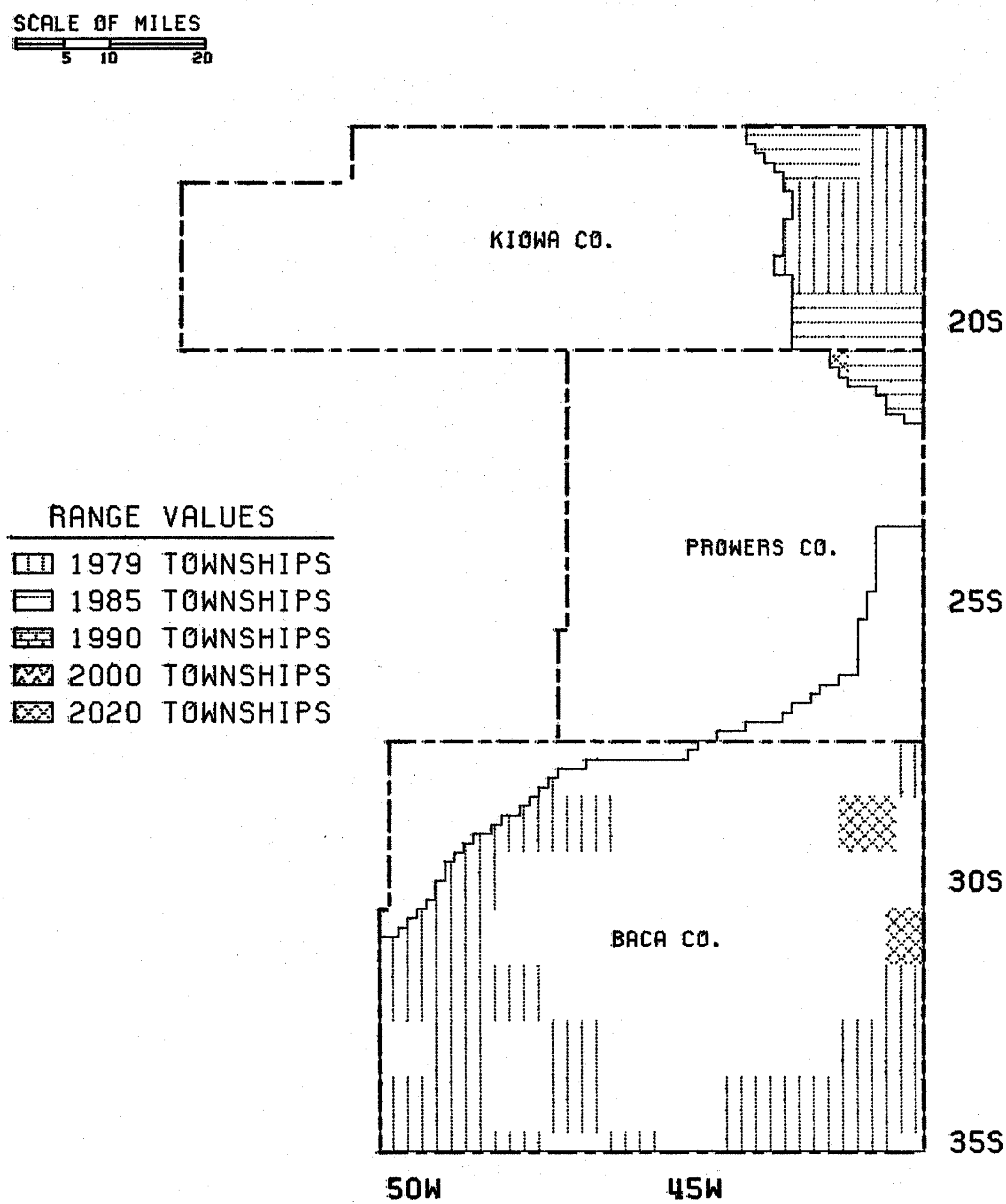
Under Scenario 2, electricity use for irrigation declines steadily over the forecast period to about 60 percent of its 1979 level. This reflects the pumpage restrictions and increasing efficiencies assumed.

Natural gas use for irrigation also declines steadily over the forecast period. Use levels stay well below those of either Scenario 1 or the Baseline until 2020, when usage under Scenario 2 is about equal to that under the Baseline.



OGALLALA AQUIFER, NORTH-EASTERN COLORADO
IRRIGATION REMOVED BY SIMULATION 2

Figure 7.1



OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
IRRIGATION REMOVED BY SIMULATION 2

Figure 7.2

Comparing crop production employment for the three scenarios on irrigated farms, we find a trend similar to that for irrigated land. Scenario 2 has the lower figures until 2020, when it shows 101 more jobs than the Baseline and 139 fewer jobs than Scenario 1. Employment in producing dryland crops is not very different from that found in the other two scenarios. A total of 437 farm jobs are lost over the forecast period.

Projection of Crop Production

Tables 7.4 and 7.5 show crop production and value of production for Scenario 2. Even with the restrictions on water supply, corn remains the dominant crop under irrigation, but by 2020 the output of sunflowers, wheat, and pinto beans is higher than under the previous scenarios.

The value of irrigated crop production is lower than in the Baseline or in Scenario 1 for all time periods except 2020, when the Scenario 2 value in between the other two (greater than the Baseline figure, but below that for Scenario 1). Returns to land and management comparisons follow the same pattern over time.

The value of dryland crop production and returns to land and management for the three scenarios discussed so far are all within about 5 percent of each other.

Table 7.6 shows selected figures from Scenario 2 as a percentage of the correspondent Baseline figures. Comparisons of Scenario 1 and Scenario 2 can be made by studying Tables 6.5 and 7.6.

Aquifer Status Projections

Table 7.7 shows the water table declines under Scenario 2 in the representative townships selected for Table 5.12. Water table declines under

Table 7.4. Projected Colorado Irrigated Production and Value of Production, Colorado Ogallala Region, Scenario 2, by Years.

	1985	1990	2000	2020
Crop Production				
Corn (mil. bu.)	59.1	54.2	56.1	43.7
Sorghum (mil. bu.)	3.4	2.8	2.0	0.2
Wheat (mil. bu.)	0	0	0	3.7
Sunflowers (th. cwt.)	404.8	1,149.6	278.5	3,818.1
Sugar Beets (th. tons)	115.6	102.2	29.1	0
Pinto Beans (th. cwt.)	317.5	300.4	273.8	244.9
Alfalfa (th. tons)	81.9	84.8	60.0	57.9
Value of Production (in millions of 1979 dollars)				
Corn	181.1	168.8	186.3	152.4
Sorghum	8.8	7.4	5.7	0.6
Wheat	0	0	0	14.3
Sunflowers	4.5	12.4	3.2	48.1
Sugar Beets	3.8	3.4	1.0	0
Pinto Beans	7.7	7.4	7.1	6.9
Alfalfa	5.1	5.4	3.9	3.8
Total	211.0	204.8	207.2	225.5
Returns to Land and Management	52.8	43.5	57.3	83.3

Scenario 2 are about two-thirds as large as the declines found under Baseline conditions over the 40 year projection period.

Table 7.8 shows the projections of water remaining in the aquifer under Scenario 2.

After 1985, there is more water remaining in the aquifer under Scenario 2 than there is under the Baseline conditions. By 2020, there is 17 percent more recoverable water left in storage. Water use restriction conserves the supply of water, but entails considerable costs in terms of forgone farm production and income.

Table 7.5. Projected Dryland Production and Value of Production, Scenario 2, Subareas 1-6.

	1985	1990	2000	2020
Crop Production				
Wheat (mil. bu.)	39.3	43.1	49.1	54.8
Sorghum (mil. bu.)	2.7	2.3	2.0	2.3
Sunflowers (mil. cwt.)	1.0	1.3	1.9	2.9
Corn (th. bu.)	401.8	427.0	457.1	525.5
Hay (th. tons)	21.2	39.8	16.5	16.5
Value of Crop Production (in millions of 1979 dollars)				
Wheat	127.7	141.8	164.8	201.0
Sorghum	7.0	6.0	5.5	6.7
Sunflowers	10.7	14.4	22.0	36.7
Corn	1.2	1.3	1.5	1.9
Hay	1.3	2.5	1.1	1.1
Total	147.9	166.0	194.9	247.4
Returns to Land and Management	53.0	58.3	76.5	117.0

Table 7.6. Projected Resource Use, Crop Production Values, and Returns to Land and Management -- Scenario 2 Figures as a Percent of Baseline Figures.

	1985	1990	2000	2020
Irrigated Cropland	99	99	94	131
Dry Cropland Harvested	100	100	100	96
Irrigation Water Pumped	90	81	68	89
Electricity for Irrigation	91	77	60	65
Natural Gas for Irrigation	92	74	53	103
Total Crop Production Employment	98	96	94	102
Value of Irrigated Crop Production	95	89	81	109
Value of Dryland Crop Production	100	100	100	97
Returns to Land and Management				
Irrigation	92	91	87	125
Dryland	100	100	100	96

Table 7.7. Projected Water Level Declines in Representative Townships, Scenario 2.

Subarea	Number of Wells (1979)	Water Level Decline (feet) 1979-1985[a]	1985-1990	1990-2000	2000-2020	Total Decline (feet)	Average Decline (ft./year)
1	26	9	7	11	17	44	1.1
2	15	5	4	6	8	23	0.6
3	18	5	4	6	9	24	0.6
	13	3	2	3	4	12	0.3
4	28	10	7	12	18	47	1.2
	31	11	9	18	36	74	1.8
5	24	8	6	10	15	39	1.0
6	19	3	2	2	4	11	0.3

[a] Same as Baseline.

Table 7.8. Projected Volumes of Water Remaining in the Ogallala Aquifer, Scenario 2. (millions of acre feet)

	1979	1985	1990	2000	2020
Total Water in Storage	94	89	87	83	79
Recoverable Water in Storage	61	57	53	48	43

CHAPTER VIII

SCENARIO 3: LOCAL WATER SUPPLY IMPROVEMENT

Treatment of Scenario 3

Scenario 3 contemplated innovative local water supply improvement policies, including such possibilities as local rainfall capture (as on playa lake beds) or weather modification. In the judgment of the study team, the prospects for this form of supply augmentation are quite remote for Colorado conditions. Any objective probabilities of such augmentation and their associated costs are not available from state agencies concerned with water supply management. Hence, no systematic analysis of Scenario 3 was conducted.

CHAPTER IX

SCENARIO 4: IN-STATE WATER IMPORTS

Treatment of Scenario 4

Scenario 4 was proposed to reflect in-state importation of surface water supplies. Potential additional supplies are limited in Colorado, but conceivably could be obtained from the South Platte River system, from which, on the average, a small amount of water flows to Nebraska in excess of the inter-state compact requirements. Another potential source includes the Colorado River drainage west of the Continental Divide. No systematic analysis of costs of any of such sources has been undertaken at this writing, so the supply side of the economic picture is unclear. However, the ability-to-pay for water (the demand side) is to be treated in the following chapter in connection with Scenario 5. The interested reader is referred to Chapter X for a discussion of these projections, since the ability to pay for water imports at the farm level is independent of the source of the water supply.

The reader interested in Colorado policy implications is urged to be cautious in using our forecasts for in-state transfer evaluation. The methods used in computing ability-to-pay were established by the regional study team, but are not endorsed by the authors of this report.

CHAPTER X

SCENARIO 5 PROJECTIONS: INTERSTATE WATER IMPORTS

Scenario 5 describes the consequences of water importation from outside the state. Before describing the detailed effects on crop production and resource use, we report our estimates of farmers' ability to pay for water imports. Calculations for Scenario 5A are based on the acreage which would be lost to irrigation in Scenario 1; Scenario 5B is based on Scenario 2.

Farmers' Ability to Pay for Imported Water

The ability to pay for water for this study was computed as the sum of the net return to an acre foot of irrigation water, plus pumping costs that are no longer needed (which can therefore be applied to water from a new source). The savings in pumping costs include both pump operating costs and amortized capital costs. From this sum, the net returns to the dryland cropping that is displaced by an acre foot of irrigation water must be subtracted.

Net returns were computed as the returns to land and management.[1] Per acre figures were divided by the number of acre feet of water applied per acre to get returns on a per acre foot basis.

The savings in pumping costs were computed in each subarea on the basis of average pumping head (including water lift and pressurization), using the cost equations described earlier in this report. The energy prices and pumping plant efficiencies were the same as in Scenarios 1 and 2. The average

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[1] The formula for calculating net returns was dictated by the general contractor and the A-1 group research committee. It is the opinion of the present authors that the method selected rather substantially overstates true social benefits of water imports. See Young [1978] and Young [1981] for general discussions of this issue.

pumping cost was computed as a weighted average for electric and natural gas powered pumps in each subarea.

The distribution of irrigation systems and power sources used in computing average pumping head and costs are shown in Table 10.1

Table 10.1. Distribution of Irrigation Systems and Power Sources for Wells, by Subarea.

	Percent of Wells With		Percent of Wells Powered By	
Subarea	Gated Pipe	Center Pivot	Electricity	Natural Gas
1	0	100%	90%	10%
2	36%	64%	87%	13%
3	11%	89%	76%	24%
4	0	100%	91%	9%
5	46%	54%	48%	52%
6	79%	21%	30%	70%

The capital costs of the well, motor, pump, and utility connection were estimated for each subarea. Estimates were made by distribution system and energy source, with weighted averages taken. These costs estimates were then annualized using an 8 percent discount rate and a 20 year investment period. This amortized figure was divided by the number of acre feet of water applied by a typical pump in each subarea.

The net returns per acre of dryland was computed by dividing net dryland income by total dryland acreage. This figure was divided by the number of acre feet of water applied to an irrigated acre to show the returns from the amount of dryland that would be displaced if an acre foot of irrigation water became available.

In symbols, the ability to pay (ATP) for an acre foot of irrigation water was computed as:

$$ATP = (IR + PC + FC - DR)/WA \quad (10.1)$$

where IR = returns to irrigated land and management per acre;

PC = average per acre pumping cost saved;

FC = average annualized capital cost saved;

DR = net returns per acre of dryland (the opportunity cost of land); and

WA = average number of acre feet of water applied per acre.

In this formulation, both PC and FC must be net figures. Using surface water for gated pipe and sprinkler systems would require pumps for pressurization. These pumps would be small relative to those needed for irrigation from a well, and both their capital costs and operating costs would be relatively low. Under the conditions found in eastern Colorado, these costs would be about $18 per acre foot by 2000 ($15 would be pumping costs, with about $3 capital costs).

The estimates of ability to pay are shown in Table 10.2 for the years 2000 and 2020. Earlier dates are not considered since any water importation scheme is not likely to be implemented before 2000. The estimated costs of interstate water importation are about five times the estimated ability to pay in most of the subareas.

Table 10.2. Projected Ability to Pay for Imported Water at Farm Headgate, Scenarios 5A and 5B. (1979 dollars per acre foot)

	Scenario 5A		Scenario 5B	
Subarea	2000	2020	2000	2020
1	103	146	109	165
2	102	146	113	172
3	101	151	109	165
4	109	152	97	152
5	109	154	115	170
6	57	99	59	109

Production and Income Effects of Water Importation

The detailed effects of water importation into the Ogallala area of Colorado are shown in appendix tables for Scenario 5.

It was assumed that imported water would be applied only to land that had gone out of irrigation and would not be used to develop new irrigated lands. It was further assumed that water would be made available on a per acre basis equal to that being used by farmers who were still irrigating from wells, and that the same crop mix would be employed regardless of water source.

The appendix tables show changes in resource use and crop production that would result from water importation under the above assumption. There are no tables for subarea 1, because no land goes out of irrigated production under either Scenario 1 or Scenario 2 in this subarea.

Table 10.3 shows the land that goes out of irrigated crop production in each subarea under each scenario, and the volume of imported water that would be required to maintain irrigation on this land.

Table 10.4 shows the increase in electricity consumption associated with the pressurization requirements for this irrigation. The electricity consumption reported is only for on-farm production activities; the energy required for water importation is not accounted for here. The figures reflect the mix of irrigation systems found on the land that remained in irrigation in each subarea, and the assumption that these pumps will be electrically powered. Also shown in Table 10.4 are the changes in labor requirements for irrigated and dryland crop production. The water importation increases the number of jobs in crop production by about 200 worker-equivalents.

The net increase in the gross value of regional crop production due to water importation is shown in Table 10.5. Under Scenario 5A, the value of

Table 10.3. Land Restored to Irrigation with Imported Water and the Amount of Water Required.

Subarea	Land Restored (acres) 2000	2020	Water Application Rate (acre ft./acre) 2000	2020	Total Water Required (acre feet) 2000	2020
Scenario 5A						
1	0	0			0	0
2	300	9,200	1.90	1.69	570	15,550
3	12,200	28,800	1.83	1.69	22,330	48,670
4	800	3,200	1.83	1.73	1,460	5,540
5	30,200	90,400	1.88	1.65	56,780	149,160
6	53,500	21,800	1.62	1.45	86,670	31,610
Total	97,000	153,400	1.73	1.64	167,810	250,080
Scenario 5B						
1	0	0			0	0
2	300	3,300	1.34	1.18	400	3,900
3	19,100	19,100	1.28	1.18	24,450	22,540
4	41,300	20,600	1.70	1.38	70,210	28,430
5	39,500	78,900	1.34	1.18	52,930	93,100
6	55,800	25,100	1.14	1.06	63,600	26,600
Total	156,000	147,000	1.36	1.19	211,590	174,570

Table 10.4 Projected Changes in Resource Use Resulting from Water Importation, Colorado Ogallala Region, Scenario 5.

	Scenario 5A 2000	Scenario 5A 2020	Scenario 5B 2000	Scenario 5B 2020
Electricity Use for Irrigation (million KWH)[a/]	+28.2	+39.5	+35.6	+27.9
Crop Production Employment (man-years)				
Irrigated Farms	+203	+335	+285	+256
Non-Irrigated Farms	-39	-62	-48	-53
Total	+164	+273	+237	+203

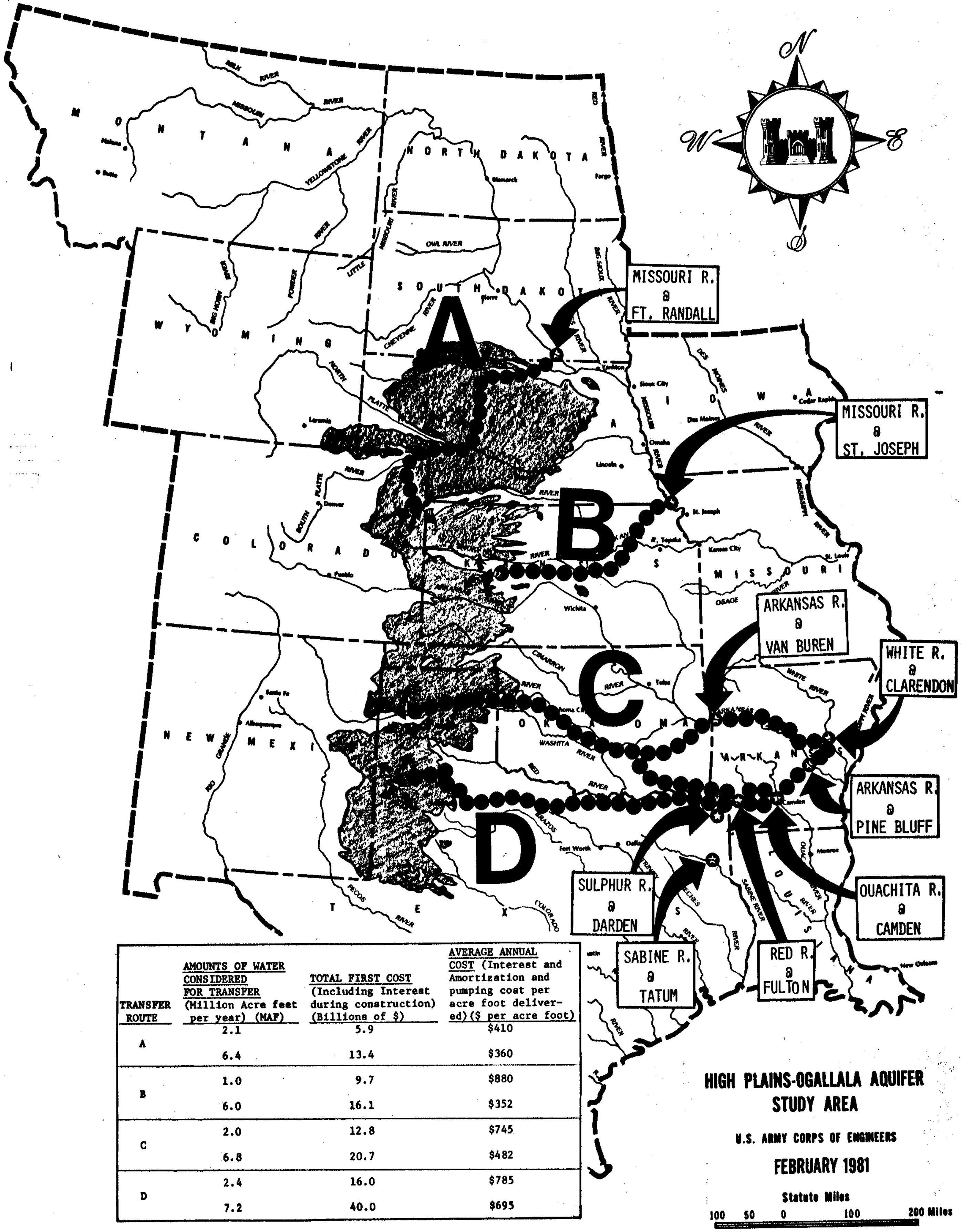
[a/] Excludes energy requirements to supply water to farm.

Table 10.5. Changes in the Value of Crop Production Due to Water Importation (all figures in thousands of 1979 dollars).

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Increases in the Value of Irrigated Crop Production				
Corn	30,859	73,365	50,506	48,566
Sugar Beets	20	64	5	0
Pinto Beans	14	0	904	1,732
Sorghum	6,465	486	6,757	192
Wheat	0	5,089	0	3,108
Sunflowers	4,040	4,116	3,705	14,248
Alfalfa	2,408	3,689	1,461	1,139
Total	43,806	86,809	63,338	68,985
Decreases in the Value of Dryland Crop Production				
Wheat	3,883	8,702	4,718	7,168
Sunflowers	869	1,477	957	1,325
Corn	1	33	1	12
Sorghum	279	146	303	169
Grassland Hay	52	215	317	305
Total	5,084	10,573	6,296	8,979

crop output is about $39 million above the level of Scenario 1 in 2000, and $76 million higher in 2020. Under Scenario 5B, the value of crop output is about $60 million greater than in Scenario 2 for both years.

As in Scenarios 1 and 2, the costs of implementing the policy changes are not included in our calculations. Since the ability to pay for water is about one-fifth of the estimated costs of interstate water importation, the returns to land and management will be negative if the cost of the water is included in the calculations. The costs of interstate water imports have been calculated by a group from the U.S. Army Corps of Engineers (see Figure 10.1).



TRANSFER ROUTE	AMOUNTS OF WATER CONSIDERED FOR TRANSFER (Million Acre feet per year) (MAF)	TOTAL FIRST COST (Including Interest during construction) (Billions of $)	AVERAGE ANNUAL COST (Interest and Amortization and pumping cost per acre foot delivered) ($ per acre foot)
A	2.1	5.9	$410
	6.4	13.4	$360
B	1.0	9.7	$880
	6.0	16.1	$352
C	2.0	12.8	$745
	6.8	20.7	$482
D	2.4	16.0	$785
	7.2	40.0	$695

Figure 10.1. Proposed Alternative Routes for Water Import Projects.

CHAPTER XI

SCENARIO 6 PROJECTIONS: LESS FAVORABLE ENERGY PRICE, CROP PRICE, AND CROP YIELD ASSUMPTIONS

Scenario 6 represents an addition to the project which examines the sensitivity of Baseline forecasts to a less favorable set of assumptions. This portion of the effort was not funded from the federal contract funds.

The motivation for performing the sensitivity analysis of Scenario 6 was as follows. First, the NIRAP price forecasts assumed trends in U.S. export levels which, although consistent with trends in the past decade, were much higher (as a percentage of U.S. output) than have been experienced over the longer term. If the underlying export projections incorporated into the NIRAP model fail to be realized, substantial downward pressure on real crop prices would be expected. Second, the energy price forecasts incorporated into the Baseline model have seemed to some to be overoptimistic, particularly in view of the enormous rise in OPEC petroleum prices since the energy price forecasts were made in 1979. Finally, a school of thought among plant scientists feels that past trends in improving crop production technology cannot be expected to continue in the future (an opinion not necessarily endorsed by the authors, let it be noted). In view of these considerations, and given the highly favorable forecasts of the future of the Colorado Ogallala region provided by the Baseline, it was deemed desirable to have in hand the forecasted impacts of a somewhat more conservative set of assumptions.

Scenario 6, like the Baseline scenario, assumed no change in public policy toward water management. The difference between Scenario 6 and the Baseline lies, then, entirely in the assumptions concerning future crop prices, energy costs, and yield projections. These assumptions, in the judgment of the authors, are each individually quite possible of occurring. Taken together, they represent a rather unlikely but not completely implausible set of assumptions.

For Scenario 6 crop prices were held constant in real dollars at their 1979 level. The prices of energy intensive inputs (electricity, natural gas, gasoline, diesel fuel, and fertilizer) were projected to increase twice as fast as in the Baseline. Grain and sunflower yields were projected to increase one-half as fast as in the Baseline, and fertilizer use was scaled back proportionately. For other crops, the rather modest yield increases projected in the Baseline scenario were included in Scenario 6. The figures on prices, yields, and fertilizer use are shown in Tables 11.1 to 11.4.

Table 11.1. Projected Energy and Energy-Related Prices, Scenario 6 (1979 dollars).

	Unit	1979	1985	1990	2000	2020
Electricity	¢/KWH	5.00	7.40	8.80	12.40	14.40
Natural Gas	$/MCF	1.70	7.14	11.20	11.90	12.60
Diesel Fuel	$/Gal.	0.80	1.36	1.38	1.46	1.56
Gasoline	$/Gal.	0.90	1.36	1.38	1.46	1.56
Anhydrous Ammonia	$/Lb.	0.09	0.27	0.41	0.43	0.45
Other Fertilizer	$/Lb.	0.11	0.26	0.38	0.40	0.42

Table 11.2. Projected Grain and Sunflower Yields, Scenario 6.

Crop	Subarea	Irrigation Level	1979	1985	1990	2000	2020
Irrigated Crops							
Corn (bu./ac.)	1,2,3,5	Full	130	136	141	148	158
		Two-thirds	110	114	122	128	136
		One-third	65	68	70	74	79
	4	Full	130	136	141	148	158
		Two-thirds	97	102	105	111	119
		One-third	45	48	50	54	59
	6	Full	120	126	131	138	148
		Two-thirds	102	106	114	120	128
		One-third	60	63	65	69	74
Sorghum (bu./ac.)	1,2,3	Full	60	63	66	68	73
		Two-thirds	54	56	58	60	64
		One-third	39	40	42	43	46
	4	Full	60	63	66	68	73
		Two-thirds	48	50	52	54	58
		One-third	33	34	36	37	40
	5	Full	75	78	80	83	96
		Two-thirds	67	69	71	73	77
		One-third	49	50	52	53	56
	6	Full	90	93	96	98	103
		Two-thirds	81	83	85	87	91
		One-third	58	60	61	62	65
Wheat (bu./ac.)	1,2,3,5,6	Full	50	52	54	58	66
		Two-thirds	47	49	51	55	62
		One-third	32	34	36	38	44
	4	Full	50	52	54	58	66
		Two-thirds	40	42	44	48	56
		One-third	27	29	31	34	40
Sunflowers (cwt./ac.)	1,2,3,5,6	Full	18	19.5	21	22.5	25.5
		Two-thirds	16.2	17.4	19	20	22
		One-third	11.7	12.7	13.7	14.7	16.7
	4	Full	18	19.5	21	22.5	25.5
		Two-thirds	14.4	15.6	16.8	17.8	19.8
		One-third	9.9	10.7	11.5	12.5	14.5
Dryland Crops							
Corn	1,2		30	31	32	33	36
	3,5,6		20	21	22	23	26
Sorghum	1,2,3,5,6		20	21	22	23	25

(continued on the following page)

Table 11.2. Projected Grain and Sunflower Yields, Scenario 6. (continued)

Crop	Subarea	Irrigation Level	1979	1985	1990	2000	2020
Dryland Crops (continued)							
Wheat	1,2		32	33.5	35	37	40
	3		25	26.5	28	30	32.5
	4,5		22	23.5	25	27	30
	6		18	19.5	21	23	26
Sunflowers	1,2,3,5,6		9	9.5	10	10.5	11.5

Table 11.3. Projected Use of Anhydrous Ammonia, Scenario 6.

Crop	Subarea	Irrigation Level	Application Level (lb./ac.) 1979	1985	1990	2000	2020
Corn	All	Full	200	209	217	228	244
		Two-thirds	180	188	193	203	215
		One-third	100	105	109	115	122
	1,2,3,5,6	Dry	50	52	54	56	60
Sorghum	1,2,3,5,6	Full	100	105	109	114	122
		Two-thirds	90	94	97	100	107
		One-third	70	73	75	78	85
	4	Full	120	126	131	136	146
		Two-thirds	100	104	108	112	120
		One-third	70	73	76	79	85
	1,2,3,5,6	Dry	50	52	54	58	64
Sunflowers	1,2,3,5,6	Full	90	98	105	123	138
		Two-thirds	90	98	105	110	122
		One-third	60	65	70	75	85
	4	Full	120	130	140	150	170
		Two-thirds	120	130	140	148	165
		One-third	80	87	94	102	118
	1,2,3,5,6	Dry	44	46	50	52	56
Wheat	1,2,3,5,6	Full	60	62	65	70	80
		Two-thirds	60	62	65	70	80
		One-third	50	53	55	60	70
	4	Full	75	78	81	87	98
		Two-thirds	75	78	81	87	98
		One-third	60	65	68	75	88
	All	Dry	40	44	46	50	56

Table 11.4. Projected Use of Other Fertilizer, Scenario 6

Crop	Subarea	Irrigation Level	Application Level (lb./ac.) 1979	1985	1990	2000	2020
Corn	1,2,3,5,6	Full	150	157	163	172	184
		Two-thirds	135	140	145	152	162
		One-third	75	78	81	85	90
	4	Full	200	209	217	228	244
		Two-thirds	150	157	163	172	184
		One-third	100	105	109	114	122
	1,2,3,5,6	Dry	50	52	54	56	60
Sorghum	1,2,3,5,6	Full	100	105	109	114	122
		Two-thirds	90	94	97	100	106
		One-third	60	62	64	66	71
	4	Full	120	126	131	136	146
		Two-thirds	100	104	108	112	120
		One-third	60	62	64	67	72
Wheat	1,2,3,5,6	Full	100	104	108	116	132
		Two-thirds	100	104	108	116	132
		One-third	70	75	80	87	100
	4	Full	120	125	130	139	157
		Two-thirds	120	125	130	139	157
		One-third	70	75	79	87	95
		Dry	60	64	68	72	80

Results of Scenario 6

This scenario was run as a sensitivity analysis to see what would happen in response to rather dramatic (although not unreasonable) changes in some of the basic projections of prices and crop yields. The shift in assumptions leads to a bleak outlook: irrigation disappears completely from the Colorado High Plains by 2020 and is substantially (60 percent) gone by 1990.

Resource Use

Table 11.5 shows the Scenario 6 projections for cropland, irrigation water pumped, energy used for irrigation and farm labor. Under the assumptions of Scenario 6, irrigation is not profitable enough to justify reinvestment in

Table 11.5. Projected Resource Use, by Year, Colorado Ogallala Region, Scenario 6.

	1979	1985	1990	2000	2020
Irrigated Cropland (1000 acres)	600	470	235	72	0
Dry Cropland Harvested (1000 acres)	1,683	1,750	1,828	1,887	1,918
Irrigation Pumps, Electric	3,048	2,849	2,389	1,311	0
Irrigation Pumps, Natural Gas	1,719	1,606	1,266	642	0
Irrigation Water Pumped (1000 acre feet)	1,148	706	202	56	0
Electricity Use for Irrigation (million KWH)	441	364	108	26	0
Natural Gas Use for Irrigation (1000 MCF)	4,279	950	188	96	0
Crop Production Employment (man-years)					
Irrigated Farms	1,332	886	318	101	0
Non-Irrigated Farms	1,344	1,391	1,455	1,501	1,529
Total	2,676	2,277	1,733	1,602	1,529

irrigation facilities. This occurs by 1985 in most subareas and depth zones, where irrigation pumps go out of existence as fast as the irrigation feasibility test will allow, with one-quarter disappearing by 1990, one-half going out by 2000, and the rest by 2020. In most subareas, some irrigation facilities are carried "on the books" because they have not been completely amortized, even though they are not in use (the linear programming model specifies dryland production).

With the demise of irrigation, crop production employment declines rapidly in the study area. A total of 1,147 farm jobs are lost over the 40 year period.

Crop Production

Tables 11.6 and 11.7 show how crop production and value of production changes under Scenario 6. After 1979, there is a strong shift to wheat production on irrigated land. Alfalfa, which is not forced into the linear programming solutions for Scenario 6, disappears by 1985. Irrigated corn disappears by 1990, and, as noted, all irrigated crop production ceases by 2020. Net irrigated crop income is negative after 1979, until it becomes zero in 2020.

Table 11.6. Projected Irrigated Crop Production and Value of Production, Scenario 6, Subareas 1-6.

	1979	1985	1990	2000	2020
Crop Production					
Corn (mil. bu.)	56.0	37.1	0	0	0
Sorghum (mil. bu.)	2.7	0.05	0	0	0
Wheat (mil. bu.)	1.9	7.7	9.4	3.0	0
Sunflowers (th. cwt.)	0	36.4	714.1	303.7	0
Sugar Beets (th. tons)	390.0	266.8	161.4	43.7	0
Pinto Beans (th. cwt.)	366.6	340.9	277.0	163.2	0
Alfalfa (th. tons)	179.3	0	0	0	0
Value of Production (in millions of 1979 dollars)					
Corn	145.7	96.5	0	0	0
Sorghum	5.9	0.1	0	0	0
Wheat	6.8	27.1	33.3	10.7	0
Sunflowers	0	0.4	7.2	3.1	0
Sugar Beets	11.7	8.1	4.8	1.3	0
Pinto Beans	8.9	8.1	6.6	4.0	0
Alfalfa	9.8	0	0	0	0
Total	188.8	140.3	51.9	19.1	0
Returns to Land and Management	48.8	-1.8	-16.7	-11.0	0

Table 11.7. Projected Dryland Crop Production and Value of Production, Scenario 6, Subareas 1-6.

	1979	1985	1990	2000	2020
Crop Production					
Wheat (mil. bu.)	35.0	38.7	43.6	49.2	51.4
Sorghum (mil. bu.)	3.8	3.8	3.3	3.0	2.0
Sunflowers (mil. cwt.)	0	0	0	0	2.0
Corn (th. bu.)	376.5	389.3	404.8	437.0	522.9
Grass Hay (th. tons)	8.0	19.1	19.6	19.6	16.5
Value of Production (in millions of 1979 dollars)					
Wheat	122.3	135.7	152.7	172.0	179.8
Sorghum	8.5	8.2	7.4	5.3	4.5
Sunflowers	0	0	0	0	19.9
Corn	1.0	1.0	1.0	1.1	1.4
Grass Hay	0.4	1.0	1.0	1.1	0.9
Total	132.2	145.9	162.1	179.5	206.5
Returns to Land and Management	56.5	40.7	35.0	42.1	60.4

The diligent reader will notice in the appendix tables for subarea 6 that sunflowers occupy most of the irrigated land, seemingly without regard to the acreage constraint (whereby sunflowers can occupy only one-quarter of the cropland). This occurs because a large part of the irrigable land is farmed as dryland. This should be interpreted to mean that sunflowers are still being grown in a rotation, but the rotation involves dryland production in the intervening years.

Table 11.7 shows that, under the yield and price assumptions of Scenario 6, sunflowers do not appear in the dryland cropping mix until 2020. In the intevening years, wheat output is similar to that of the Baseline. The value of wheat output is higher for Scenario 6 because the constant price of $3.50 per bushel is higher than that used in the Baseline for these years.

The total value of dryland crop production is lower in each time period than it is in the Baseline due to the lower yields and prices assumed in Scenario 6. The differences are fairly small until 2020, when the Scenario 6 figure is $50 million less than the Baseline figure. In 2020, the output and value of production of almost every crop is lower.

From 1985 on, the returns to land and management in dryland farming are substantially lower in Scenario 6 than for the Baseline.

Table 11.8 shows selected figures from Scenario 6 as a percentage of the corresponding Baseline figures. Everything associated with irrigation declines rapidly over the study period, especially natural gas usage. Dry cropland, because of the large existing base, increases rather modestly in percentage terms. The value of dryland crop output remains somewhat below that in the Baseline, while dryland returns to land and management are not only very much lower but also declining over time.

Table 11.8. Resource Use, Crop Production Values, and Returns to Land and Management -- Scenario 6 Figures as a Percentage of Baseline Figures.

	1985	1990	2000	2020
Irrigated Cropland	84	44	14	0
Dry Cropland Harvested	102	105	108	106
Irrigation Water Pumped	66	20	6	0
Electricity for Irrigation	84	24	6	0
Natural Gas for Irrigation	24	6	3	0
Total Crop Production Employment	88	68	64	70
Value of Irrigated Crop Production	63	23	7	0
Value of Dryland Crop Production	99	98	92	81
Returns to Land and Management				
Irrigation	(a)	(a)	(a)	0
Dryland	77	60	55	50

(a) Returns to land and management were negative for irrigation for Scenario 6.

Aquifer Status

Table 11.9 shows the water table decline in each of the representative townships chosen for Table 5.12. Negative numbers in Table 11.9 indicate a rise in the water table. This occurs from natural recharge after irrigation pumping has stopped.

Table 11.9. **Water Level Declines in Representative Townships, Scenario 6.**

Subarea	Number of Wells (1979)	Water Level Decline (feet) 1979-1985*	1985-1990	1990-2000	2000-2020	Total Decline (feet)	Average Decline (ft./year)
1	26	9	7	-4	-8	4	0.1
2	15	5	4	1	-1	9	0.2
3	18	5	1	-3	-7	-4	-0.1
	13	3	2	-1	-8	-4	-0.1
4	28	10	5	-2	-8	5	0.1
	21	11	10	6	-5	22	0.5
5	24	8	0	-3	-7	-2	0.05
6	19	3	0	-2	-6	-5	0.1

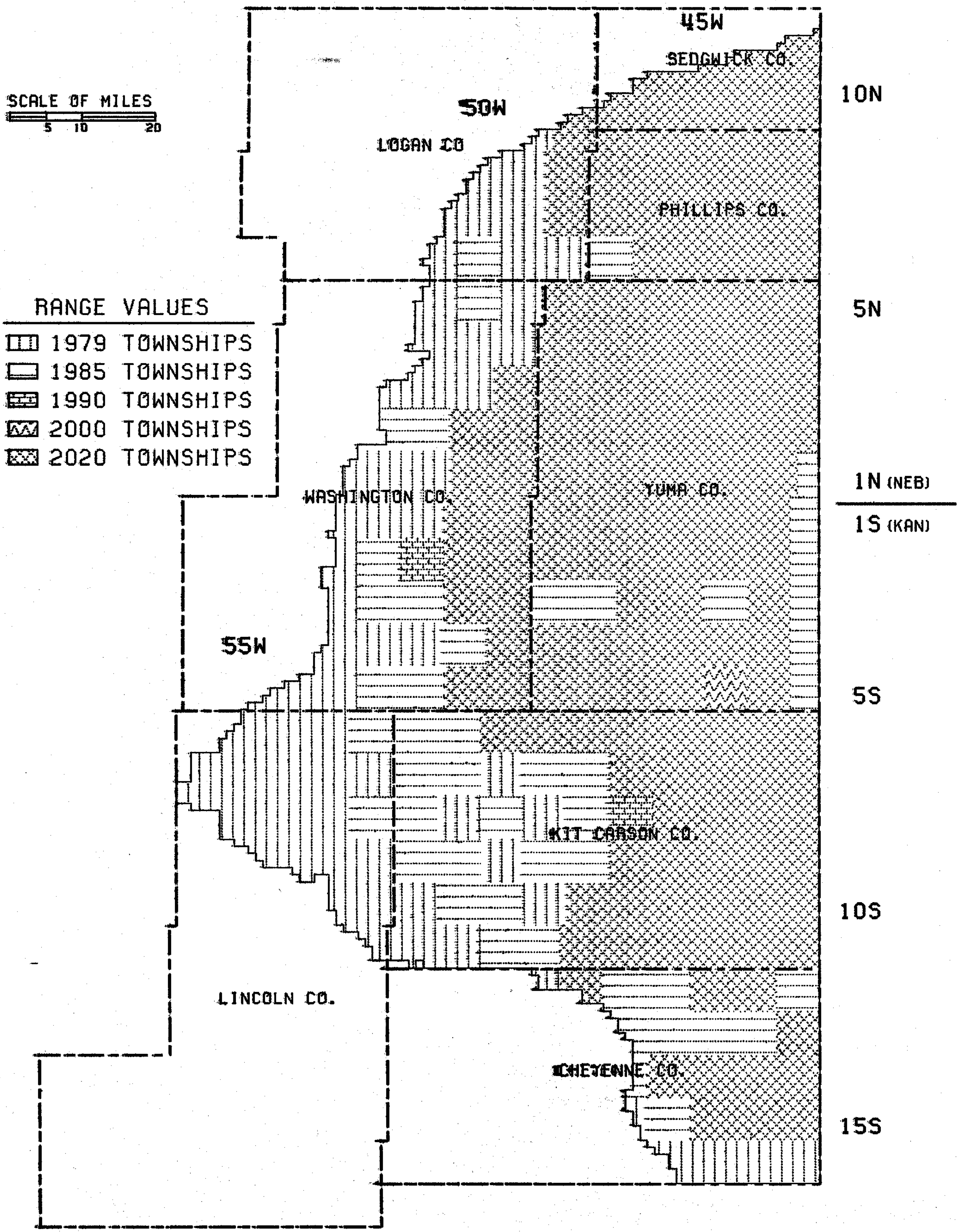
As expected, non-use of the water results in preservation of the aquifer. However, this preservation comes at the expense of irrigated agriculture and a large decline in crop output and farm incomes for the study area.

Table 11.10 shows the projections of water remaining in the aquifer under Scenario 6.

Table 11.10. Projected Volumes of Water Remaining in the Ogallala Aquifer, Scenario 6. (millions of acre feet)

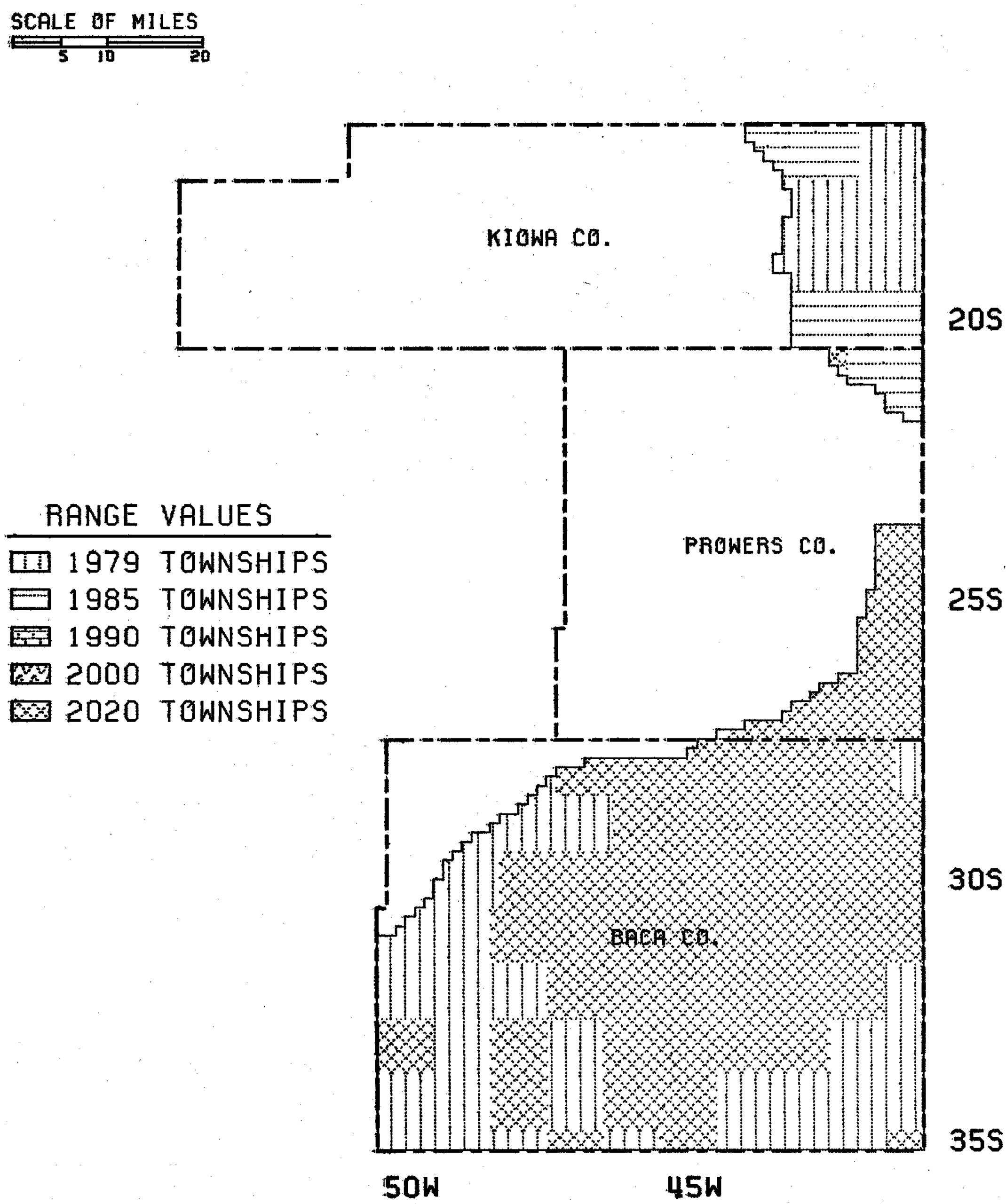
	1979	1985	1990	2000	2020
Total Water in Storage	94	90	88	90	98
Recoverable Water in Storage	61	57	55	56	51

Under this scenario, the demise of irrigated agriculture preserves the water in the aquifer, which increases in volume after 1990 as total recharge exceeds irrigation pumpage. As under Scenario 2, the preservation comes at considerable cost in terms of forgone farm production and income.



OGALLALA AQUIFER, NORTH-EASTERN COLORADO
IRRIGATION REMOVED BY SIMULATION 6

Figure 11.1



OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
IRRIGATION REMOVED BY SIMULATION 6

Figure 11.2

CHAPTER XII

SUMMARY AND CONCLUSIONS

The purpose of this study was to examine the impacts of groundwater depletion and rising energy prices on irrigated agriculture for that portion of eastern Colorado that is underlain by the Ogallala aquifer over the 40 year period ending in 2020.

Summary

The problem was conceptualized in terms of modeling how a rational, profit-oriented farmer will respond to changes in water availability, energy costs, crop prices, and irrigation technology. The solution technique involved combining a hydrologic model (which predicts depth to water and the quantity of water remaining for each township), with a linear programming farm management model (which projects water and energy demand for expected water supply, water cost, and crop production conditions). In general terms, the hydrologic model describes water availability and costs and the linear programming model allocates the available water and energy to various production activities so as to maximize the net returns to land, water, and management. The forecasts assumed that no major changes in outside physical (e.g., climatic) and social (e.g., wars) conditions will occur over the forecast period.

The study area was divided into six subareas on the basis of soil and climatic differences significant to irrigation and cropping practices. A specific model was created for each subarea. Initial year (1979) estimates of production costs, technology, and water supplies were obtained from surveys in the study area and from published sources.

The study produced forecasts of water and energy consumption, crop production employment, and farm income (returns to land and management) for the years 1979, 1985, 1990, 2000, and 2020 for each of six different "scenarios." The "Baseline" scenario assumed no change in public policy toward groundwater use and a continuation of current trends in irrigation management. Scenarios 1 through 5 each represented hypothetical policy changes which would either modify water demand or supply. Scenario 1 involves improvements in pumping plant and water application efficiencies which reduce the energy and water demands associated with irrigation. Scenario 2 added a regulatory change to the conditions assumed for Scenario 1, consisting of state-enforced limits on groundwater withdrawals.

Farmers' ability to pay for imported water in each subarea was estimated. Scenario 5A considered the water importation that would be necessary to maintain irrigated acreage at 1979 levels under Scenario 1 conditions while Scenario 5B did the same for Scenario 2 conditions. (Scenario 3 was proposed as a study of local water supply augmentation, but the prospects for any significant augmentation of water supplies originating within the Colorado study area were judged to be remote and unquantifiable. Scenario 4 was proposed to be a study of how water imported to the study area from other parts of Colorado might be used. The possible sources and costs of obtaining such water were beyond the scope of this report but the on-farm ability to pay for water would be the same regardless of its source, and this is reported in the results for Scenarios 5A and 5B.)

The implications of a final set of conditions, termed Scenario 6, which assumes much less favorable conditions of energy prices, crop prices, and crop yield increases than the previous scenarios, were also forecast. Energy prices, for this case, were assumed to increase twice as fast (in constant dollar terms) while crop prices were assumed unchanged and crop yields assumed to increase only one-half as rapidly as in the Baseline case. This "pessimistic" scenario was analyzed as a form of sensitivity analysis.

Comparison of Scenario Results

The major results from the various scenarios are presented for each time period in Tables 12.1 to 12.8.

Irrigated Cropland. Table 12.1 and Figure 12.1 show forecasted changes in irrigated cropland. We see that irrigated land drops steadily from one time period to the next under both the Baseline scenario and Scenario 1. The Baseline scenario shows a 40 percent decrease in irrigated land by 2020, while Scenario 2 shows a decline of about 20 percent. Under Scenario 2, irrigated land reaches a low point in 2000, then expands a bit by 2020. The figures for Scenarios 5A and 5B show the restoration of irrigated acreage to 625,000 with imported water. Under the less optimistic conditions of Scenario 6, irrigated acreage disappears rapidly, falling to zero by 2020.

Table 12.1. Projected Cropland Under Irrigation in the Colorado Ogallala-High Plains Region, by Scenario and Time Period.(thousands of acres).

Scenario	1979	1985	1990	2000	2020
Baseline	600	562	529	501	364
1	600	562	567	528	472
2	600	557	524	469	478
5A	600	562	567	625	625
5B	600	557	524	625	625
6	600	470	235	72	0

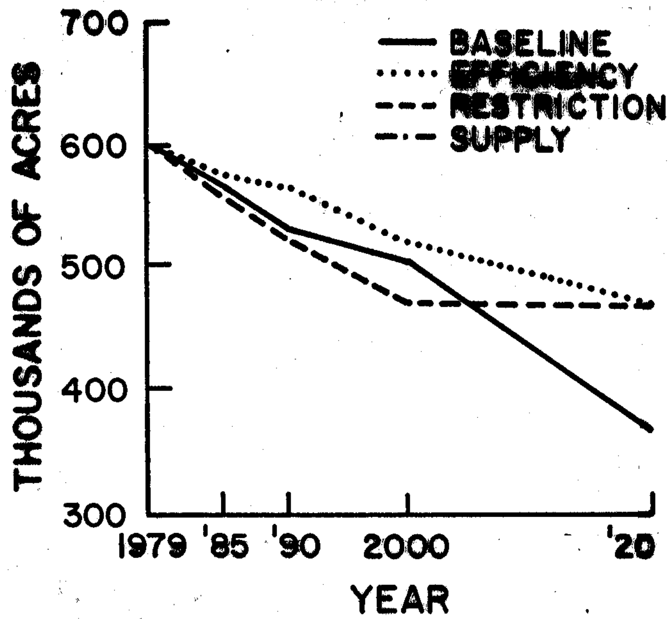


Figure 12.1. Projected Cropland Under Irrigation in the Colorado Ogallala-High Plains Region.

Groundwater Pumped. Table 12.2 and Figure 12.2 show the projections of groundwater pumped for irrigation with each scenario. Notice that groundwater pumpage is the same for Scenarios 1 and 5A (differences between these two scenarios in irrigated acreage, other resource use, and agricultural output are due to imported surface water). The same relationship holds for Scenarios 2 and 5B.

Table 12.2 Projections of Groundwater Pumped for Irrigation in the Study Area, by Year (thousands of acre feet).

Scenario	1979	1985	1990	2000	2020
Baseline	1,148	1,076	1,005	965	656
1 and 5A	1,148	1,076	1,059	971	783
2 and 5B	1,148	968	815	656	584
6	1,148	706	202	56	0

For the Baseline scenario, the amount of water pumped in 2020 is projected to be about 57 percent of the amount pumped in 1979.

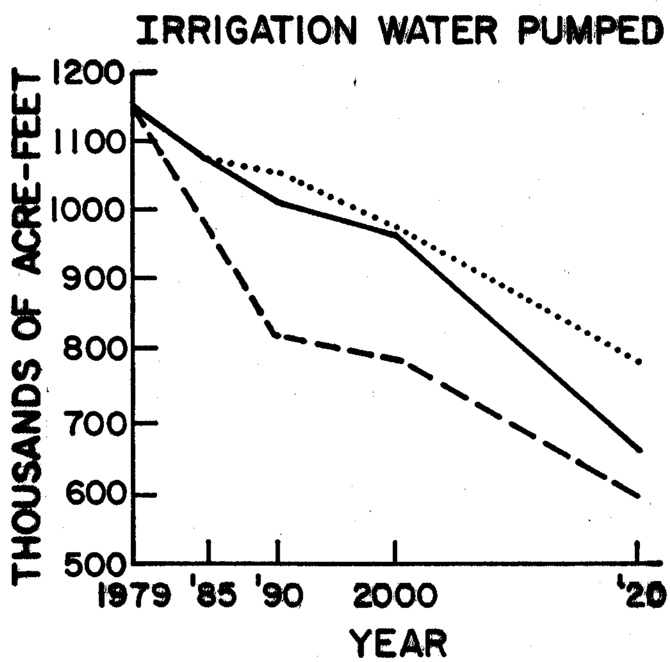


Figure 12.2. Projections of Groundwater Pumped for Irrigation in the Study Area.

Irrigation pumpage in 2020 is projected to be about 80 percent of the amount pumped in 1979 under Scenario 1 due to assumed improvements in water use efficiency which preserve the aquifer for later utilization. About 50 pecent of the amount pumped in 1979 would continue under Scenario 2, the regulatory situation (but more would be available for withdrawal after 2020). Under Scenario 6, pumpage declines to zero by 2020 along with irrigated acreage.

Energy Use. Table 12.3 and Figure 12.3 show the projections of electricity use for irrigation pumping. With the Baseline scenario, electricity use peaks in 2000 at 475 million KWH. With Scenario 1, it peaks in 1990 at 442 million KWH. The shift reflects the assumed improvements in irrigation efficiencies in the later years. For Scenarios 2 and 6, electricity use declines continuously over the 40 year period, to 58 percent of the amount used in 1979 in the

Table 12.3. Projections of Electricity Use for Irrigation Pumping in the Study Area, by Year (million KWH).

Scenario	1979	1985	1990	2000	2020
Baseline	441	432	447	475	389
1	441	432	442	423	351
2	441	392	345	285	254
5A	441	432	442	451	391
5B	441	392	345	321	282
6	441	364	108	26	0

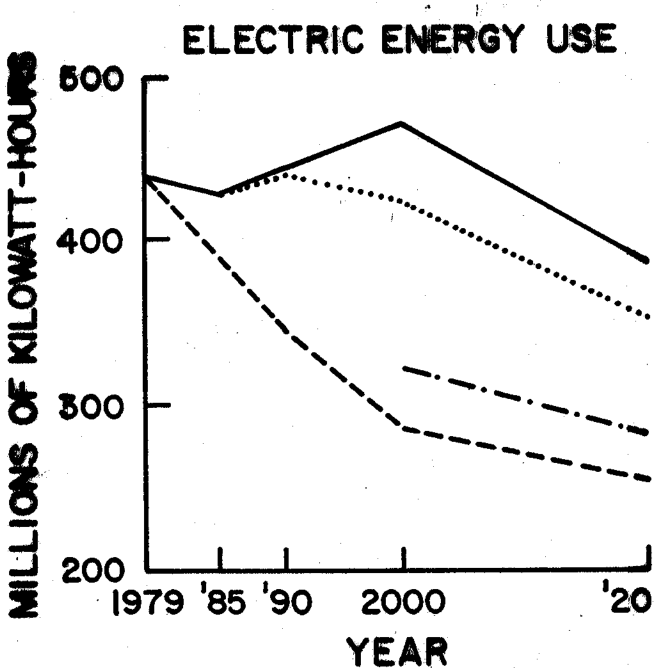


Figure 12.3. Projections of Electricity Use for Irrigation Pumping in the Study Area.

case of Scenario 2 and to zero in the case of Scenario 6.

For Scenarios 5A and 5B, electricity consumption is the same as for Scenarios 1 and 2, respectively, until 2000 when additional electricity is used to pressurize some of the imported water for use in sprinklers. On the basis of relative fuel costs, it was assumed that all of this pressurization would be done with electric pumps. This explains why the figures on natural gas use, shown in Table 12.4, are the same for Scenarios 1 and 5A and for Scenarios 2 and 5B.

Table 12.4. Projections of Natural Gas Use for Irrigation Pumping in the Study Area, by Year (thousands MCF).

Scenario	1979	1985	1990	2000	2020
Baseline	4,279	3,989	3,248	2,810	1.160
1 and 5A	4,279	3,989	3,055	2,136	1,423
2 and 5B	4,279	3,659	2,406	1,503	1,200
6	4,279	950	188	96	0

Natural gas use for irrigation (Table 12.4) declines steadily with all of the scenarios; usage in 2020 ranges from 33 percent of the amount used in 1979 in the case of Scenario 1 (and 5A) down to zero for Scenario 6. This trend derives from the expectation that natural gas prices will rise much more rapidly than will electricity rates and because gas powered pumps tend to be located in the areas developed earliest, and therefore most likely to deplete water supply in the forecast period.

Value of Crop Production. Table 12.5 shows the projections of the value of crop production (1979 price levels). The value of irrigated crop production reaches a peak in 2000 under the Baseline scenario, then declines almost 20 percent by 2020. Under Scenario 1, the peak value also occurs in 2000 but the peak value is higher than for the Baseline and the 2020 value is not much below the peak.

For Scenario 2, the value of irrigated crop production is lower than in the Baseline or in Scenario 1 for all time periods except the last, when it is between the other two (greater than the Baseline figure, but below that for Scenario 1).

Table 12.5. Projections of the Value of Crop Production in the Study Area, by Year (in millions of 1979 dollars).

Scenario	1979	1985	1990	2000	2020
Irrigated Crops					
Baseline	189	223	230	255	208
1	189	223	245	272	270
2	189	211	205	207	226
5A	189	223	245	316	357
5B	189	211	205	270	295
6	189	140	52	19	0
Dryland Crops					
Baseline	132	148	166	195	256
1	132	148	164	194	249
2	132	148	166	195	247
5A	132	148	164	189	238
5B	132	148	166	183	238
6	132	146	162	180	206
All Crops					
Baseline	321	371	396	450	464
1	321	371	409	466	519
2	321	359	371	402	473
5A	321	371	409	505	595
5B	321	359	371	453	533
6	321	286	214	199	206

The importation of water by 2000 would cause the value of irrigated crop production to rise continuously over the next 40 years for both Scenarios 5A and 5B. Under Scenario 6, the value of irrigated crop production drops rapidly to zero by 2020.

For all scenarios, the value of dryland crop production is projected to increase steadily over time (Table 12.5). The rate of increase for Scenario 6 is substantially less than for the other scenarios, reflecting the assumptions of slower yield increases and lower commodity prices.

The value of dryland crop production increases enough under each scenario to dominate the overall picture in terms of the value of crop production. The total value of all crops produced in the study area is projected to rise steadily (in terms of constant value dollars) for all scenarios except 6. Under Scenario 6, crop production becomes an exclusively dryland enterprise over time and the value of crop output in 2020 is only about two-thirds of what it was in 1979.

The total value of crop production (in 1979 dollars) is shown in Table 12.5 and Figure 12.4. The projected increases in both dryland and irrigated crop yields per acre is more than sufficient to offset the drop in irrigation. Hence, all scenarios show a comfortable increase over time.

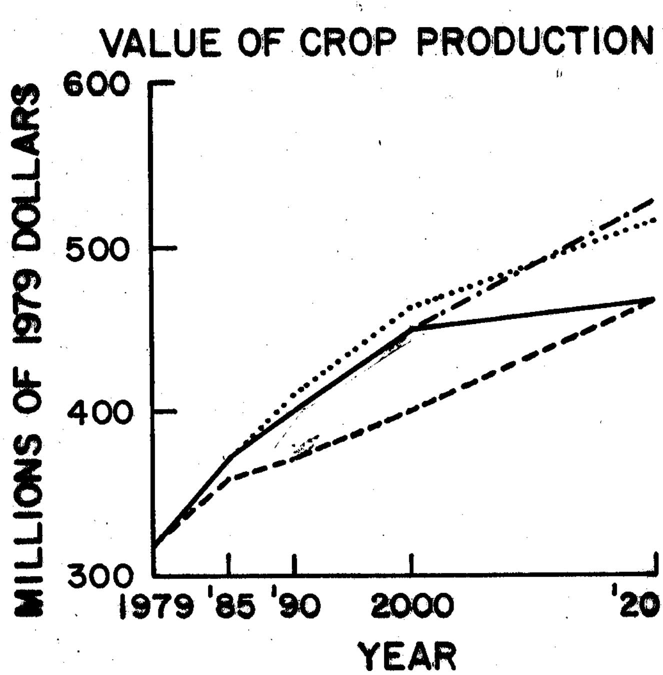


Figure 12.4. Projections of the Value of Crop Production in the Study Area.

Returns to Land and Management. Table 12.6 shows the projections of the returns to land and management in the study area. For the first three scenarios, the trend over time for irrigated crop production is rather flat until 1990, followed by higher returns in 2000 and 2020 due to favorable price and yield trends and the flattening of energy cost increases. Scenario 1 shows the highest returns over the study period. This is not surprising since it assumes the greatest efficiency in input use and does not have any input use restrictions.

For Scenarios 5A and 5B, the returns to land and management after imported water becomes available will depend on the cost of that water to farmers. If the cost exceeds farmers' ability to pay, the water importation will actually reduce the returns to land and management to levels below what they would be without water importation.

Under Scenario 6, the returns to land and management are negative from 1985 until irrigation disappears.

For dryland crops, the returns to land and management are very similar over time for all of the scenarios except 6, where they are dramatically lower because of the less favorable price and yield assumptions.

For all crop production, the trend in returns to land and management is generally similar to that for irrigated crops: flat until 2000, then rising. This holds for the first three scenarios.

The price of water to farmers under a water import scheme is uncertain, which poses a problem in determining returns under Scenarios 5A and 5B. The annual cost of either import scheme greatly exceeds the projected net returns, so net returns would be negative in the absence of a major subsidy.

Table 12.6. Projections of the Returns to Land and Management in the Study Area, by Year (in millions of 1979 dollars).

Scenario	1979	1985	1990	2000	2020
Irrigated Crops					
Baseline	49	57	48	65	66
1	49	57	57	84	102
2	49	53	44	57	83
5A	49	57	57	(a)	(a)
5B	49	53	44	(a)	(a)
6	49	-2	-17	-11	0
Dryland Crops					
Baseline	56	53	58	77	121
1	56	53	58	76	118
2	56	53	58	76	117
5A	56	53	58	74	113
5B	56	53	58	73	112
6	56	41	35	42	60
All Crops					
Baseline	105	110	106	142	187
1	105	110	115	160	220
2	105	106	102	133	200
5A	105	110	115	(a)	(a)
5B	105	106	102	(a)	(a)
6	105	39	18	31	60

(a) Depends on the cost of imported water.

The methods used to compute ability to pay were established by the regional study team. The present authors believe that the method selected substantially overstates the true willingness to pay for water imports. In any case, the estimates ranged from $60 to $170 per acre foot, depending on the subarea, time, and scenario.

Under Scenario 6, returns to crop production fall spectacularly from 1979 levels and remain very low over the study period.

Employment. Table 12.7 shows the projections of crop production employment in the study area. In the first three scenarios, employment in irrigated crop production declines by 400-600 jobs over 40 years from the present 1,300+ man-years. The decline is considerably less under Scenarios 5A and 5B. Under Scenario 6, of course, no labor is employed in irrigated crop production by 2020.

Employment in dryland crop production increases over the study period by 100 jobs or so in the first three scenarios, by about 200 jobs in Scenario 6. In Scenarios 5A and 5B, dryland crop production employment is relatively stable over time.

From 1979 to 2020, total crop production employment in the study area would decline by 300-500 jobs under the first three scenarios. With water importation, this decline would be less; only 17 jobs lost under Scenario 5A, 240 jobs lost under Scenario 5B. Under Scenario 6, over 1,100 jobs in crop production are lost by 2020.

Aquifer Status. Table 12.8 and Figure 12.5 show the projections of the volume of water remaining in the aquifer. In this regard, there is very little difference between the Baseline scenario and Scenario 1 (the latter involves less water used per acre, but more irrigated acres). Since Scenario 2 involves considerably less irrigation pumping, more water is left in the aquifer at the end of the study period. This is also true for Scenario 6, where the demise of irrigation leads to an increase in the volume of water in the aquifer by 2020.

Table 12.7. Projections of Crop Production Employment in the Study Area, by Year, (in man-years).

Scenario	1979	1985	1990	2000	2020
Irrigated Crops					
Baseline	1,332	1,239	1,164	1,114	737
1	1,332	1,239	1,262	1,192	983
2	1,332	1,174	1,065	969	841
5A	1,332	1,239	1,262	1,395	1,318
5B	1,332	1,174	1,065	1,254	1,097
6	1,332	886	318	101	0
Dryland Crops					
Baseline	1,344	1,361	1,376	1,393	1,445
1	1,344	1,361	1,359	1,381	1,403
2	1,344	1,362	1,376	1,389	1,392
5A	1,344	1,361	1,359	1,342	1,341
5B	1,344	1,362	1,376	1,341	1,339
6	1,344	1,391	1,455	1,501	1,529
All Crops					
Baseline	2,676	2,600	2,540	2,507	2,182
1	2,676	2,600	2,621	2,573	2,386
2	2,676	2,536	2,441	2,358	2,233
5A	2,676	2,600	2,621	2,737	2,659
5B	2,676	2,536	2,441	2,595	2,436
6	2,676	2,277	1,733	1,602	1,529

Table 12.8. Projections of the Volume of Water Remaining in the Ogallala Aquifer in Colorado, by Year (millions of acre feet).

Scenario	1979	1985	1990	2000	2020
Total Water in Storage					
Baseline	94	89	86	81	71
1 and 5A	94	89	86	80	70
2 and 5B	94	89	87	83	79
6	94	90	88	90	98
Recoverable Water in Storage[a]					
Baseline	61	57	53	46	36
1 and 5A	61	57	53	46	35
2 and 5B	61	57	53	48	43
6	61	57	55	56	61

[a] Quantity of water in excess of a saturated thickness of 35 feet in those portions of the study area where it is presently economically feasible to pump.

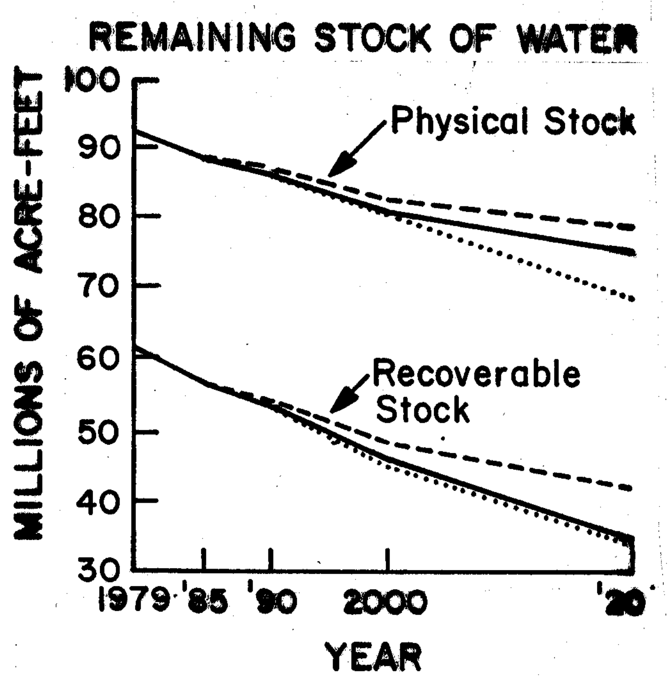


Figure 12.5. Projections of the Volume of Water Remaining in the Ogallala Aquifer in Colorado.

Present Value of Returns, by Policy Scenario. It is of interest for economic evaluation of the alternative policy scenarios to determine the net economic value of production under each scenario. This may be measured by computing the present value of the time stream of returns to land, water, and management for each scenario.

This measure is an indicator of the economic value of alternative scenarios. Table 12.9 shows the results of such a computation for only lands under irrigation and for all croplands in the region.

Table 12.9. Present Value of Net Returns to Land, Water, and Management for Selected Scenarios. (millions of 1979 dollars)

Scenario[a]	Irrigated Lands	All Lands
Baseline	642	1,362
1	705	1,423
2	603	1,324
6	155	708

[a]Scenarios 3, 4, 5 not computed, since assumptions concerning the financing of water supply projects would be required.

The results show that Scenario 1 has a present value somewhat larger than those for either the Baseline or Scenario 2. The difference between Scenario 1 and the Baseline is $60 million, but less than 5 percent. This difference, while not large, supports the policy conclusion that research on water conservation techniques is warranted. The fact that the value of the more restrictive scenario (number 2) is somewhat less than the value of the present management policy, exemplified in the Baseline, suggests that little further effort in this direction is warranted.

Conclusions

This study addressed the problem of making projections concerning the future of crop production in the portion of eastern Colorado that is underlain by the Ogallala aquifer. The general conclusions are presented here with reference to the hypotheses described in the Introduction to this report.

Hypothesis 1 - The Hydrologic Failure Hypothesis

The supply of economically recoverable water in the aquifer is not projected to be exhausted in the next 40 years. For most of the scenarios examined, the projected supply of recoverable water in the aquifer in 2020 is at least 60 percent of what it was in 1979.

Water level declines are expected to slow as pumping decreases, due to water availability constraints and increased pumping costs caused by rising energy costs and greater pumping lifts. The amount of natural recharge to the entire area is assumed to remain constant with time. The amount of water leaving as groundwater underflow to adjacent states is expected to decrease as the saturated thickness decreases with time. The combination of constant recharge, reduced pumping, and reduced groundwater outflow is expected to eventually result in a stabilized pumping rate which will approximate that amount of natural recharge captured by pumping. Mathematically, it can be expressed as the natural recharge rate minus the groundwater outflow when water table elevations stabilize. Some hydrologists predict that from 250,000 to 300,000 acre feet might be pumped continuously in the future after the stabilization occurs.

However, the supply of water is not evenly distributed over the study area, and diversity in water availability will increase over time. In some portions of the study area, mainly in the south and along the western edge, irrigation is already becoming restricted by limited water availability. Many farms in these areas will go out of irrigation entirely, creating adjustment problems for the farm operators and the local communities involved.

Hypothesis 2 - The Economic Failure Hypothesis

Whether or not the combination of increased energy prices and increased pumping lifts will cause pumping costs to rise to such an extent that irrigation becomes economically infeasible depends on the time paths of future energy and commodity prices and on future crop yield increases. In each of the first three scenarios, most of the land that went out of production did so because of physical exhaustion of the water supply. In Scenario 6, the projections of prices and yield increases (which are considered possible but not likely, at least not in combination) are such that irrigation disappears from the study area by 2020. Most of this impact is accounted for by the economic infeasibility of irrigation under this scenario.

Hypothesis 3 - The Regional Economic and Social Impact Hypothesis

This hypothesis is studied in detail in an accompanying report on the Colorado regional economic impact analysis, designed to examine the impact of the farm sector adjustments for each scenario [McKean, 1982].

The changes in crop production patterns described in this report will be large enough to cause economic adjustment problems in several counties in eastern Colorado. However, the fact that less than one-half of 1 percent of the Colorado work force is directly dependent on the Ogallala suggests that even the realization of Scenario 6 would not have a particularly destabilizing effect on the state's economy. The fact that total value of agricultural output is expected to rise in all scenarios suggests that the affected communities will not lose their economic base. Nevertheless, the decline in irrigated crop production will affect those sectors dependent on supplying inputs to the irrigated farms and the businesses who process or otherwise deal with crops grown with irrigation.

Hypothesis 4 - The National Agricultural Commodity Surplus Hypothesis

The two major crops in the study area are irrigated corn and dryland wheat (wheat can also be grown under irrigation as a less water-intensive crop than corn). Wheat production in the study area is almost certainly going to increase with time. This was projected by every scenario in this study.

Future corn output in the study area is somewhat less certain. For the Baseline scenario, irrigated corn output is projected to be above the 1979 level until 2020, when it will be 14 percent below that level. Under Scenario 1, corn production is above the 1979 level in all future time periods. In contrast, Scenario 6 projects the disappearance of corn production by 1990. This variation in the scenario results indicates that future corn output will be very sensitive to future cost-price relationships and future yield increases. It appears likely that corn production in the study area will not decrease until 2000 and that output in 2020 will be 20 to 30 percent below the 1979 level.

One can expect an increase in wheat marketed from the study area over the next 40 years and a decline in corn marketings sometime after the turn of the century. The magnitude of any production shifts within Colorado will account for only a tiny fraction of total U.S. production and probably will not be great enough to affect national commodity markets. However, these markets might be affected if a similar shift occurred in the entire High Plains region that is underlain by the Ogallala aquifer. The general contractor is expected to report projections of the magnitude of such effects in the overall completion report for this project.

Policy Conclusions

The ability to pay for water of Colorado Ogallala irrigators is not large relative to estimated interstate import project costs. Costs are estimated to exceed ability to pay by a factor of five to ten. Costs of instate imports (i.e., from the South Platte), may not be so high, but still are likely to substantially exceed benefits. Hence, very large subsidies would be required to finance any water import scheme. It is not at all obvious that such financial support will be forthcoming from any level of government in the present and prospective political and economic climate.

Mandatory pumping requirements which are more stringent than those presently in force will also postpone the date at which the equilibrium rate of withdrawals is reached. Such restrictions would be difficult to apply and unpopular to enforce, and little or no economic gain would be experienced. In fact, the particular restricted pumping scenario studied has a major adverse impact on farm income, but does not appear to have a significant impact on aquifer life. Hence, we do not urge such a policy on the basis of our present knowledge.

Therefore, the most productive policy initiatives appear to be those which reduce water use per acre by improving efficiency of pumping and water application systems, and by finding profitable crops with reduced water requirements. Comparison of the results for the Baseline scenario and Scenario 1 show that efficiency improvements on the order of 15 to 20 percent can have significant effects on extending the life of the aquifer in many parts of the study area. Further, reductions, in pumping costs indicate a favorable effect on net income. A combination of research, extension, and individual farmer initiatives toward reduction of water extractions will postpone somewhat the time when the minimum withdrawal equilibrium is reached.

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APPENDIX A -- RESEARCH DETAILS BY SUBAREA, BASELINE SCENARIO

List of Tables

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Table A1. Projected Returns to Land and Management, Baseline.

		Returns to Land and Management (Dollars)		
Subarea	Year	Irrigated Crops	Dryland Crops	All Crops
1	1979	1,308,000	3,168,000	4,476,000
	1985	1,947,000	2,880,000	4,827,000
	1990	1,773,000	2,976,000	4,749,000
	2000	2,435,000	3,552,000	5,987,000
	2020	3,091,000	4,704,000	7,795,000
2	1979	6,899,000	12,992,000	19,891,000
	1985	8,606,000	11,783,000	20,389,000
	1990	7,947,000	12,189,000	20,136,000
	2000	9,603,000	14,627,000	24,230,000
	2020	9,208,000	20,251,000	29,459,000
3	1979	10,590,000	22,100,000	32,690,000
	1985	11,567,000	21,284,000	32,851,000
	1990	9,543,000	22,474,000	32,017,000
	2000	12,665,000	28,182,000	40,847,000
	2020	11,370,000	41,480,000	52,850,000
4	1979	11,681,000	1,280,000	12,961,000
	1985	17,291,000	1,131,000	18,422,000
	1990	16,260,000	1,050,000	17,310,000
	2000	23,470,000	1,401,000	24,871,000
	2020	30,060,000	1,978,000	32,038,000
5	1979	16,485,000	11,072,000	27,557,000
	1985	17,204,000	9,858,000	27,062,000
	1990	13,185,000	11,377,000	24,562,000
	2000	16,471,000	15,427,000	31,898,000
	2020	10,456,000	26,494,000	36,950,000
6	1979	1,818,000	5,874,000	7,692,000
	1985	483,000	5,966,000	6,449,000
	1990	-720,000	8,086,000	7,366,000
	2000	845,000	13,436,000	14,281,000
	2020	2,266,000	26,449,000	28,715,000
1-5	1979	46,963,000	50,612,000	97,575,000
	1985	56,615,000	46,936,000	103,551,000
	1990	48,708,000	50,066,000	98,774,000
	2000	64,644,000	63,189,000	127,833,000
	2020	64,185,000	94,907,000	159,092,000
1-6	1979	48,781,000	56,486,000	105,267,000
	1985	57,098,000	52,902,000	110,000,000
	1990	47,988,000	58,152,000	106,140,000
	2000	65,489,000	76,625,000	142,114,000
	2020	66,451,000	121,356,000	187,807,000

Table A2. Projected Irrigated Crop Acreage, Production, and Value of Production, Baseline, Subareas 1-6.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	433,000	425,300	420,300	410,600	259,100
Sorghum	32,300	40,300	19,400	20,800	2,000
Wheat	41,000	0	0	0	11,200
Sunflowers	0	21,700	18,800	12,200	65,200
Sugar Beets	22,500	8,500	6,300	5,600	0
Pinto Beans	22,500	20,900	20,300	11,100	2,200
Alfalfa	47,900	44,900	44,000	40,900	24,700
Total	599,200	561,600	529,100	501,200	364,400
Crop Production					
Corn (mil. bu.)	56.0	60.3	63.5	68.4	48.5
Sorghum (mil. bu.)	2.7	3.5	1.7	1.8	0.2
Wheat (mil. bu.)	1.9	0	0	0	0.9
Sunflowers (mil. cwt.)	0	0.4	0.4	0.3	2.0
Beets (th. tons)	390.0	156.9	120.4	108.5	0
Beans (th. cwt.)	366.6	342.5	327.2	180.8	34.0
Alfalfa (th. tons)	179.3	173.9	178.7	173.6	137.6
Value of Production (in millions of 1979 dollars)					
Corn	145.7	184.7	197.6	226.9	168.9
Sorghum	5.9	9.0	4.6	5.2	0.6
Wheat	6.8	0	0	0	3.2
Sunflowers	0	4.7	4.4	3.4	24.7
Sugar Beets	11.7	5.1	4.0	3.7	0
Pinto Beans	8.9	8.4	8.1	4.6	1.0
Alfalfa	9.8	10.9	11.3	11.4	9.3
Total	188.8	222.8	230.0	255.2	207.7

Table A3. Projected Irrigated Crop Acreage, Production, and Value of Production, Baseline, Subarea 1.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	14,500	14,500	14,500	14,500	12.600
Wheat	0	0	0	0	1,400
Sunflowers	0	0	0	0	500
Alfalfa	1,500	1,500	1,500	1,500	1,500
Total	16,000	16,000	16,000	16,000	16,000
Crop Production					
Corn (mil. bu.)	1.9	2.1	2.2	2.4	2.4
Wheat (th. bu.)	0	0	0	0	105.9
Sunflowers (th. cwt.)	0	0	0	0	16.3
Alfalfa (th. tons)	5.6	5.8	5.8	6.8	7.0
Value of Production (in millions of 1979 dollars)					
Corn	4.9	6.3	6.9	8.0	8.2
Wheat	0	0	0	0	0.4
Sunflowers	0	0	0	0	0.2
Alfalfa	0.3	0.4	0.4	0.4	0.5
Total	5.2	6.7	7.3	8.4	9.3

Table A4. Projected Irrigated Crop Acreage, Production, and Value of Production, Baseline, Subarea 2.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	45,300	45,100	45,100	45,800	30,000
Sunflowers	0	0	0	0	11,100
Sugar Beets	6,300	6,300	6,300	5,600	0
Pinto Beans	6,300	6,300	6,300	6,300	2,200
Alfalfa	5,100	5,000	5,000	5,000	3,800
Total	63,000	62,700	62,700	62,700	47,100
Crop Production					
Corn (mil. bu.)	5.9	6.4	6.9	7.7	5.6
Sunflowers (th. cwt.)	0	0	0	0	368.5
Beets (th. tons)	119.7	119.8	120.4	108.5	0
Beans (th. cwt.)	107.1	107.2	107.8	109.3	34.0
Alfalfa (th. tons)	18.9	19.6	19.7	22.6	12.7
Value of Production (in millions of 1979 dollars)					
Corn	15.3	19.7	21.3	25.4	19.6
Sunflowers	0	0	0	0	4.6
Sugar Beets	3.6	3.9	4.0	3.7	0
Pinto Beans	2.6	2.6	2.7	2.8	1.0
Alfalfa	1.0	1.2	1.2	1.5	0.9
Total	22.5	27.4	29.2	33.4	26.1

Table A5. Projected Irrigated Crop Acreage, Production, and Value of Production, Baseline, Subarea 3.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	89,400	82,200	79,200	80,300	43,400
Wheat	0	0	0	0	700
Sunflowers	0	0	0	0	13,800
Sugar Beets	6,400	0	0	0	0
Pinto Beans	6,400	5,500	5,300	800	0
Alfalfa	7,800	6,600	6,400	6,200	4,400
Total	110,000	94,300	90,900	87,300	62,300
Crop Production					
Corn (mil. bu.)	11.6	11.7	12.0	13.4	8.1
Wheat (th. bu.)	0	0	0	0	57.8
Sunflowers (th. cwt.)	0	0	0	0	457.2
Beets (th. tons)	109.1	0	0	0	0
Beans (th. cwt.)	102.7	89.0	85.2	12.7	0
Alfalfa (th. tons)	28.9	26.0	23.6	26.3	18.6
Value of Production (in millions of 1979 dollars)					
Corn	30.0	35.8	37.4	44.5	28.3
Wheat	0	0	0	0	0.2
Sunflowers	0	0	0	0	5.8
Sugar Beets	3.3	0	0	0	0
Pinto Beans	2.5	2.2	2.1	0.3	0
Alfalfa	1.6	1.6	1.5	1.7	1.2
Total	37.4	39.6	41.0	46.5	35.5

Table A6. Projected Irrigated Crop Acreage, Production, and Value of Production, Baseline, Subarea 4.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	127,000	132,400	138,300	148,000	134,600
Sunflowers	0	0	0	0	14,900
Alfalfa	13,000	13,600	14,300	15,300	9,000
Total	140,000	146,000	152,600	163,300	158,500
Crop Production					
Corn (mil. bu.)	16.5	18.8	21.0	24.7	25.2
Sunflowers (th. cwt.)	0	0	0	0	298.8
Alfalfa (th. tons)	49.3	53.6	58.7	70.2	74.3
Value of Production (millions of 1979 dollars)					
Corn	43.0	57.7	65.4	82.1	87.8
Sunflowers	0	0	0	0	3.8
Alfalfa	2.7	3.4	3.7	4.6	5.0
Total	45.7	61.1	69.1	86.7	96.6

Table A7. Projected Irrigated Crop Acreage, Production, and Value of Production, Baseline, Subarea 5.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	135,600	133,000	129,100	111,900	33,500
Wheat	0	0	0	0	0
Sunflowers	0	0	0	0	18,900
Sugar Beets	9,800	2,200	0	0	0
Pinto Beans	9,800	9,100	8,700	4,000	0
Alfalfa	11,800	10,800	10,400	8,800	4,000
Total	167,000	155,100	148,200	124,700	56,400
Crop Production					
Corn (mil. bu.)	17.6	18.9	19.6	18.7	6.3
Wheat (th. bu.)	0	0	0	0	0
Sunflowers (th. cwt.)	0	0	0	0	623.5
Beets (th. tons)	161.2	37.1	0	0	0
Beans (th. cwt.)	156.8	146.3	134.2	58.8	0
Alfalfa	44.1	42.7	34.7	31.6	14.8
Value of Production (in millions of 1979 dollars)					
Corn	45.9	58.0	61.0	62.0	21.9
Wheat	0	0	0	0	0
Sunflowers	0	0	0	0	7.8
Sugar Beets	4.8	1.2	0	0	0
Pinto Beans	3.8	3.6	3.3	1.5	0
Alfalfa	2.4	2.7	2.2	2.1	1.0
Total	56.9	65.5	66.5	65.6	30.7

Table A8. Projected Irrigated Crop Acreage, Production, and Value of Production, Baseline, Subarea 6.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	21,200	18,100	14,100	10,000	5,000
Sorghum	32,300	40,300	19,400	20,800	2,000
Wheat	41,000	0	0	0	9,100
Sunflowers	0	21,700	18,800	12,200	6,000
Alfalfa	8,700	7,400	6,400	4,100	2,000
Total	103,200	87,500	58,700	47,200	24,100
Crop Production					
Corn (mil. bu.)	2.5	2.4	1.8	1.5	0.9
Sorghum (mil. bu.)	2.7	3.5	1.7	1.8	0.2
Wheat (th. bu.)	1,930.2	0	0	0	713.7
Sunflowers (th. cwt.)	0	418.6	403.1	301.8	199.5
Alfalfa (th. tons)	32.5	26.2	36.2	16.1	10.2
Value of Production (in millions of 1979 dollars)					
Corn	6.6	7.2	5.6	4.9	3.1
Sorghum	5.9	9.0	4.6	5.2	0.6
Wheat	6.8	0	0	0	2.6
Sunflowers	0	4.7	4.4	3.4	2.5
Alfalfa	1.8	1.6	2.3	1.1	0.7
Total	21.1	22.5	16.9	14.6	9.5

Table A9. Projected Dryland Crop Acreage, Production, and Value of Production, Baseline, Subareas 1-6.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	1,470,700	1,460,400	1,469,000	1,479,000	1,489,800
Sorghum	191,700	124,200	100,700	77,500	79,400
Sunflowers	0	95,300	121,300	162,500	216,400
Corn	12,600	12,600	12,600	12,500	12,900
Hay	8,000	16,800	33,300	18,200	16,500
Total	1,683,000	1,709,300	1,737,000	1,749,800	1,815,000
Crop Production					
Wheat (mil. bu.)	35.0	39.3	43.1	49.1	63.6
Sorghum (mil. bu.)	3.8	2.7	2.3	2.0	2.4
Sunflowers (mil. cwt.)	0	1.0	1.3	1.9	3.0
Corn (th. bu.)	376.5	401.8	427.0	457.1	538.6
Hay (th. tons)	8.0	16.7	33.2	18.2	16.5
Value of Crop Production (in millions of 1979 dollars)					
Wheat	122.3	127.7	141.9	165.2	207.9
Sorghum	8.5	7.0	6.0	5.5	7.1
Sunflowers	0	10.7	14.5	22.0	38.3
Corn	1.0	1.2	1.3	1.5	1.9
Hay	0.4	1.0	2.1	1.2	1.1
Total	132.2	147.6	165.8	195.4	256.3

Table A10. Projected Dryland Crop Acreage, Production, and Value of Production, Baseline, Subarea 1.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	45,600	45,600	45,600	43,200	43,200
Sunflowers	0	0	0	2,400	2,400
Corn	2,400	2,400	2,400	2,400	2,400
Total	48,000	48,000	48,000	48,000	48,000
Crop Production					
Wheat (mil. bu.)	1.5	1.6	1.7	1.8	2.0
Sunflowers (th. cwt.)	0	0	0	28.8	33.6
Corn (th. bu.)	72.0	76.8	81.6	87.4	99.8
Value of Production (in millions of 1979 dollars)					
Wheat	5.1	5.2	5.6	6.0	7.3
Sunflowers	0	0	0	0.3	0.4
Corn	0.2	0.2	0.3	0.3	0.4
Total	5.3	5.4	5.9	6.6	8.1

Table A11. Projected Dryland Crop Acreage, Production, and Value of Production, Baseline, Subarea 2.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	192,800	192,800	192,800	182,800	190,000
Sunflowers	0	0	0	10,100	10,500
Corn	10,200	10,200	10,200	10,100	10,500
Total	203,000	203,000	203,000	203,000	211,000
Crop Production					
Wheat (mil. bu.)	6.2	6.8	7.3	7.6	8.8
Sunflowers (th. cwt.)	0	0	0	121.9	147.7
Corn (th. bu.)	304.5	325.0	345.4	369.7	438.8
Value of Production (in millions of 1979 dollars)					
Wheat	21.6	22.0	23.9	25.6	32.2
Sunflowers	0	0	0	1.4	1.9
Corn	0.8	1.0	1.0	1.2	1.5
Total	22.4	23.0	24.9	28.2	35.6

Table A12. Projected Dryland Crop Acreage, Production, and Value of Production, Baseline, Subarea 3.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	524,900	532,100	533,700	535,400	518,500
Sorghum	27,600	0	0	0	0
Sunflowers	0	28,000	28,100	28,200	57,600
Total	552,500	560,100	561,800	563,600	576,100
Crop Production					
Wheat (mil. bu.)	13.1	14.9	16.2	18.4	20.5
Sorghum (mil. bu.)	0.6	0	0	0	0
Sunflowers (th. cwt.)	0	280.0	309.0	338.2	806.6
Value of Crop Production (in millions of 1979 dollars)					
Wheat	45.9	48.6	53.4	61.9	75.1
Sorghum	1.2	0	0	0	0
Sunflowers	0	3.1	3.4	3.8	10.2
Total	47.1	51.7	56.8	65.7	85.3

Table A13. Projected Dryland Crop Acreage, Production, and Value of Production, Baseline, Subarea 4.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	36,000	32,300	32,300	33,000	33,000
Grass Hay	8,000	16,200	16,200	16,500	16,500
Total	44,000	48,500	48,500	49,500	49,500
Crop Production					
Wheat (mil. bu.)	0.8	0.8	0.9	1.0	1.2
Grass Hay (th. tons)	8.0	16.1	16.1	16.5	16.5
Value of Production (in millions of 1979 dollars)					
Wheat	2.8	2.6	2.9	3.5	4.4
Grass Hay	0.4	1.0	1.0	1.1	1.1
Total	3.2	3.6	3.9	4.6	5.5

Table A14. Projected Dryland Crop Acreage, Production, and Value of Production, Baseline, Subarea 5.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	328,700	334,500	337,700	348,900	361,300
Sorghum	17,300	0	0	0	0
Sunflowers	0	17,600	17,800	18,400	40,100
Total	346,000	352,100	355,500	367,300	401,400
Crop Production					
Wheat (mil. bu.)	7.2	8.4	9.3	11.0	13.2
Sorghum (mil. bu.)	0.3	0	0	0	0
Sunflowers (th. cwt.)	0	176.0	195.5	220.4	562.0
Value of Crop Production (in millions of 1979 dollars)					
Wheat	25.3	27.2	30.7	37.1	48.1
Sorghum	0.8	0	0	0	0
Sunflowers	0	2.0	2.1	2.5	7.1
Total	26.1	29.2	32.8	39.6	55.2

Table A15. Projected Dryland Crop Acreage, Production, and Value of Production, Baseline, Subarea 6.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	342,700	323,100	327,000	335,800	343,800
Sorghum	146,000	124,200	100,700	77,500	79,400
Sunflowers	0	49,700	75,400	103,400	105,800
Grass Hay	0	600	17,100	1,700	0
Total	489,500	497,600	520,200	518,400	529,000
Crop Production					
Wheat (mil. bu.)	6.2	6.8	7.7	9.3	11.1
Sorghum (mil. bu.)	2.9	2.7	2.3	2.0	2.4
Sunflowers (th. cwt.)	0	497.0	830.2	1,239.9	1,481.2
Grass Hay (th. tons)	0	0.6	17.1	1.7	0
Value of Crop Production (in millions of 1979 dollars)					
Wheat	21.6	22.1	25.4	31.1	40.8
Sorghum	6.5	7.0	6.0	5.5	7.1
Sunflowers	0	5.6	9.0	14.0	18.7
Grass Hay	0	a/	1.1	0.1	0
Total	28.1	34.7	41.5	50.7	66.6

a/ Insignificant

Table A16. Projected Irrigation Water Use, Baseline, Subareas 1-6.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	841,990	827,150	812,180	797,530	501,030
Wheat	41,610	0	0	0	10,610
Sugar Beets	52,900	22,500	16,720	14,840	0
Pinto Beans	32,710	29,890	26,380	13,020	1,840
Sunflowers	0	22,910	18,240	14,040	64,870
Alfalfa	135,420	124,230	108,040	103,200	74,550
Sorghum	43,580	50,220	23,490	22,520	3,150
Total	1,148,210	1,076,900	1,005,050	965,150	656,050
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.3	23.3	23.2	23.3	23.2
Wheat	12.2	0	0	0	11.4
Sugar Beets	28.2	31.8	31.8	31.8	0
Pinto Beans	17.4	17.2	15.6	14.1	10.0
Sunflowers	0	12.7	11.6	13.8	11.9
Alfalfa	33.9	33.2	29.5	30.3	36.2
Sorghum	16.2	15.0	14.5	13.0	19.1
All Crops	23.0	23.0	22.8	23.1	21.6
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.14	0.12
Wheat (bu.)	0.26	0	0	0	0.14
Sugar Beets (ton)	1.63	1.72	1.67	1.64	0
Pinto Beans (cwt.)	1.07	1.05	0.97	0.86	0
Sunflowers (cwt.)	0	0.66	0.54	0.56	0.40
Alfalfa (ton)	9.06	8.40	7.26	7.13	6.50
Sorghum (bu.)	0.19	0.17	0.16	0.15	0.18

Table A17. Projected Irrigation Water Use, Baseline, Subarea 1.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	27,810	27,810	27,810	27,810	24,260
Wheat	0	0	0	0	910
Sunflowers	0	0	0	0	490
Alfalfa	3,740	3,740	3,550	3,740	3,550
Total	31,550	31,550	31,360	31,550	29,210
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.0	23.0	23.0	23.0	23.0
Wheat	0	0	0	0	8.0
Sunflowers	0	0	0	0	12.0
Alfalfa	30.2	30.2	28.6	30.2	28.6
All Crops	23.7	23.7	23.5	23.7	21.9
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.14	0.12
Wheat (bu.)	0	0	0	0	0.10
Sunflowers (cwt.)	0	0	0	0	0.36
Alfalfa (ton)	8.04	7.70	7.28	6.58	6.10

Table A18. Projected Irrigation Water Use, Baseline, Subarea 2.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	87,980	87,710	88,340	90,720	58,500
Sugar Beets	16,800	16,720	16,720	14,840	0
Pinto Beans	9,450	9,350	8,930	8,290	1.840
Sunflowers	0	0	0	0	12,570
Alfalfa	14,630	14,560	13,750	14,350	7,880
Total	128,860	128,340	127,740	128,200	80,790
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.3	23.3	23.5	23.7	23.4
Sugar Beets	32.0	32.0	32.0	32.0	0
Pinto Beans	18.0	17.9	17.1	15.9	10.0
Sunflowers	0	0	0	0	13.5
Alfalfa	34.8	34.8	32.9	34.3	25.1
All Crops	24.5	24.5	24.4	24.5	20.6
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.14	0.13
Sugar Beets (ton)	1.68	1.68	1.67	1.64	0
Pinto Beans (cwt.)	1.06	1.05	0.99	0.91	0.65
Sunflowers (cwt.)	0	0	0	0	0.41
Alfalfa (ton)	9.29	8.89	8.39	7.61	7.46

Table A19. Projected Irrigation Water Use, Baseline, Subarea 3.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	170,630	157,500	151,730	153,940	83,100
Wheat	0	0	0	0	500
Sugar Beets	14,980	0	0	0	0
Pinto Beans	8,560	7,370	6,880	880	0
Sunflowers	0	0	0	0	13,850
Alfalfa	20,350	17,120	14,720	14,730	9,630
Total	214,520	181,990	173,330	169,550	107,080
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.0	23.0	23.0	23.0	23.0
Wheat	0	0	0	0	8.0
Sugar Beets	28.0	0	0	0	0
Pinto Beans	16.0	16.0	15.5	12.5	0
Sunflowers	0	0	0	0	12.0
Alfalfa	31.7	31.0	27.7	28.8	26.4
All Crops	23.5	23.2	22.9	23.3	20.6
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.14	0.12
Wheat (bu.)	0	0	0	0	0.10
Sugar Beets (ton)	1.65	0	0	0	0
Pinto Beans (cwt.)	1.00	0.99	0.97	0.83	0
Sunflowers (cwt.)	0	0	0	0	0.36
Alfalfa (ton)	8.45	7.91	7.50	6.71	6.22

Table A20. Projected Irrigation Water Use, Baseline, Subarea 4.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	243,680	253,680	265,020	283,700	257,900
Sunflowers	0	0	0	0	9,050
Alfalfa	33,060	34,420	35,500	38,490	37,350
Total	276,740	288,100	300,520	322,190	304,300
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.0	23.0	23.0	23.0	23.0
Sunflowers	0	0	0	0	12.0
Alfalfa	30.2	30.2	29.8	30.2	30.2
All Crops	23.7	23.7	23.6	23.7	23.0
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.14	0.12
Sunflowers (cwt.)	0	0	0	0	0.36
Alfalfa (ton)	8.04	7.70	7.26	6.58	6.03

Table A21. Projected Irrigation Water Use, Baseline, Subarea 5.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	262,400	259,260	253,180	219,730	65,710
Sugar Beets	21,120	5,780	0	0	0
Pinto Beans	14,700	13,170	10,570	3,850	0
Sunflowers	0	0	0	0	19,890
Alfalfa	34,150	31,660	24,600	20,630	9,020
Total	332,370	309,870	288,350	244,210	94,080
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.2	23.4	23.5	23.6	23.3
Sugar Beets	25.9	32.0	0	0	0
Pinto Beans	18.0	17.4	14.6	11.6	0
Sunflowers	0	0	0	0	12.6
Alfalfa	34.8	34.8	28.3	28.2	27.3
All Crops	23.8	24.0	23.3	23.5	20.0
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.14	0.12
Sugar Beets (ton)	1.57	1.87	0	0	0
Pinto Beans (cwt.)	1.13	1.08	0.95	0.78	0
Sunflowers (cwt.)	0	0	0	0	0.38
Alfalfa (ton)	9.28	8.89	8.50	7.93	7.31

Table A22. Projected Irrigation Water Use, Baseline, Subarea 6.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	49,490	41,190	26,100	21,630	12,100
Wheat	41,610	0	0	0	9,200
Sunflowers	0	22,910	18,240	14,040	9,020
Alfalfa	29,490	22,730	15,920	11,260	7,120
Sorghum	43,580	50,220	23,490	22,520	3,150
Total	164,170	137,050	83,750	69,450	40,590
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	28.0	27.3	22.2	25.8	29.2
Wheat	12.2	0	0	0	12.1
Sunflowers	0	12.7	11.6	13.8	17.9
Alfalfa	40.8	36.8	29.9	32.9	42.0
Sorghum	16.2	15.0	14.5	13.0	19.1
All Crops	19.1	18.8	17.1	17.7	20.1
Water Use Per Unit of Yield (acre inch/acre)					
Corn (bu.)	0.23	0.21	0.17	0.18	0.16
Wheat (bu.)	0.26	0	0	0	0.15
Sunflowers (cwt.)	0	0.66	0.54	0.56	0.54
Alfalfa (ton)	10.88	10.41	5.28	8.40	8.40
Sorghum (bu.)	0.19	0.17	0.16	0.15	0.18

Table A23. Projected Resource Use, Baseline, Subareas 1-6.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	5,571	5,268	4,608	4,289	2,432
Electricity Use for Irrigation (million KWH)	441	432	447	475	389
Natural Gas Use for Irrigation (1000 MCF)	4,279	3,989	3,248	2,810	1,160
Irrigation Pumps:					
Electric	3,048	2,849	2,845	2,853	2,365
Natural Gas	1,719	1,606	1,466	1,078	465
Total	4,767	4,455	4,311	3,931	2,830
Farm Consumption of:					
Diesel Fuel (1000 gal.)	13,951	13,758	13,622	13,449	12,257
Gasoline (1000 gal.)	2,739	2,607	2,543	2,511	2,192
NH_3 (tons)	81,862	89,524	94,731	104,596	103,149
Other Fertilizer (tons)	46,504	46,446	48,000	51,026	38,319
Irrigated Farm Labor (man-years)	1,332	1,239	1,164	1,114	737
Dryland Farm Labor (man-years)	1,344	1,361	1,376	1,393	1,445
Total Crop Labor (man-years)	2,676	2,600	2,540	2,507	2,182

Table A24. Projected Resource Use, Baseline, Subarea 1.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	95	95	99	102	93
Electricity Use for Irrigation (million KWH)	18	18	19	19	19
Natural Gas Use for Irrigation (1000 MCF)	35	35	35	38	30
Irrigation Pumps:					
Electric	112	112	112	112	112
Natural Gas	12	12	12	12	12
Total	124	124	124	124	124
Farm Consumption of:					
Diesel Fuel (1000 gal.)	387	387	386	387	379
Gasoline (1000 gal.)	74	74	74	74	72
NH_3 (tons)	2,423	2,695	2,907	3,259	3,522
Other Fertilizer (tons)	1,222	1,331	1,416	1,560	1,652
Irrigated Farm Labor (man-years)	33	33	33	33	31
Dryland Farm Labor (man-years)	38	38	38	38	38
Total Crop Labor (man-years)	71	71	71	71	69

Table A25. Projected Resource Use, Baseline, Subarea 2.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	407	405	406	442	277
Electricity Use for Irrigation (million KWH)	67	68	69	75	49
Natural Gas Use for Irrigation (1000 MCF)	187	184	180	196	116
Irrigation Pumps:					
Electric	365	364	364	364	273
Natural Gas	55	54	54	54	41
Total	420	418	418	418	314
Farm Consumption of:					
Diesel Fuel (1000 gal.)	1,716	1,713	1,712	1,710	1,493
Gasoline (1000 gal.)	334	333	333	329	261
NH_3 (tons)	9,020	10,009	10,781	12,135	12,228
Other Fertilizer (tons)	4,851	5,176	5,455	5,914	3,882
Irrigated Farm Labor (man-years)	177	177	177	176	103
Dryland Farm Labor (man-years)	162	162	162	162	169
Total Crop Labor (man-years)	339	339	339	339	272

Table A26. Projected Resource Use, Baseline, Subarea 3.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	881	783	794	757	526
Electricity Use for Irrigation (million KWH)	96	86	87	93	62
Natural Gas Use for Irrigation (1000 MCF)	583	516	523	463	330
Irrigation Pumps:					
Electric	653	560	533	533	373
Natural Gas	203	177	177	149	114
Total	856	737	710	682	487
Farm Consumption of:					
Diesel Fuel (1000 gal.)	3,804	3,661	3,634	3,610	3,407
Gasoline (1000 gal.)	721	657	651	648	588
NH_3 (tons)	20,476	21,867	23,365	25,849	26,493
Other Fertilizer (tons)	8,024	7,359	7,508	8,135	4,986
Irrigated Farm Labor (man-years)	242	194	186	180	118
Dryland Farm Labor (man-years)	442	448	450	451	461
Total Crop Labor (man-years)	684	642	636	631	579

Table A27. Projected Resource Use, Baseline, Subarea 4.

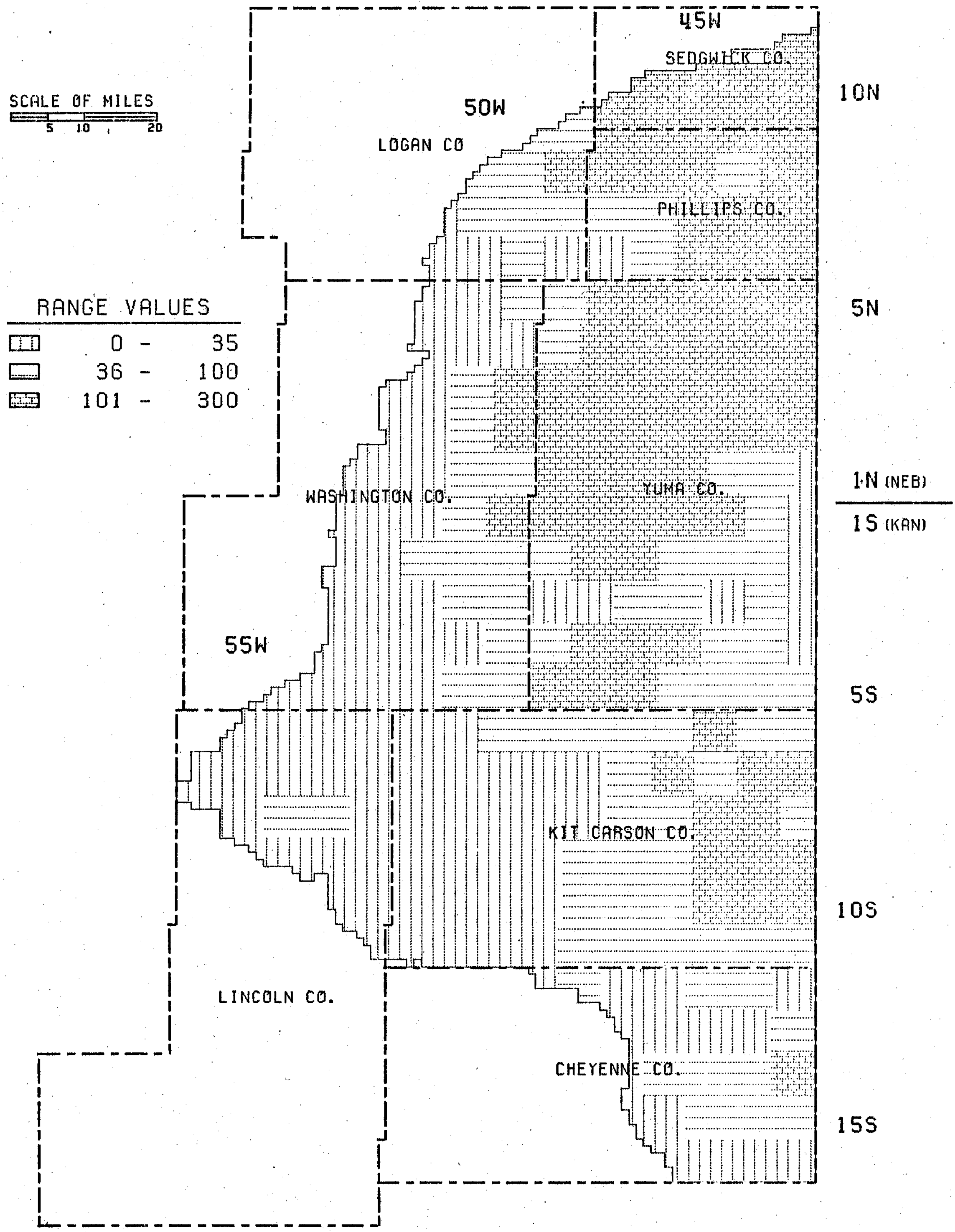
	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	741	818	870	926	942
Electricity Use for Irrigation (million KWH)	142	156	172	197	201
Natural Gas Use for Irrigation (1000 MCF)	270	302	297	267	268
Irrigation Pumps:					
Electric	1,001	1,046	1,097	1,194	1,146
Natural Gas	95	95	95	82	92
Total	1,096	1,141	1,192	1,276	1,238
Farm Consumption of:					
Diesel Fuel (1000 gal.)	1,490	1,544	1,603	1,707	1,653
Gasoline (1000 gal.)	345	358	373	397	379
NH_3 (tons)	13,434	15,170	16,986	19,976	21,475
Other Fertilizer (tons)	14,651	16,637	18,581	21,756	22,432
Irrigated Farm Labor (man-years)	290	302	315	338	321
Dryland Farm Labor (man-years)	32	32	32	33	33
Total Crop Labor (man-years)	322	334	347	371	354

Table A28. Projected Resource Use, Baseline, Subarea 5.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	2,047	2,058	1,908	1,674	507
Electricity Use for Irrigation (million KWH)	90	83	77	69	37
Natural Gas Use for Irrigation (1000 MCF)	1,832	1,867	1,731	1,515	400
Irrigation Pumps:					
Electric	632	558	525	439	252
Natural Gas	675	654	633	535	189
Total	1,307	1,212	1,158	974	441
Farm Consumption of:					
Diesel Fuel (1000 gal.)	3,455	3,333	3,258	3,081	2,502
Gasoline (1000 gal.)	696	638	612	573	430
NH_3 (tons)	21,138	22,739	24,030	25,032	19,669
Other Fertilizer (tons)	12,186	12,138	12,195	11,414	3,819
Irrigated Farm Labor (man-years)	423	377	351	297	116
Dryland Farm Labor (man-years)	277	282	284	294	321
Total Crop Labor (man-years)	700	659	635	591	437

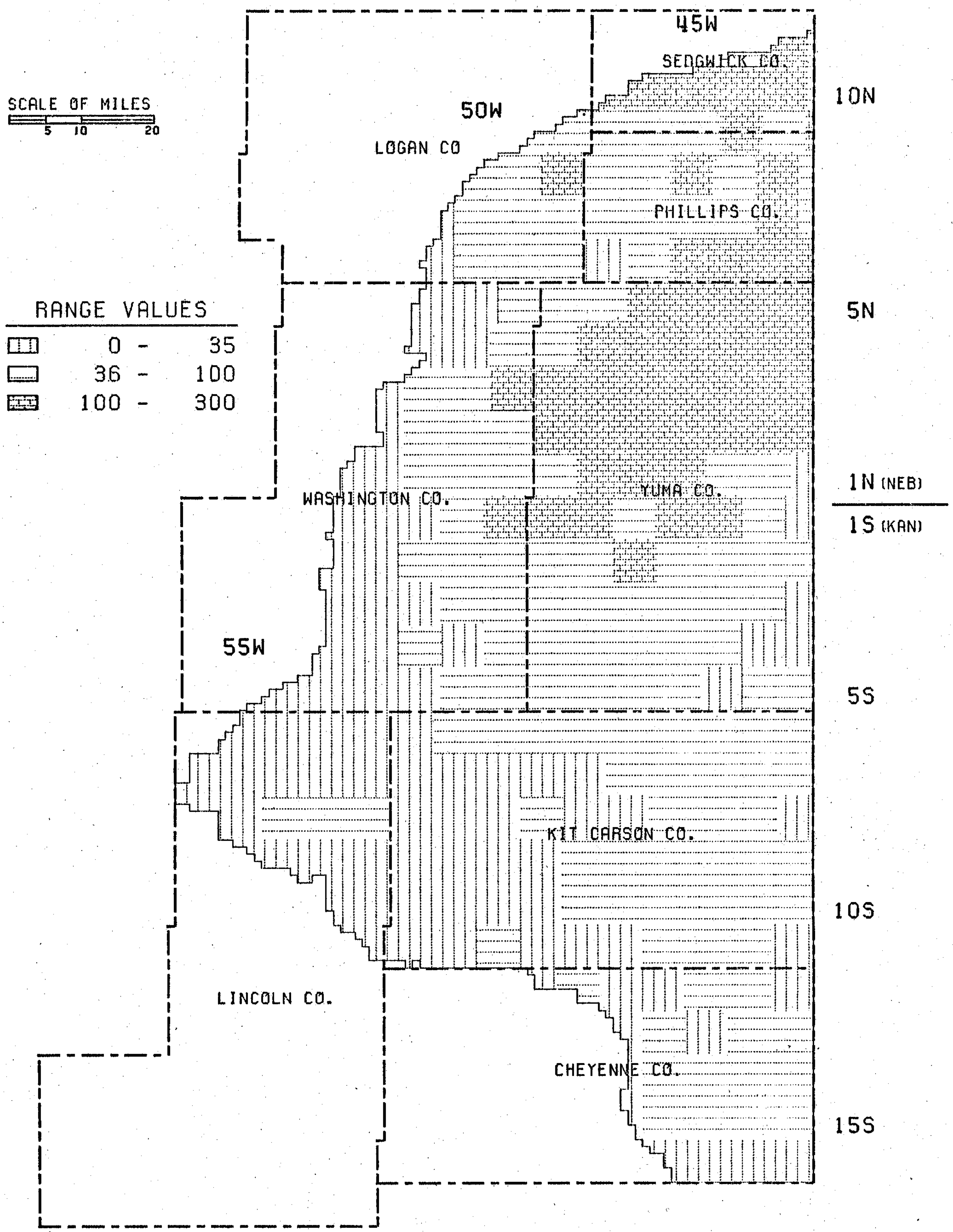
Table A29. Projected Resource Use, Baseline, Subarea 6.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	1,400	1,109	531	389	88
Electricity Use for Irrigation (million KWH)	28	22	22	22	21
Natural Gas Use for Irrigation (1000 MCF)	1,372	1,086	482	332	17
Irrigation Pumps:					
Electric	285	209	214	211	209
Natural Gas	679	614	495	246	17
Total	964	823	709	457	226
Farm Consumption of:					
Diesel Fuel (1000 gal.)	3,099	3,120	3,029	2,954	2,873
Gasoline (1000 gal.)	569	547	500	490	462
NH_3 (tons)	15,371	17,044	16,662	18,345	19,762
Other Fertilizer (tons)	5,570	3,805	2,845	2,247	1,548
Irrigated Farm Labor (man-years)	166	157	102	91	48
Dryland Farm Labor (man-years)	392	398	409	414	423
Total Crop Labor (man-years)	558	555	511	505	471



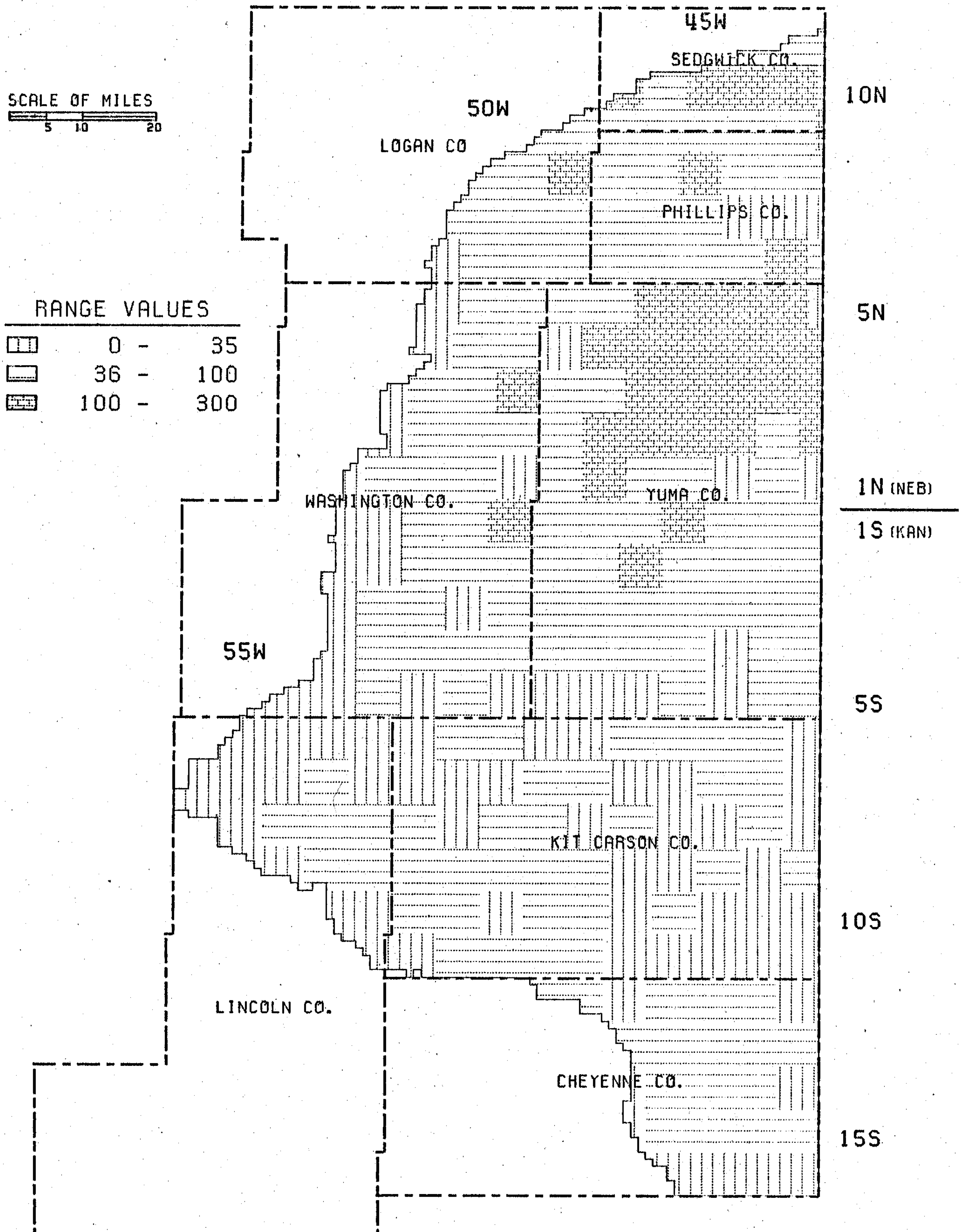
OGALLALA AQUIFER, NORTH-EASTERN COLORADO
TOWNSHIPS BY 1979 SATURATION THICKNESS

Figure A1.



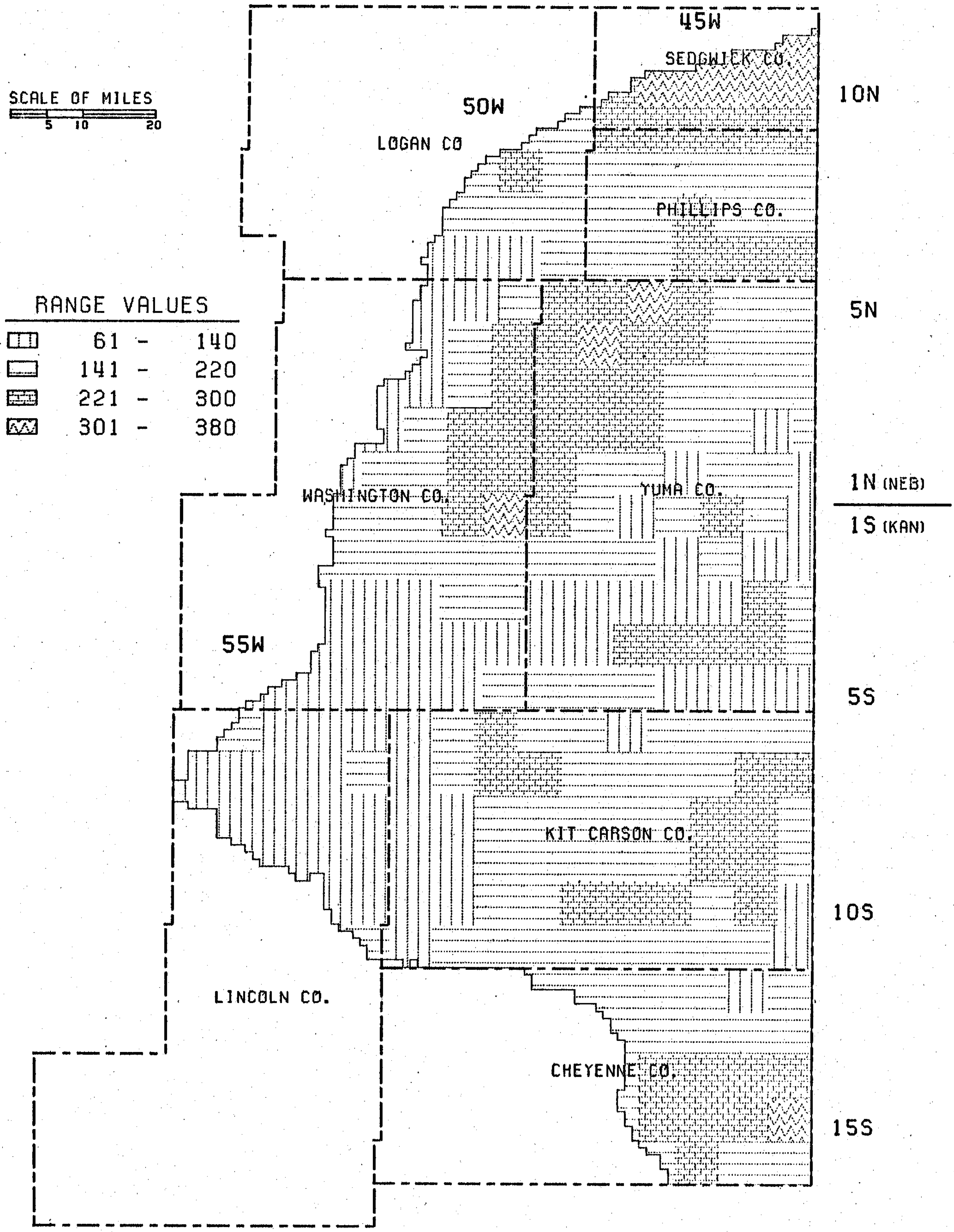
OGALLALA AQUIFER, NORTH-EASTERN COLORADO
TOWNSHIPS BY 2000 SATURATION THICKNESS

Figure A2.

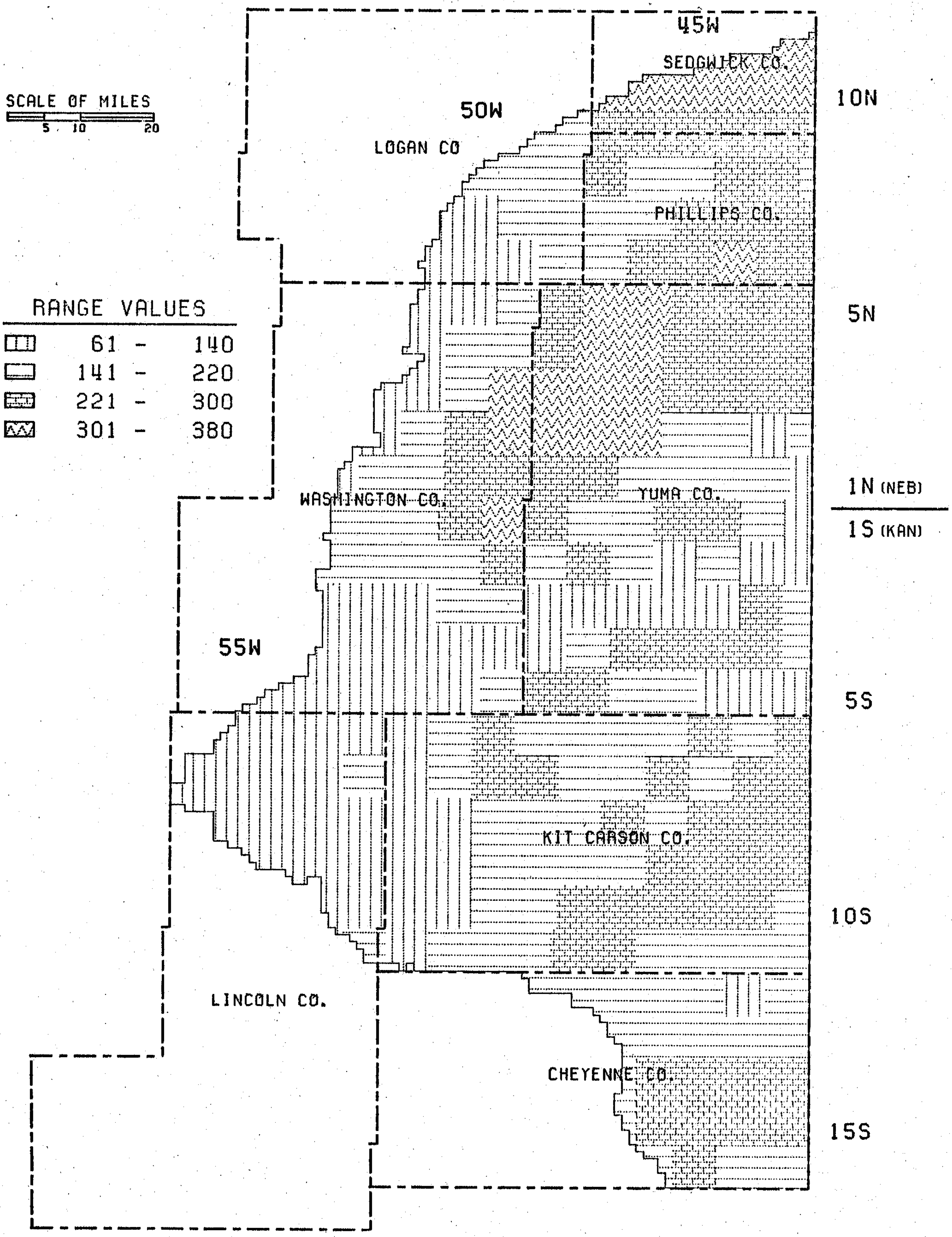


OGALLALA AQUIFER, NORTH-EASTERN COLORADO
TOWNSHIPS BY 2020 SATURATION THICKNESS

Figure A3.

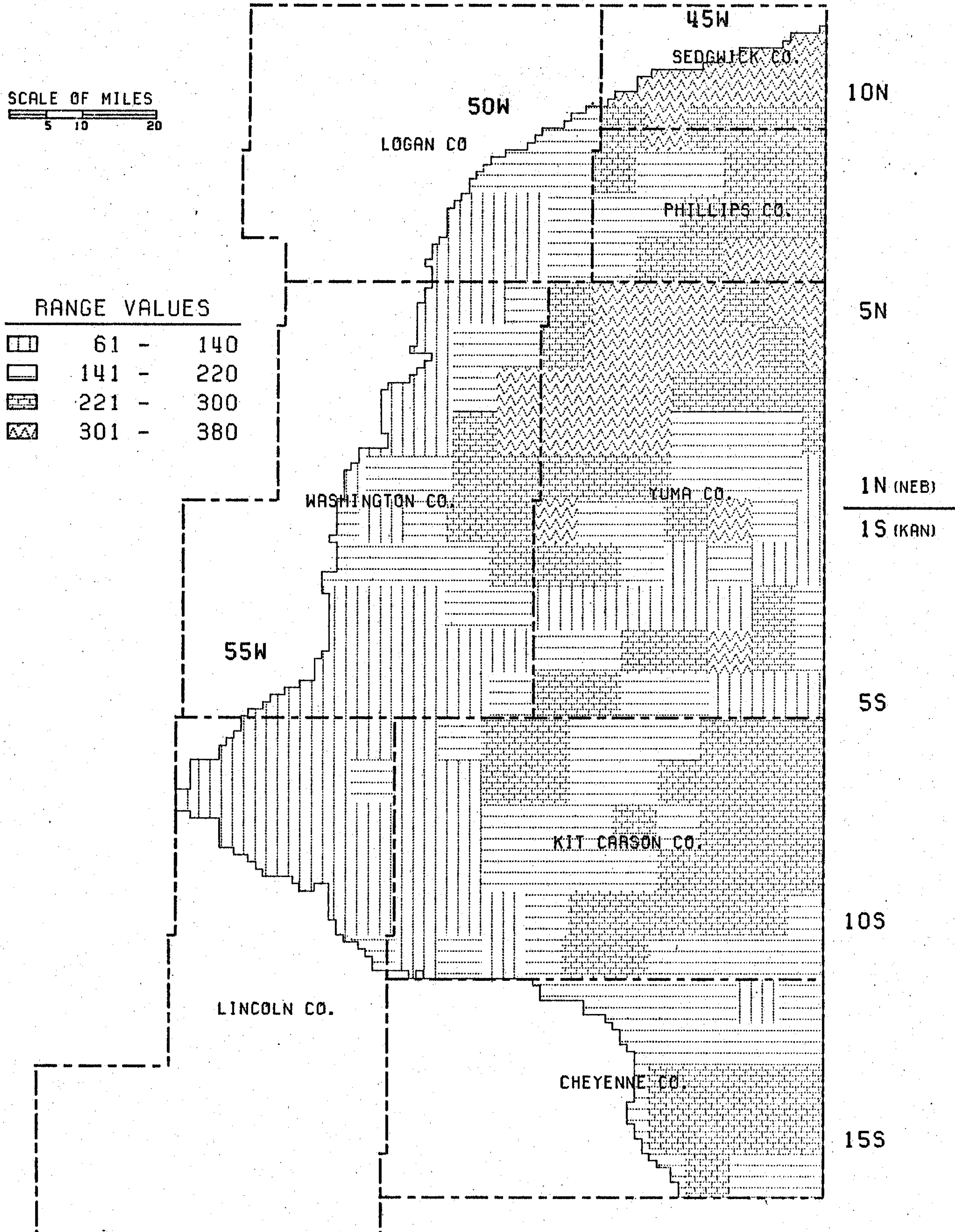


OGALLALLA AQUIFER, NORTH-EASTERN COLORADO
TOWNSHIPS BY 1979 DEPTH-ZONES
Figure A4.



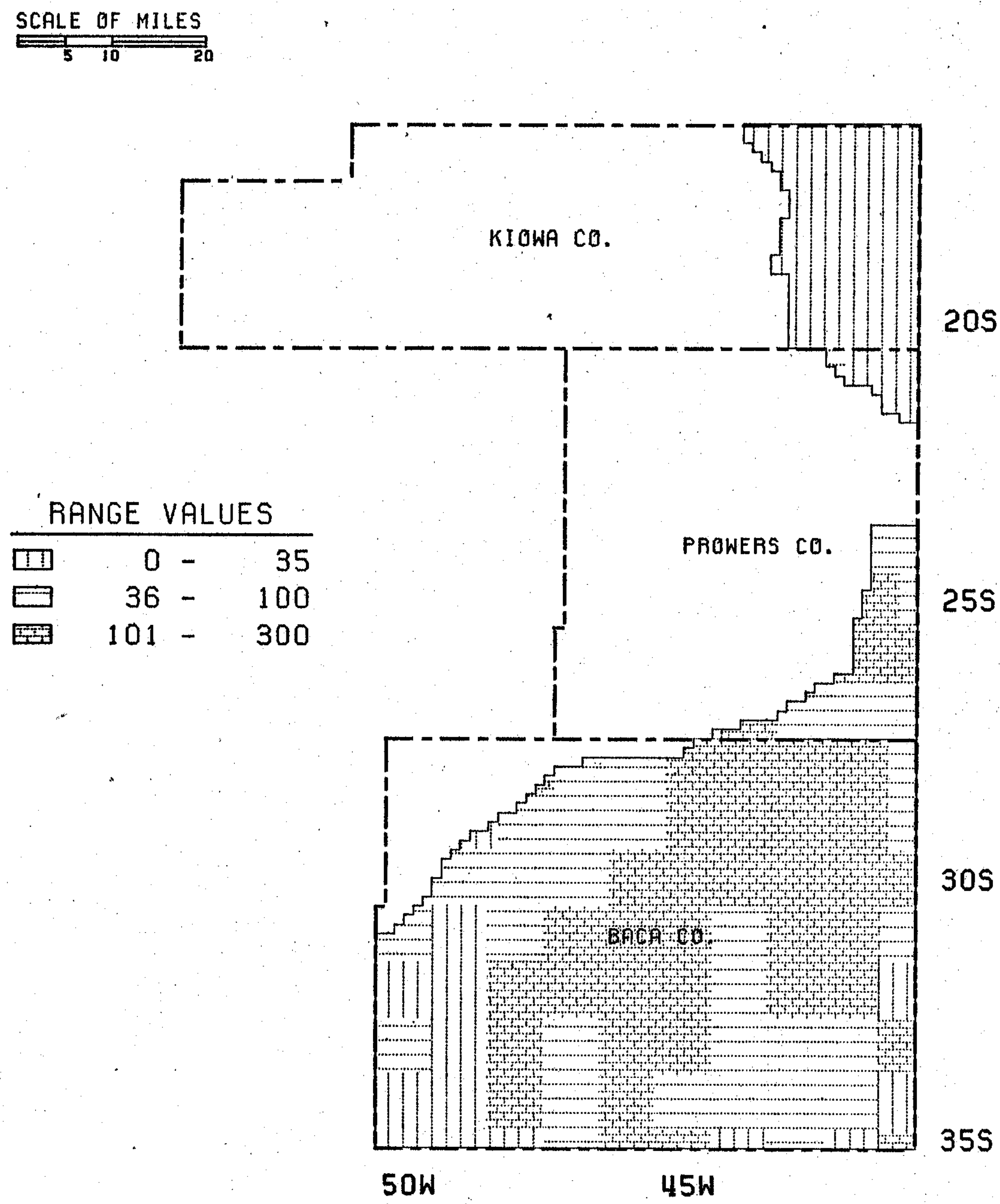
OGALLALA AQUIFER, NORTH-EASTERN COLORADO TOWNSHIPS BY 2000 DEPTH-ZONES

Figure A5.



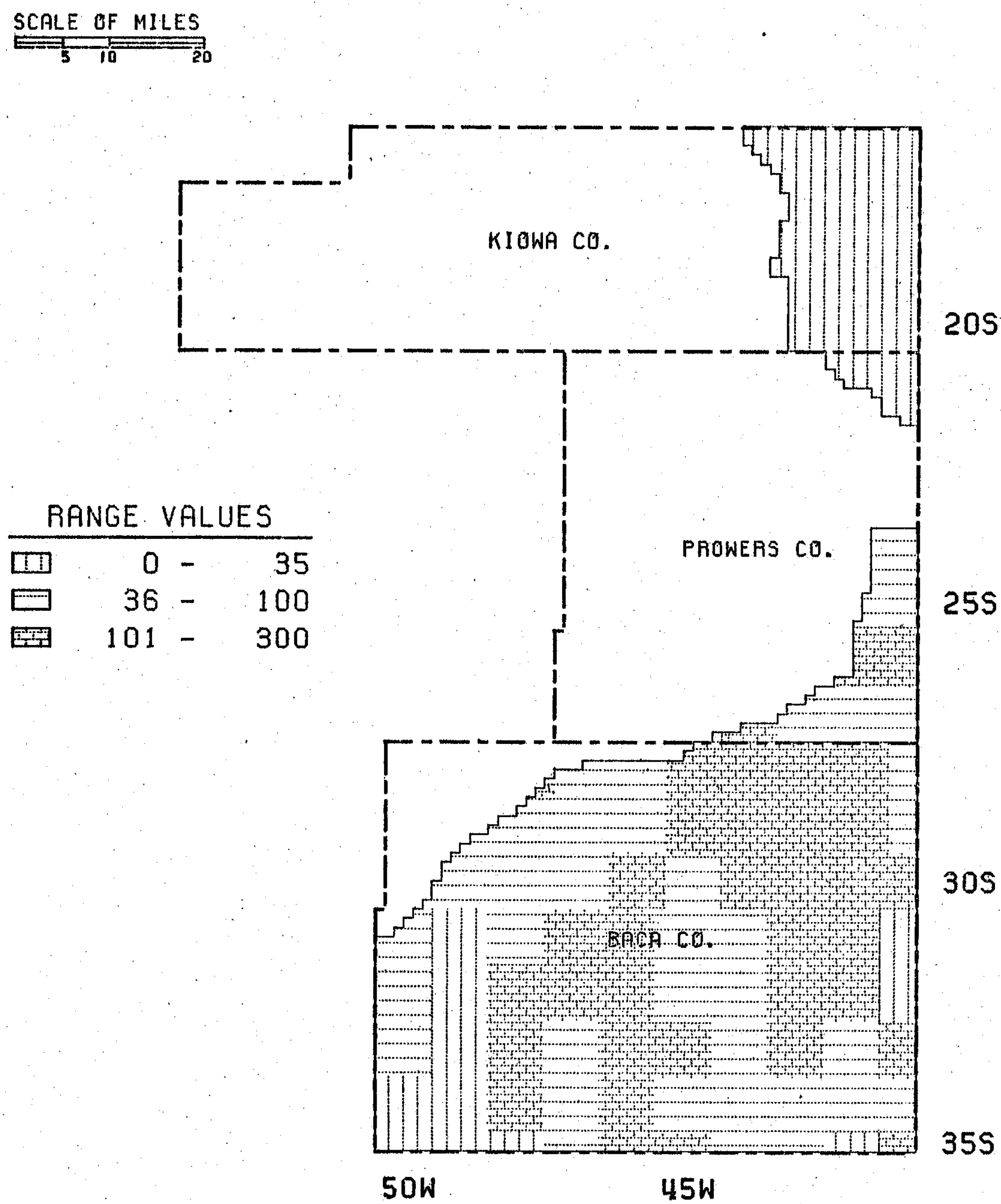
OGALLALA AQUIFER, NORTH-EASTERN COLORADO
TOWNSHIPS BY 2020 DEPTH-ZONES

Figure A6.



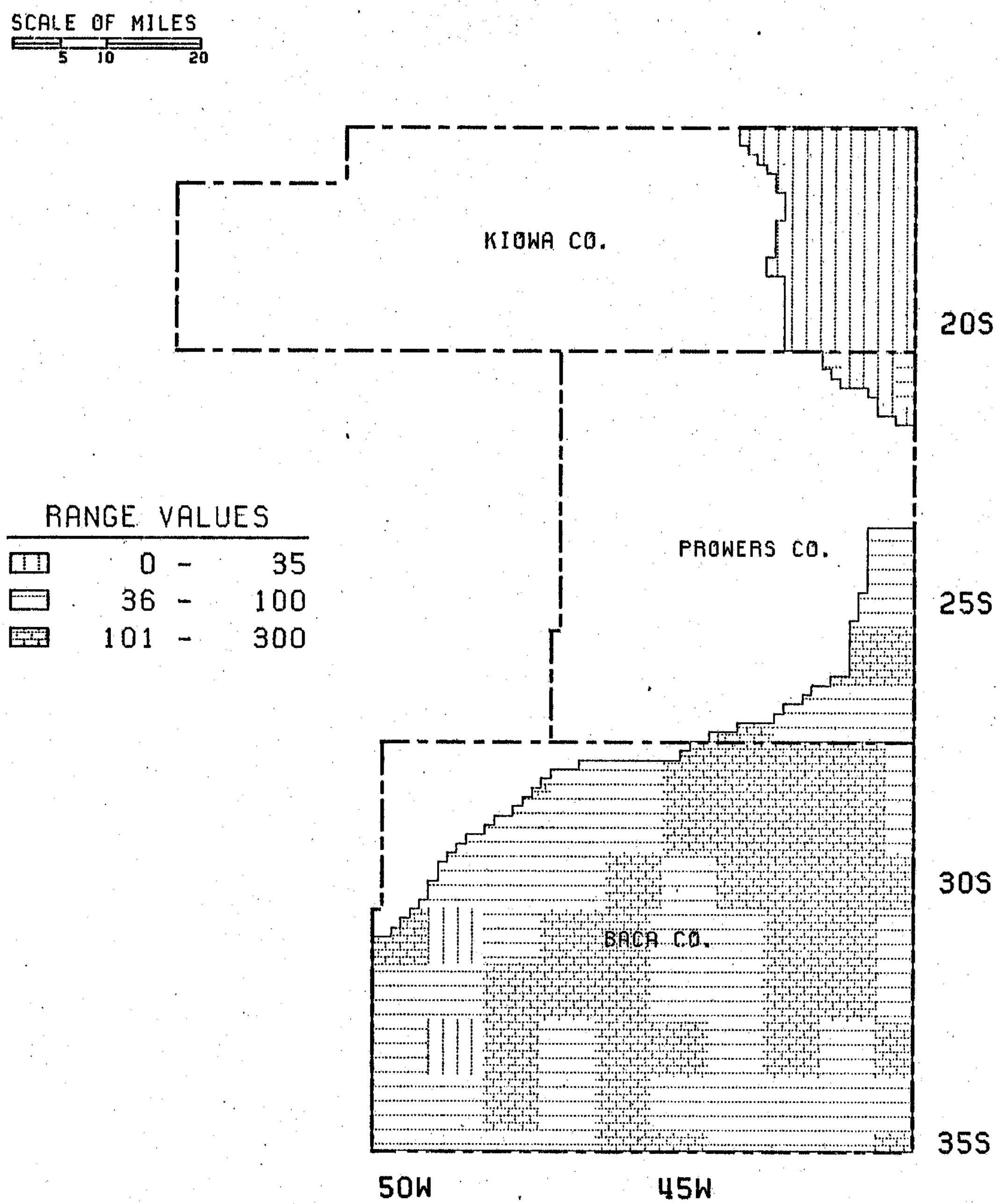
OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 1979 SATURATION THICKNESS

Figure A7.



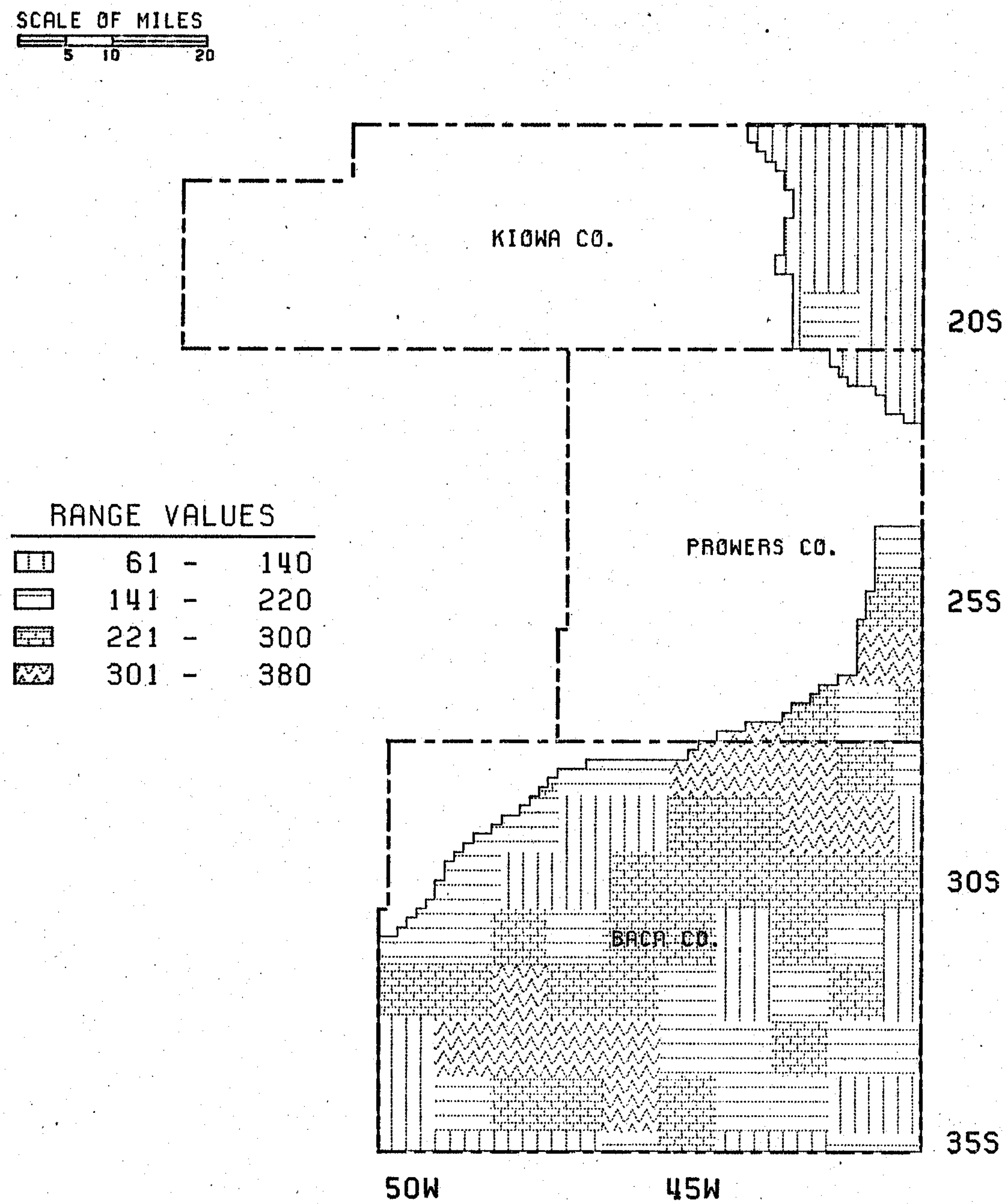
OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2000 SATURATION THICKNESS

Figure A8.



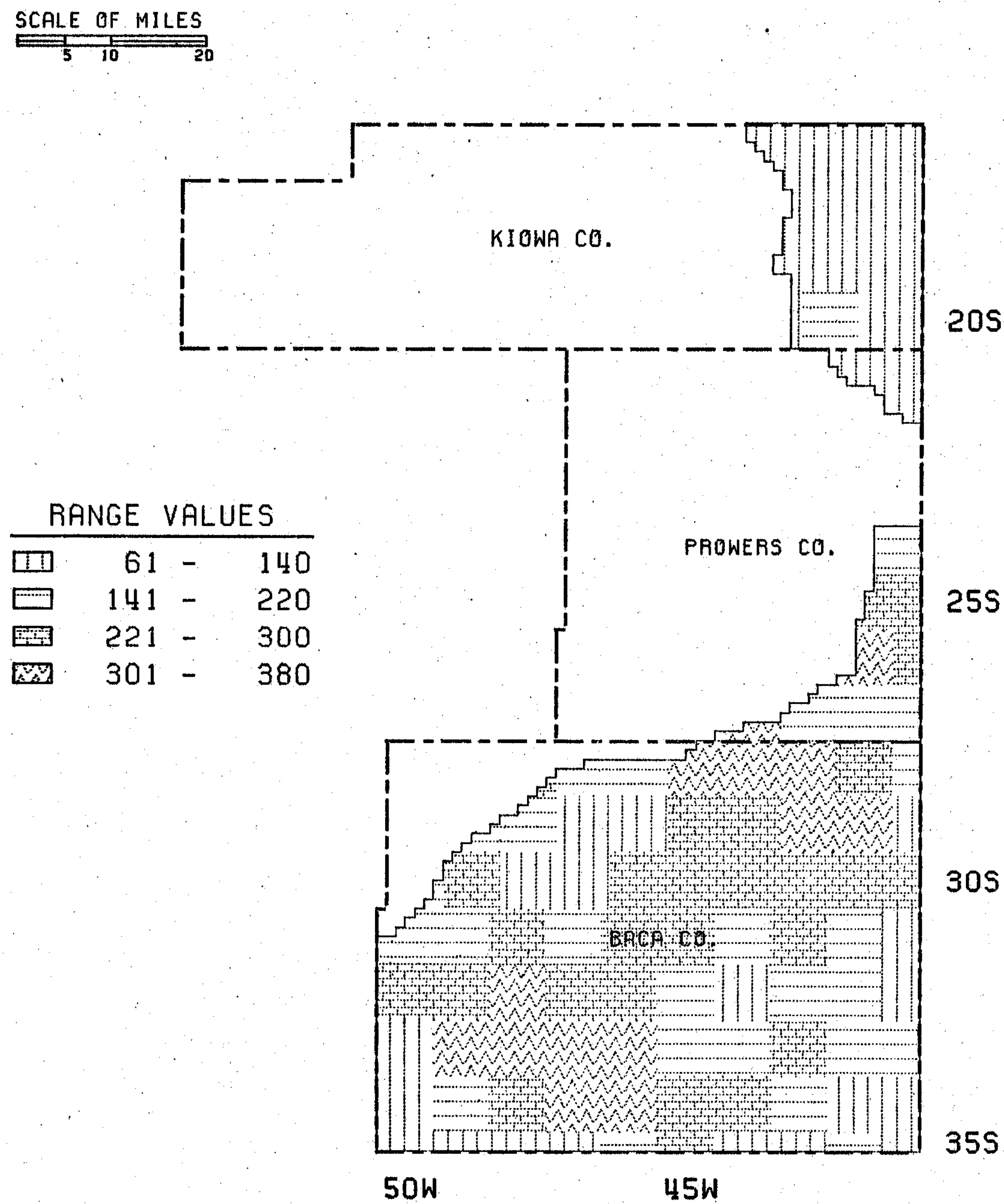
OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2020 SATURATION THICKNESS

Figure A9.



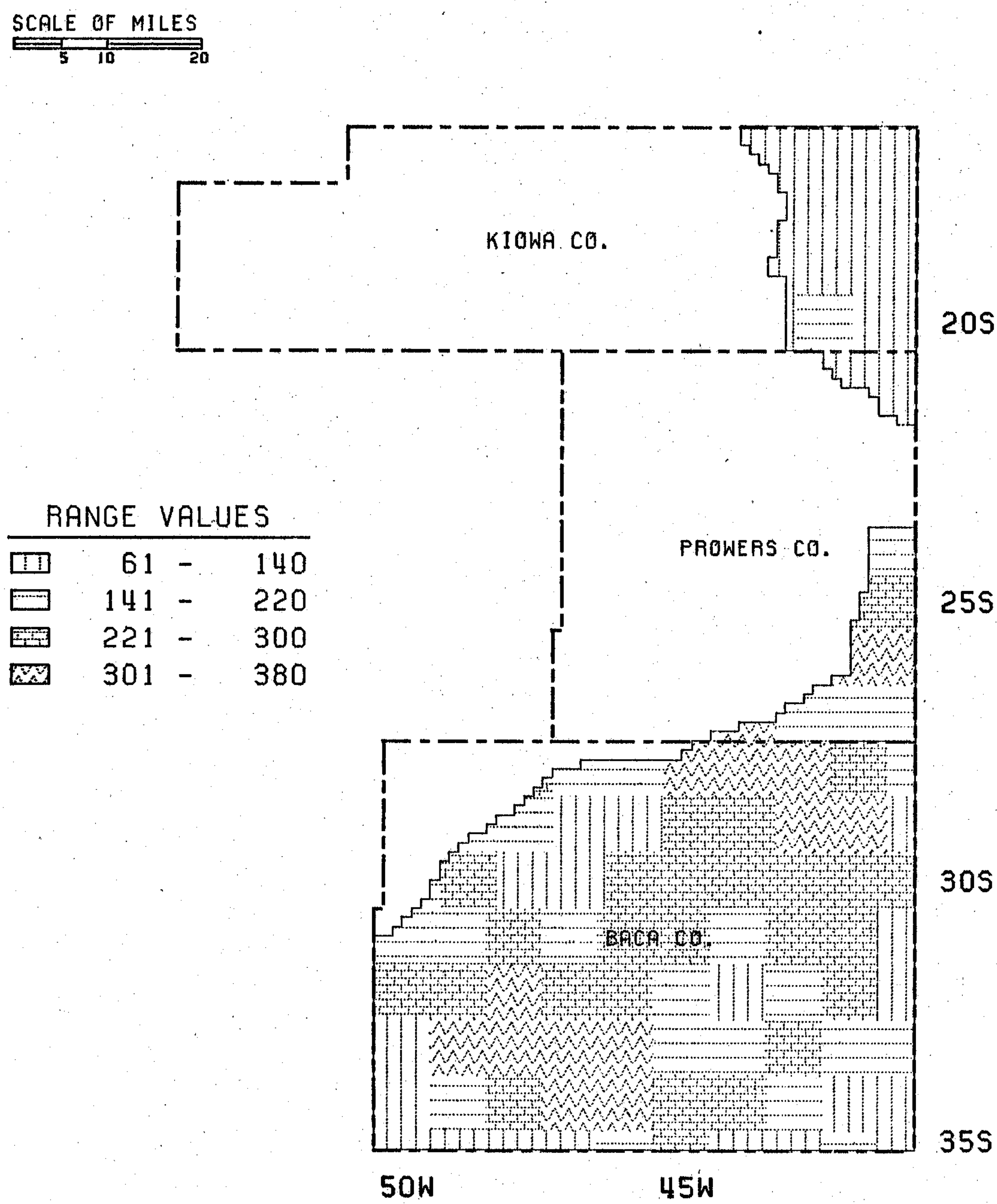
OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 1979 DEPTH-ZONES

Figure A10.



OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2000 DEPTH-ZONES

Figure A11.



OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2020 DEPTH-ZONES

Figure A12.

APPENDIX B -- RESEARCH DETAILS BY SUBAREA, SCENARIO 1

List of Tables

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Table B1 Projected Returns to Land and Management, Scenario 1.

Subarea	Year	Returns to Land and Management (Dollars) Irrigated Crops	Dryland Crops	All Crops
1	1979	1,308,000	3,168,000	4,476,000
	1985	1,947,000	2,880,000	4,827,000
	1990	1,878,000	2,976,000	4,854,000
	2000	2,743,000	3,552,000	6,295,000
	2020	3,963,000	4,704,000	8,667,000
2	1979	6,899,000	12,992,000	19,891,000
	1985	8,606,000	11,783,000	20,389,000
	1990	8,493,000	12,189,000	20,682,000
	2000	11,095,000	14,627,000	25,722,000
	2020	12,984,000	19,927,000	32,911,000
3	1979	10,590,000	22,100,000	32,690,000
	1985	11,567,000	21,284,000	32,851,000
	1990	11,713,000	22,295,000	34,008,000
	2000	16,891,000	27,919,000	44,810,000
	2020	20,708,000	40,798,000	61,506,000
4	1979	11,681,000	1,280,000	12,961,000
	1985	17,291,000	1,131,000	18,422,000
	1990	17,211,000	1,050,000	18,261,000
	2000	26,691,000	1,373,000	28,064,000
	2020	37,041,000	1,997,000	39,038,000
5	1979	16,485,000	11,072,000	27,557,000
	1985	17,204,000	9,858,000	27,062,000
	1990	17,644,000	11,140,000	28,784,000
	2000	23,827,000	15,172,000	38,999,000
	2020	18,107,000	25,831,000	43,938,000
6	1979	1,818,000	5,874,000	7,692,000
	1985	483,000	5,966,000	6,449,000
	1990	169,000	8,051,000	8,226,000
	2000	2,362,000	13,423,000	15,785,000
	2020	9,117,000	25,018,000	34,135,000
1-6	1979	48,781,000	56,486,000	105,267,000
	1985	57,098,000	52,902,000	110,000,000
	1990	57,108,000	57,707,000	114,815,000
	2000	83,609,000	76,066,000	159,675,000
	2020	101,920,000	118,275,000	220,195,000

Table B2 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 1, Subareas 1-6.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	433,000	425,300	442,500	437,400	352,100
Sorghum	32,300	40,300	31,600	22,900	6,100
Wheat	41,000	0	0	0	41,800
Sunflowers	0	21,700	19,000	12,400	32,200
Sugar Beets	22,500	8,500	6,300	6,300	500
Pinto Beans	22,500	20,900	21,700	6,300	0
Alfalfa	47,900	44,900	45,700	42,700	38,900
Total	599,200	561,600	566,800	528,000	471,600
Crop Production					
Corn (mil. bu.)	56.0	60.3	66.9	72.9	65.7
Sorghum (mil. bu.)	2.7	3.5	2.8	2.2	0.6
Wheat (mil. bu.)	1.9	0	0	0	3.3
Sunflowers (mil. cwt.)	0	0.4	0.4	0.3	1.1
Sugar Beets (th. ton)	390.0	156.9	120.4	122.3	10.2
Pinto Beans (th. cwt.)	366.6	342.5	357.4	109.7	0
Alfalfa (th. ton)	179.3	173.9	192.0	195.3	193.2
Value of Production (in millions of 1979 dollars)					
Corn	145.7	184.7	208.2	242.1	229.2
Sorghum	5.9	9.0	7.4	6.1	1.9
Wheat	6.8	0	0	0	11.9
Sunflowers	0	4.7	4.5	3.8	13.4
Sugar Beets	11.7	5.1	4.0	4.2	0.4
Pinto Beans	8.9	8.4	8.8	2.9	0
Alfalfa	9.8	10.9	12.1	12.8	12.9
Total	188.8	222.8	245.0	271.9	269.7

Table B3 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 1, Subarea 1.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	14,500	14,500	14,500	14,500	14,500
Alfalfa	1,500	1,500	1,500	1,500	1,500
Total	16,000	16,000	16,000	16,000	16,000
Crop Production					
Corn (mil. bu.)	1.9	2.1	2.2	2.4	2.7
Alfalfa (th. ton)	5.6	5.8	6.2	6.8	7.4
Value of Production (in millions of 1979 dollars)					
Corn	4.9	6.3	6.9	8.0	9.4
Alfalfa	0.3	0.4	0.4	0.4	0.5
Total	5.2	6.7	7.3	8.4	9.9

Table B4 Projected Irrigated Acreage, Production, and Value of Production, Scenario 1, Subarea 2.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	45,300	45,100	45,100	45,100	41,000
Sunflowers	0	0	0	0	8,000
Sugar Beets	6,300	6,300	6,300	6,300	500
Pinto Beans	6,300	6,300	6,300	6,300	0
Alfalfa	5,100	5,000	5,000	5,000	4,300
Total	63,000	62,700	62,700	62,700	53,800
Crop Production					
Corn (mil. bu.)	5.9	6.4	6.9	7.5	7.7
Sunflowers (th. cwt.)	0	0	0	0	264.4
Sugar Beets (th. ton)	119.7	119.8	120.4	122.3	10.2
Pinto Beans (th. cwt.)	107.1	107.2	107.8	109.7	0
Alfalfa (th. ton)	18.9	19.6	20.9	23.0	21.1
Value of Production (in millions of 1979 dollars)					
Corn	15.3	19.7	21.3	25.0	26.8
Sunflowers	0	0	0	0	3.3
Sugar Beets	3.6	3.9	4.0	4.2	0.4
Pinto Beans	2.6	2.6	2.7	2.9	0
Alfalfa	1.0	1.2	1.3	1.5	1.4
Total	22.5	27.4	29.3	33.6	31.9

Table B5 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 1, Subarea 3.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	89,400	82,200	87,000	90,900	72,200
Wheat	0	0	0	0	3,300
Sugar Beets	6,400	0	0	0	0
Pinto Beans	6,400	5,500	5,800	0	0
Alfalfa	7,800	6,600	7,000	6,900	5,700
Total	110,000	94,300	99,800	97,800	81,200
Crop Production					
Corn (mil. bu.)	11.6	11.7	13.2	15.2	13.5
Wheat (th. bu.)	0	0	0	0	259.3
Sugar Beets (th. ton)	109.1	0	0	0	0
Pinto Beans (th. cwt.)	102.7	89.0	94.8	0	0
Alfalfa (th. ton)	28.9	26.0	29.2	31.5	28.6
Value of Production (in millions of 1979 dollars)					
Corn	30.0	35.8	41.1	50.4	47.1
Wheat	0	0	0	0	0.9
Sugar Beets	3.3	0	0	0	0
Pinto Beans	2.5	2.2	2.3	0	0
Alfalfa	1.6	1.6	1.8	2.1	1.9
Total	37.4	39.6	45.2	52.5	49.9

Table B6 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 1, Subarea 4.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	127,000	132,400	138,300	149,500	146,200
Sunflowers	0	0	0	0	1,200
Alfalfa	13,000	13,600	14,300	15,500	15,200
Total	140,000	146,000	152,600	165,000	162,600
Crop Production					
Corn (mil. bu.)	16.5	18.8	21.0	25.0	27.3
Sunflowers (th. cwt.)	0	0	0	0	38.3
Alfalfa (th. ton)	49.3	53.6	59.6	70.9	76.2
Value of Production (in millions of 1979 dollars)					
Corn	43.0	57.7	65.4	82.9	95.4
Sunflowers	0	0	0	0	0.5
Alfalfa	2.7	3.4	3.8	4.6	5.1
Total	45.7	61.1	69.2	87.5	101.0

Table B7 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 1, Subarea 5.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	135,600	133,000	142,000	127,200	61,600
Wheat	0	0	0	0	7,000
Sunflowers	0	0	0	0	2,600
Sugar Beets	9,800	2,200	0	0	0
Pinto Beans	9,800	9,100	9,600	0	0
Alfalfa	11,800	10,800	11,500	9,600	5,400
Total	167,000	155,100	163,100	136,800	76,600
Crop Production					
Corn (mil. bu.)	17.6	18.9	21.6	21.2	11.5
Wheat (th. bu.)	0	0	0	0	544.3
Sunflowers (th. cwt.)	0	0	0	0	84.2
Sugar Beets (th. ton)	161.2	37.1	0	0	0
Pinto Beans (th. cwt.)	156.8	146.3	154.8	0	0
Alfalfa (th. ton)	44.1	42.7	47.8	44.0	25.7
Value of Production (in millions of 1979 dollars)					
Corn	45.9	58.0	67.1	70.5	40.2
Wheat	0	0	0	0	2.0
Sunflowers	0	0	0	0	1.1
Sugar Beets	4.8	1.2	0	0	0
Pinto Beans	3.8	3.6	3.8	0	0
Alfalfa	2.4	2.7	3.0	2.9	1.7
Total	56.9	65.5	73.9	73.4	45.0

Table B8 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 1, Subarea 6.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	21,200	18,100	15,600	10,200	16,700
Sorghum	32,300	40,300	31,600	22,900	6,100
Wheat	41,000	0	0	0	31,400
Sunflowers	0	21,700	19,000	12,400	20,400
Alfalfa	8,700	7,400	6,400	4,200	6,800
Total	103,200	87,500	72,600	49,700	81,400
Crop Production					
Corn (mil. bu.)	2.5	2.4	2.0	1.6	3.0
Sorghum (mil. bu.)	2.7	3.5	2.8	2.2	0.6
Wheat (th. bu.)	1,930.2	0	0	0	2,448.5
Sunflowers (th. cwt.)	0	418.6	416.3	332.1	671.8
Alfalfa (th. ton)	32.5	26.2	28.3	19.1	34.2
Value of Production (in millions of 1979 dollars)					
Corn	6.6	7.2	6.4	5.3	10.3
Sorghum	5.9	9.0	7.4	6.1	1.9
Wheat	6.8	0	0	0	9.0
Sunflowers	0	4.7	4.5	3.8	8.5
Alfalfa	1.8	1.6	1.8	1.3	2.3
Total	21.1	22.5	20.1	16.5	32.0

Table B9 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 1, Subareas 1-6.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	1,470,700	1,460,400	1,457,900	1,467,600	1,450,500
Sorghum	191,700	124,200	100,600	77,400	75,100
Sunflowers	0	95,300	121,800	161,800	208,800
Corn	12,600	12,600	12,600	12,500	12,900
Hay	8,000	16,800	19,500	16,200	16,600
Total	1,683,000	1,709,300	1,712,400	1,735,500	1,763,900
Crop Production					
Wheat (mil. bu.)	35.0	39.3	42.8	48.7	55.4
Sorghum (mil. bu.)	3.8	2.7	2.3	2.0	2.2
Sunflowers (mil. cwt.)	0	1.0	1.3	1.9	2.9
Corn (th. bu.)	376.0	401.8	427.0	457.1	531.5
Hay (th. ton)	8.0	16.8	19.5	16.2	16.6
Value of Crop Production (in millions of 1979 dollars)					
Wheat	122.3	127.7	140.8	163.8	202.8
Sorghum	8.5	7.0	6.0	5.5	6.7
Sunflowers	0	10.7	14.4	21.9	36.8
Corn	1.0	1.2	1.4	1.5	1.8
Hay	0.4	1.0	1.2	1.1	1.1
Total	132.2	147.6	163.8	193.8	249.2

Table B10 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 1, Subarea 1.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	45,600	45,600	45,600	43,200	43,200
Sunflowers	0	0	0	2,400	2,400
Corn	2,400	2,400	2,400	2,400	2,400
Total	48,000	48,000	48,000	48,000	48,000
Crop Production					
Wheat (mil. bu.)	1.5	1.6	1.7	1.8	2.0
Sunflowers (th. cwt.)	0	0	0	28.8	33.6
Corn (th. bu.)	72.0	76.8	81.6	87.4	99.8
Value of Production (in millions of 1979 dollars)					
Wheat	5.1	5.2	5.6	6.0	7.3
Sunflowers	0	0	0	0.3	0.4
Corn	0.2	0.2	0.3	0.3	0.3
Total	5.3	5.4	5.9	6.6	8.0

Table B11 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 1, Subarea 2.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	192,800	192,800	192,800	182,800	186,600
Sunflowers	0	0	0	10,100	10,500
Corn	10,200	10,200	10,200	10,100	10,500
Total	203,000	203,000	203,000	203,000	207,600
Crop Production					
Wheat (mil. bu.)	6.2	6.8	7.3	7.6	8.7
Sunflowers (th. cwt.)	0	0	0	121.9	145.3
Corn (th. bu.)	304.5	325.0	345.4	369.7	431.7
Value of Production (in millions of 1979 dollars)					
Wheat	21.6	22.0	23.9	25.6	31.7
Sunflowers	0	0	0	1.4	1.8
Corn	0.8	1.0	1.1	1.2	1.5
Total	22.4	23.0	25.0	28.2	35.0

Table B12 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 1, Subarea 3.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	524,900	532,100	529,500	530,500	510,000
Sorghum	27,600	0	0	0	0
Sunflowers	0	28,000	28,900	27,900	56,700
Total	552,500	560,100	558,400	558,400	566,700
Crop Production					
Wheat (mil. bu.)	13.1	14.9	16.1	18.2	20.2
Sorghum (mil. bu.)	0.6	0	0	0	0
Sunflowers (th. cwt.)	0	280.0	306.5	335.0	793.3
Value of Production (in millions of 1979 dollars)					
Wheat	45.9	48.6	53.0	61.3	73.9
Sorghum	1.2	0	0	0	0
Sunflowers	0	3.1	3.3	3.8	10.0
Total	47.1	51.7	56.3	65.1	83.9

Table B13 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario, Subarea 4.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	36,000	32,300	32,300	32,300	33,000
Hay	8,000	16,200	16,200	16,200	16,500
Total	44,000	48,500	48,500	48,500	49,500
Crop Production					
Wheat (mil. bu.)	0.8	0.8	0.9	1.0	1.2
Hay (th. ton)	8.0	16.2	16.2	16.2	16.6
Value of Production (in millions of 1979 dollars)					
Wheat	2.8	2.6	2.9	3.4	4.4
Hay	0.4	1.0	1.0	1.1	1.1
Total	3.2	3.6	3.9	4.5	5.5

Table B14 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 1, Subarea 5.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	328,700	334,500	330,700	343,200	352,200
Sorghum	17,300	0	0	0	0
Sunflowers	0	17,600	17,400	18,100	39,100
Total	346,000	352,100	348,100	361,300	391,300
Crop Production					
Wheat (mil. bu.)	7.2	8.4	9.1	10.8	12.8
Sorghum (mil. bu.)	0.3	0	0	0	0
Sunflowers (th. cwt.)	0	176.0	191.5	216.7	547.9
Value of Production (in millions of 1979 dollars)					
Wheat	25.3	27.2	30.0	36.4	46.9
Sorghum	0.8	0	0	0	0
Sunflowers	0	2.0	2.1	2.4	6.9
Total	26.1	29.2	32.1	38.8	53.8

Table B15 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 1, Subarea 6.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	342,700	323,100	327,000	335,600	325,200
Sorghum	146,800	124,200	100,600	77,400	75,100
Sunflowers	0	49,700	75,500	103,300	100,100
Hay	0	600	3,300	0	0
Total	489,500	497,600	506,400	516,300	500,400
Crop Production					
Wheat (mil. bu.)	6.2	6.8	7.7	9.3	10.5
Sorghum (mil. bu.)	2.9	2.7	2.3	2.0	2.2
Sunflowers (th. cwt.)	0	497.0	830.2	1,239.0	1,401.0
Hay (th. ton)	0	0.6	3.3	0	0
Value of Production (in millions of 1979 dollars)					
Wheat	21.6	22.1	25.4	31.1	38.6
Sorghum	6.5	7.0	6.0	5.5	6.7
Sunflowers	0	5.6	9.0	14.0	17.7
Hay	0	0	0.2	0	0
Total	28.1	34.7	40.6	50.6	63.0

Table B16 Projected Irrigation Water Use, Scenario 1, Subareas 1-6.

	1979[a]	1985[a]	1990	2000	2020
Water Use (acre feet)					
Corn	841,990	827,150	832,770	792,760	603,510
Sorghum	43,580	50,220	37,190	26,810	7,950
Wheat	41,610	0	0	0	34,250
Sunflowers	0	22,910	18,780	16,690	38,410
Sugar Beets	52,900	22,500	16,220	15,550	1,200
Pinto Beans	32,710	29,890	28,970	7,770	0
Alfalfa	135,420	124,230	124,950	111,380	97,690
Total	1,148,210	1,076,900	1,058,880	970,960	783,010
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.3	23.3	22.6	21.7	20.6
Sorghum	16.2	15.0	14.1	14.0	15.6
Wheat	12.2	0	0	0	9.8
Sunflowers	0	12.7	11.9	16.2	14.3
Sugar Beets	28.2	31.8	30.9	29.6	28.8
Pinto Beans	17.4	17.2	16.0	14.8	0
Alfalfa	33.9	33.2	32.8	31.3	30.1
All Crops	23.0	23.0	22.4	22.1	19.9
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.13	0.11
Sorghum (bu.)	0.19	0.17	0.16	0.15	0.16
Wheat (bu.)	0.26	0	0	0	0.12
Sunflowers (cwt.)	0	0.66	0.54	0.60	0.44
Sugar Beets (ton)	1.63	1.72	1.62	1.53	1.41
Pinto Beans (cwt.)	1.07	1.05	0.97	0.85	0
Alfalfa (ton)	9.06	8.40	7.81	6.84	6.07

[a] Figures for 1979 and 1985 taken from Baseline.

Table B17 Projected Irrigation Water Use, Scenario 1, Subarea 1.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	27,810	27,810	26,970	25,860	24,410
Alfalfa	3,740	3,740	3,740	3,740	3,740
Total	31,550	31,550	30,710	29,600	28,150
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.0	23.0	22.3	21.4	20.2
Alfalfa	30.2	30.2	30.2	30.2	30.2
All Crops	23.7	23.7	23.0	22.2	21.1
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.15	0.11
Alfalfa (ton)	8.04	7.70	7.24	6.58	6.03

Table B18 Projected Irrigation Water Use, Scenario 1, Subarea 2.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	87,980	87,710	85,690	82,950	70,570
Sunflowers	0	0	0	0	8,190
Sugar Beets	16,800	16,720	16,220	15,550	1,200
Pinto Beans	9,450	9,350	8,660	7,770	0
Alfalfa	14,630	14,560	14,170	13,660	10,990
Total	128,860	128,340	124,740	119,930	90,950
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.3	23.3	22.8	22.0	20.6
Sunflowers	0	0	0	0	12.3
Sugar Beets	32.0	32.0	31.0	29.8	28.2
Pinto Beans	18.0	17.9	16.6	14.9	0
Alfalfa	34.8	34.8	33.9	32.7	30.6
All Crops	24.5	24.5	23.9	23.0	20.3
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.13	0.11
Sunflowers (cwt.)	0	0	0	0	0.37
Sugar Beets (ton)	1.68	1.68	1.62	1.53	1.41
Pinto Beans (cwt.)	1.06	1.05	0.96	0.85	0
Alfalfa (ton)	9.29	8.89	8.14	7.13	6.25

Table B19 Projected Irrigation Water Use, Scenario 1, Subarea 3.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	170,630	157,500	161,690	162,060	121,850
Wheat	0	0	0	0	1,950
Sugar Beets	14,980	0	0	0	0
Pinto Beans	8,560	7,370	7,570	0	0
Alfalfa	20,350	17,120	19,240	17,630	13,880
Total	214,520	181,990	188,500	179,690	137,680
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.0	23.0	22.3	21.4	20.2
Wheat	0	0	0	0	7.0
Sugar Beets	28.0	0	0	0	0
Pinto Beans	16.0	16.0	15.5	0	0
Alfalfa	31.7	31.0	32.9	30.8	29.2
All Crops	23.5	23.2	22.7	22.0	20.3
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.13	0.11
Wheat (bu.)	0	0	0	0	0.09
Sugar Beets (ton)	1.65	0	0	0	0
Pinto Beans (cwt.)	1.00	0.99	0.96	0	0
Alfalfa (ton)	8.45	7.91	7.90	6.71	5.83

Table B20 Projected Irrigation Water Use, Scenario 1, Subarea 4.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	243,680	253,680	257,070	266,530	246,520
Sunflowers	0	0	0	0	1,020
Alfalfa	33,060	34,420	35,010	36,480	34,250
Total	276,740	288,100	292,080	303,010	281,790
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.0	23.0	22.3	21.4	20.2
Sunflowers	0	0	0	0	10.6
Alfalfa	30.2	30.2	29.4	28.3	27.0
All Crops	23.7	23.7	23.0	22.0	20.8
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.13	0.11
Sunflowers (cwt.)	0	0	0	0	0.32
Alfalfa (ton)	8.04	7.70	7.05	6.17	5.39

Table B21 Projected Irrigation Water Use, Scenario 1, Subarea 5.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	262,400	259,260	270,170	232,100	105,340
Wheat	0	0	0	0	4,680
Sunflowers	0	0	0	0	2,620
Sugar Beets	21,120	5,780	0	0	0
Pinto Beans	14,700	13,170	12,740	0	0
Alfalfa	34,150	31,660	32,400	26,170	13,430
Total	332,370	309,870	315,310	258,270	126,070
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.2	23.4	22.8	21.9	20.5
Wheat	0	0	0	0	8.0
Sunflowers	0	0	0	0	12.3
Sugar Beets	25.9	32.0	0	0	0
Pinto Beans	18.0	17.4	16.0	0	0
Alfalfa	34.8	34.8	33.9	32.6	30.0
All Crops	23.8	24.0	23.2	22.6	19.8
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.13	0.11
Wheat (bu.)	0	0	0	0	0.10
Sunflowers (cwt.)	0	0	0	0	0.37
Sugar Beets (ton)	1.57	1.87	0	0	0
Pinto Beans (cwt.)	1.13	1.08	0.99	0	0
Alfalfa (ton)	9.28	8.89	8.14	7.13	6.27

Table B22 Projected Irrigation Water Use, Scenario 1, Subarea 6.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	49,490	41,190	31,180	23,260	34,820
Sorghum	43,580	50,220	37,190	26,810	7,950
Wheat	41,610	0	0	0	27,620
Sunflowers	0	22,910	18,780	16,690	26,580
Alfalfa	29,490	22,730	20,390	13,700	21,400
Total	164,170	137,050	107,540	80,460	118,370
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	28.0	27.3	24.0	27.3	25.0
Sorghum	16.2	15.0	14.1	14.1	15.7
Wheat	12.2	0	0	0	10.6
Sunflowers	0	12.7	11.9	16.1	15.7
Alfalfa	40.8	36.8	38.4	39.4	37.5
All Crops	19.1	18.8	17.8	19.5	17.4
Water Use Per Unit of Yield (acre inch/acre)					
Corn (bu.)	0.23	0.21	0.18	0.17	0.14
Sorghum (bu.)	0.19	0.17	0.16	0.15	0.15
Wheat (bu.)	0.26	0	0	0	0.14
Sunflowers (cwt.)	0	0.66	0.54	0.60	0.47
Alfalfa (ton)	10.88	10.41	8.65	8.59	7.50

Table B23 Projected Resource Use, Scenario 1, Subareas 1-6.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	5,571	5,268	4,411	3,474	2,551
Electricity Use for Irrigation (million KWH)	441	432	442	423	351
Natural Gas Use for Irrigation (1000 MCF)	4,279	3,989	3,055	2,136	1,423
Irrigation Pumps:					
Electric	3,048	2,849	2,990	2,954	2,672
Natural Gas	1,719	1,606	1,507	1,174	1,085
Total	4,767	4,455	4,497	4,128	3,757
Farm Consumption of:					
Diesel Fuel (1000 gal.)	13,951	13,758	13,869	13,661	12,943
Gasoline (1000 gal.)	2,739	2,607	2,611	2,575	2,396
NH_3 (tons)	81,862	89,524	97,732	108,824	114,185
Other Fertilizer (tons)	46,504	46,446	50,652	53,939	52,171
Irrigated Farm Labor (man-years)	1,332	1,239	1,262	1,192	983
Dryland Farm Labor (man-years)	1,344	1,361	1,359	1,381	1,403
Total Crop Labor (man-years)	2,676	2,600	2,621	2,573	2,386

Table B24 Projected Resource Use, Scenario 1, Subarea 1.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	95	95	92	81	71
Electricity Use for Irrigation (million KWH)	18	18	18	17	15
Natural Gas Use for Irrigation (1000 MCF)	35	35	31	24	20
Irrigation Pumps:					
Electric	112	112	112	112	112
Natural Gas	12	12	12	12	12
Total	124	124	124	124	124
Farm Consumption of:					
Diesel Fuel (1000 gal.)	387	387	387	387	387
Gasoline (1000 gal.)	74	74	74	74	74
NH_3 (tons)	2,423	2,695	2,907	3,259	3,675
Other Fertilizer (tons)	1,222	1,331	1,420	1,560	1,744
Irrigated Farm Labor (man-years)	33	33	33	33	33
Dryland Farm Labor (man-years)	38	38	38	38	38
Total Crop Labor (man-years)	71	71	71	71	71

Table B25 Projected Resource Use, Scenario 1, Subarea 2.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	407	405	364	339	236
Electricity Use for Irrigation (million KWH)	67	68	65	64	48
Natural Gas Use for Irrigation (1000 MCF)	187	184	150	126	76
Irrigation Pumps:					
Electric	365	364	364	364	318
Natural Gas	55	54	54	54	51
Total	420	418	418	418	369
Farm Consumption of:					
Diesel Fuel (1000 gal.)	1,716	1,713	1,713	1,713	1,566
Gasoline (1000 gal.)	334	333	333	333	282
NH_3 (tons)	9,020	10,009	10,781	12,088	13,481
Other Fertilizer (tons)	4,851	5,176	5,468	5,923	5,117
Irrigated Farm Labor (man-years)	177	176	177	178	128
Dryland Farm Labor (man-years)	162	162	162	162	166
Total Crop Labor (man-years)	339	339	339	340	294

Table B26 Projected Resource Use, Scenario 1, Subarea 3

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	881	783	761	671	462
Electricity Use for Irrigation (million KWH)	96	86	90	85	65
Natural Gas Use for Irrigation (1000 MCF)	583	516	478	401	252
Irrigation Pumps:					
Electric	653	560	591	575	488
Natural Gas	203	177	189	189	147
Total	856	737	780	764	635
Farm Consumption of:					
Diesel Fuel (1000 gal.)	3,804	3,661	3,698	3,682	3,558
Gasoline (1000 gal.)	721	657	667	669	635
NH_3 (tons)	20,476	21,867	24,165	27,876	29,325
Other Fertilizer (tons)	8,024	7,359	8,288	9,180	8,439
Irrigated Farm Labor (man-years)	242	194	208	204	167
Dryland Farm Labor (man-years)	442	448	446	447	453
Total Crop Labor (man-years)	684	642	654	651	620

Table B27 Projected Resource Use, Scenario 1, Subarea 4.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	741	818	797	778	713
Electricity Use for Irrigation (million KWH)	142	156	164	171	164
Natural Gas Use for Irrigation (1000 MCF)	270	302	249	203	162
Irrigation Pumps:					
Electric	1,001	1,046	1,097	1,194	1,178
Natural Gas	95	95	95	95	92
Total	1,096	1,141	1,192	1,289	1,270
Farm Consumption of:					
Diesel Fuel (1000 gal.)	1,490	1,544	1,604	1,719	1,699
Gasoline (1000 gal.)	345	358	373	400	395
NH_3 (tons)	13,434	15,170	16,986	20,151	22,273
Other Fertilizer (tons)	14,651	16,637	18,590	21,922	24,099
Irrigated Farm Labor (man-years)	290	302	315	341	335
Dryland Farm Labor (man-years)	32	32	32	32	33
Total Crop Labor (man-years)	322	334	347	373	368

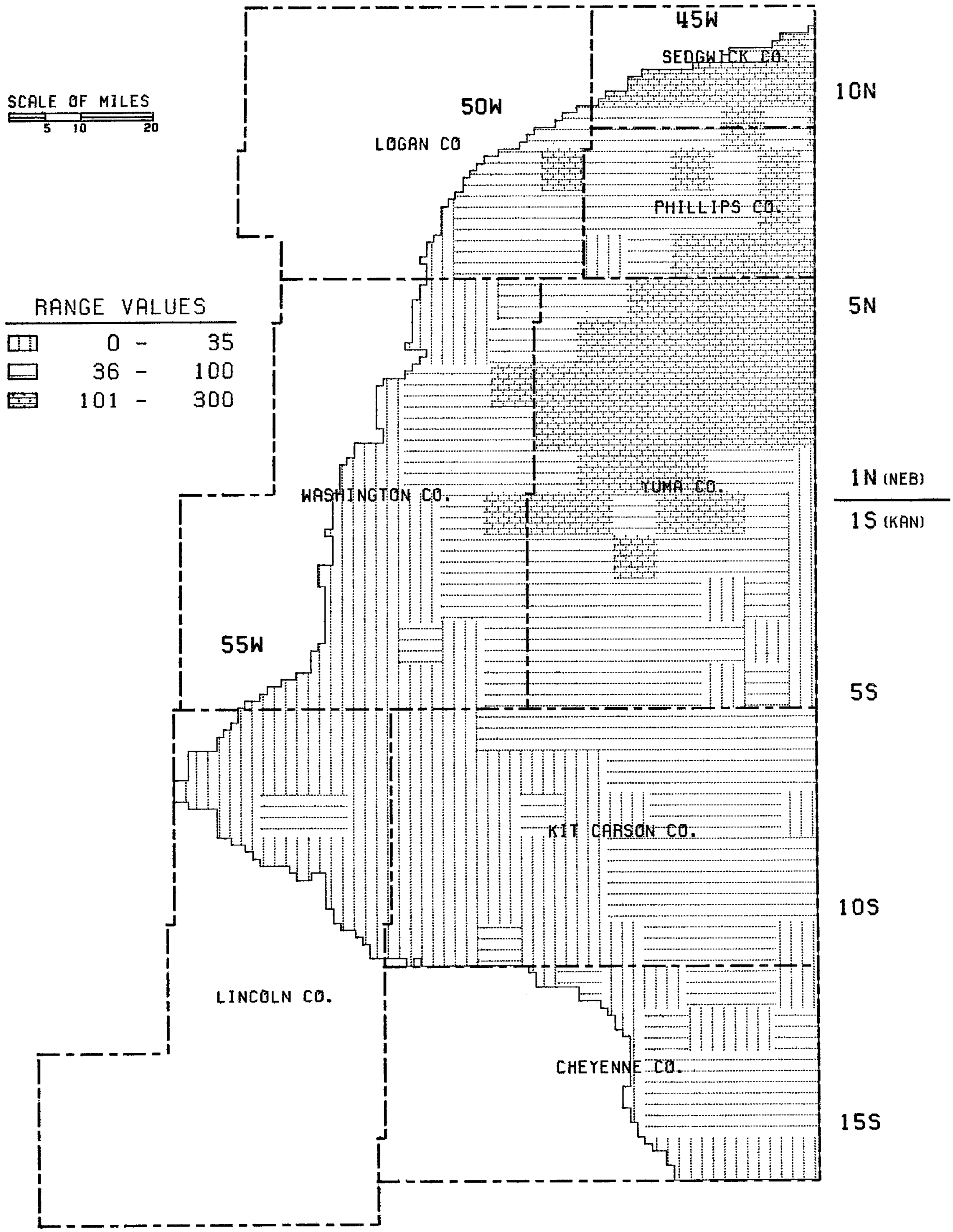
Table B28 Projected Resource Use, Scenario 1, Subarea 5.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	2,047	2,058	1,737	1,245	497
Electricity Use for Irrigation (million KWH)	90	83	84	67	39
Natural Gas Use for Irrigation (1000 MCF)	1,832	1,867	1,526	1,069	384
Irrigation Pumps:					
Electric	632	558	612	498	328
Natural Gas	675	654	662	571	270
Total	1,307	1,212	1,274	1,069	598
Farm Consumption of:					
Diesel Fuel (1000 gal.)	3,455	3,333	3,383	3,181	2,663
Gasoline (1000 gal.)	696	638	640	600	478
NH_3 (tons)	21,138	22,739	25,358	26,822	22,389
Other Fertilizer (tons)	12,186	12,138	13,538	12,845	7,558
Irrigated Farm Labor (man-years)	423	377	391	331	170
Dryland Farm Labor (man-years)	277	282	278	289	313
Total Crop Labor (man-years)	700	659	669	620	483

Table B29 Projected Resource Use, Scenario 1, Subarea 6.

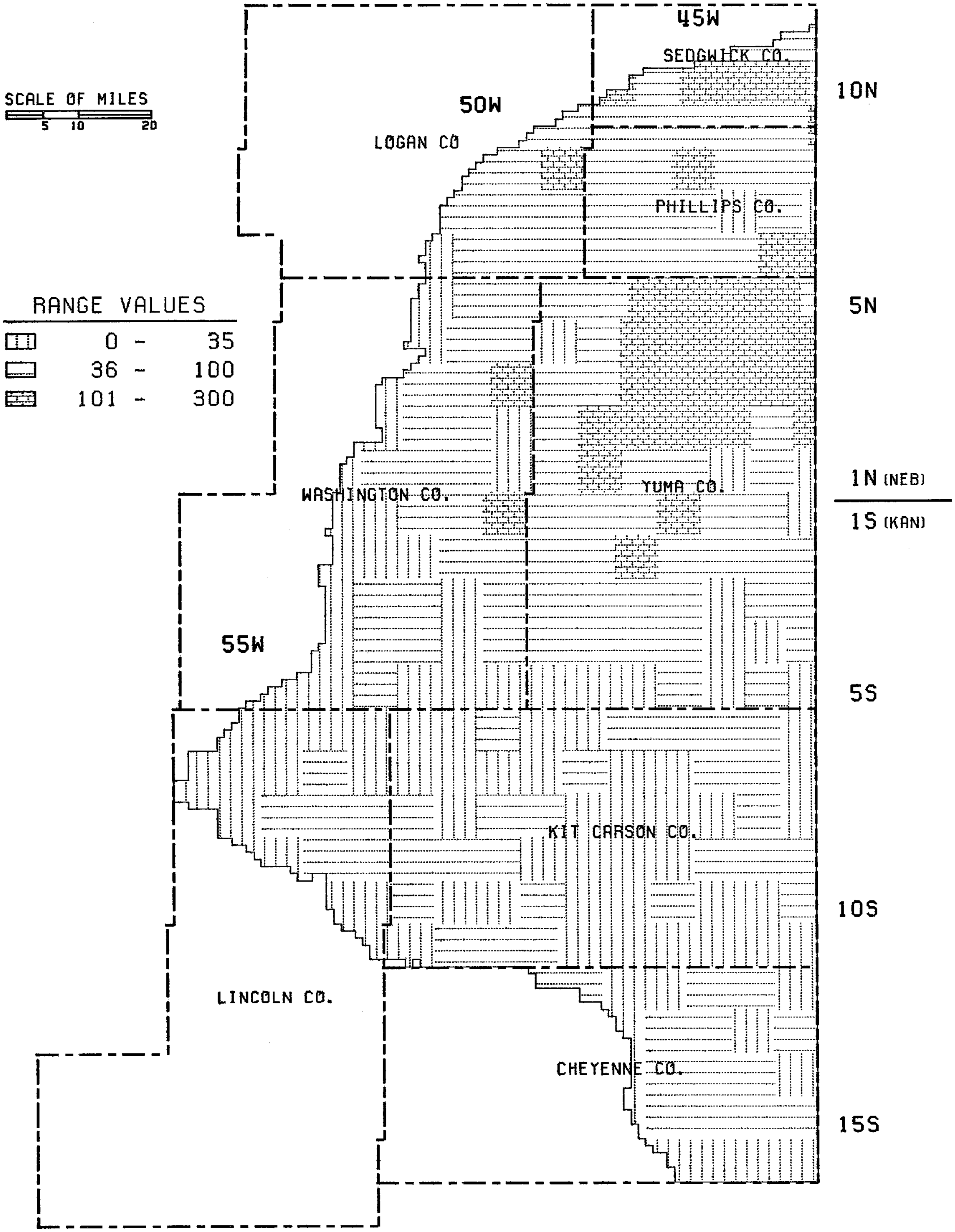
	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	1,400	1,109	659	361	571
Electricity Use for Irrigation (million KWH)	28	22	20	19	20
Natural Gas Use for Irrigation (1000 MCF)	1,372	1,086	621	312	529
Irrigation Pumps:					
Electric	285	209	214	211	248
Natural Gas	679	614	495	253	513
Total	964	823	709	464	761
Farm Consumption of:					
Diesel Fuel (1000 gal.)	3,099	3,120	3,084	2,979	3,070
Gasoline (1000 gal.)	569	547	524	499	532
NH_3 (tons)	15,371	17,044	17,535	18,628	23,042
Other Fertilizer (tons)	5,570	3,805	3,348	2,509	5,214
Irrigated Farm Labor (man-years)	166	157	138	95	150
Dryland Farm Labor (man-years)	392	398	403	423	400
Total Farm Labor (man-years)	558	555	541	518	550

SCENARIO I



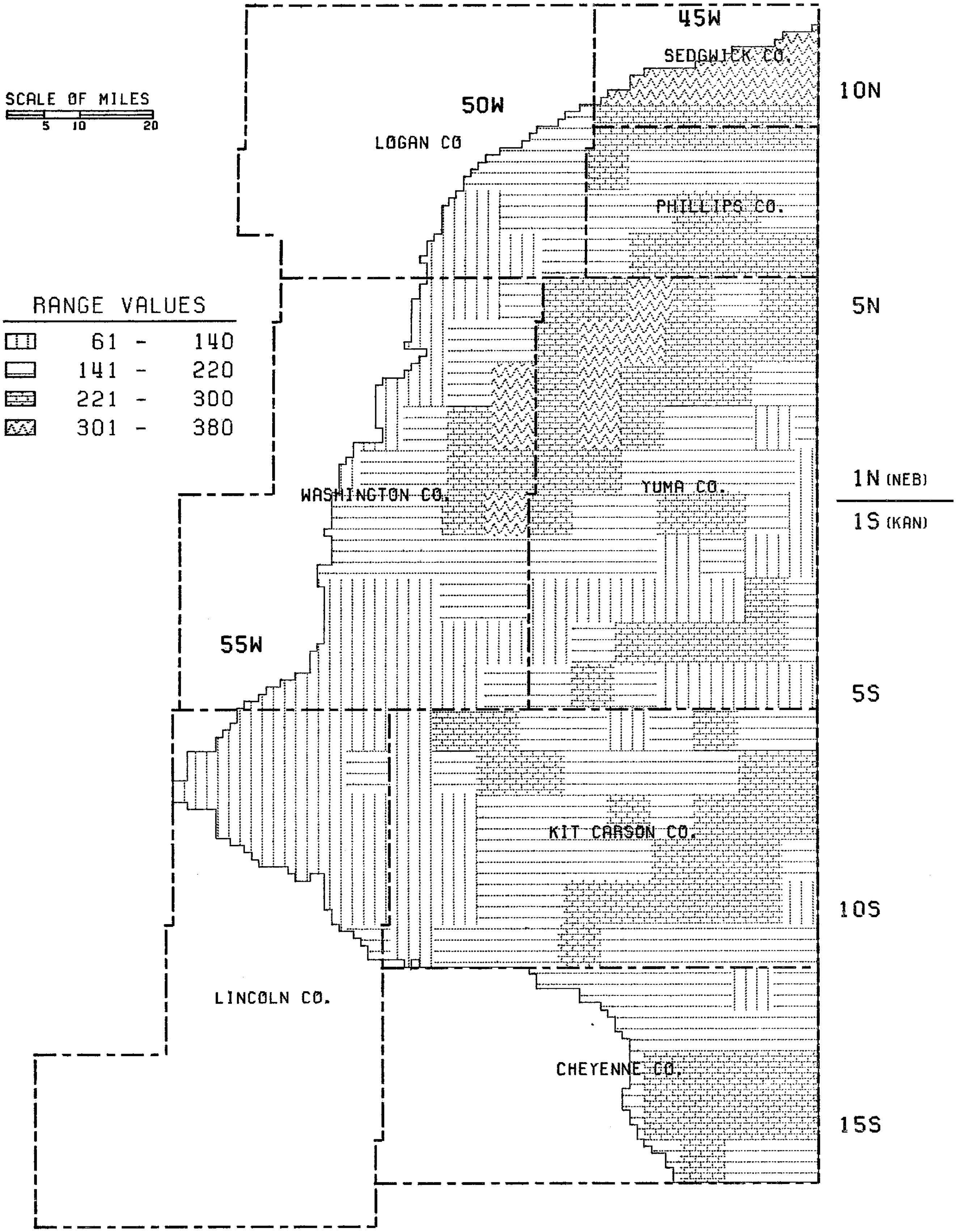
ØGALLALA AQUIFER, NØRTH-EASTERN CØLØRADØ
TØWNSHIPS BY 2000 SATURATED THICKNESS

Figure B1



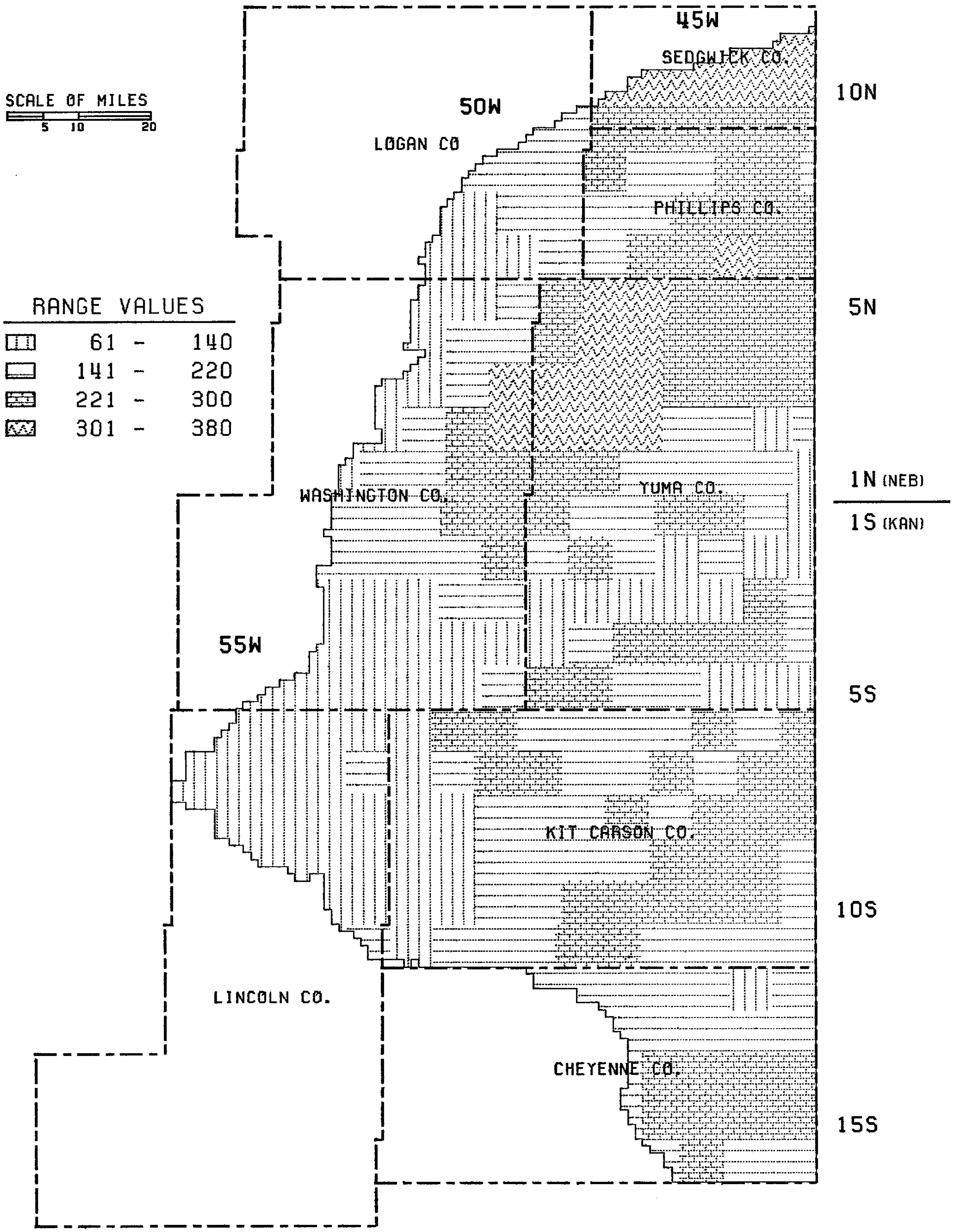
OGALLALA AQUIFER, NORTH-EASTERN COLORADO
TOWNSHIPS BY 2020 SATURATED THICKNESS

Figure B2



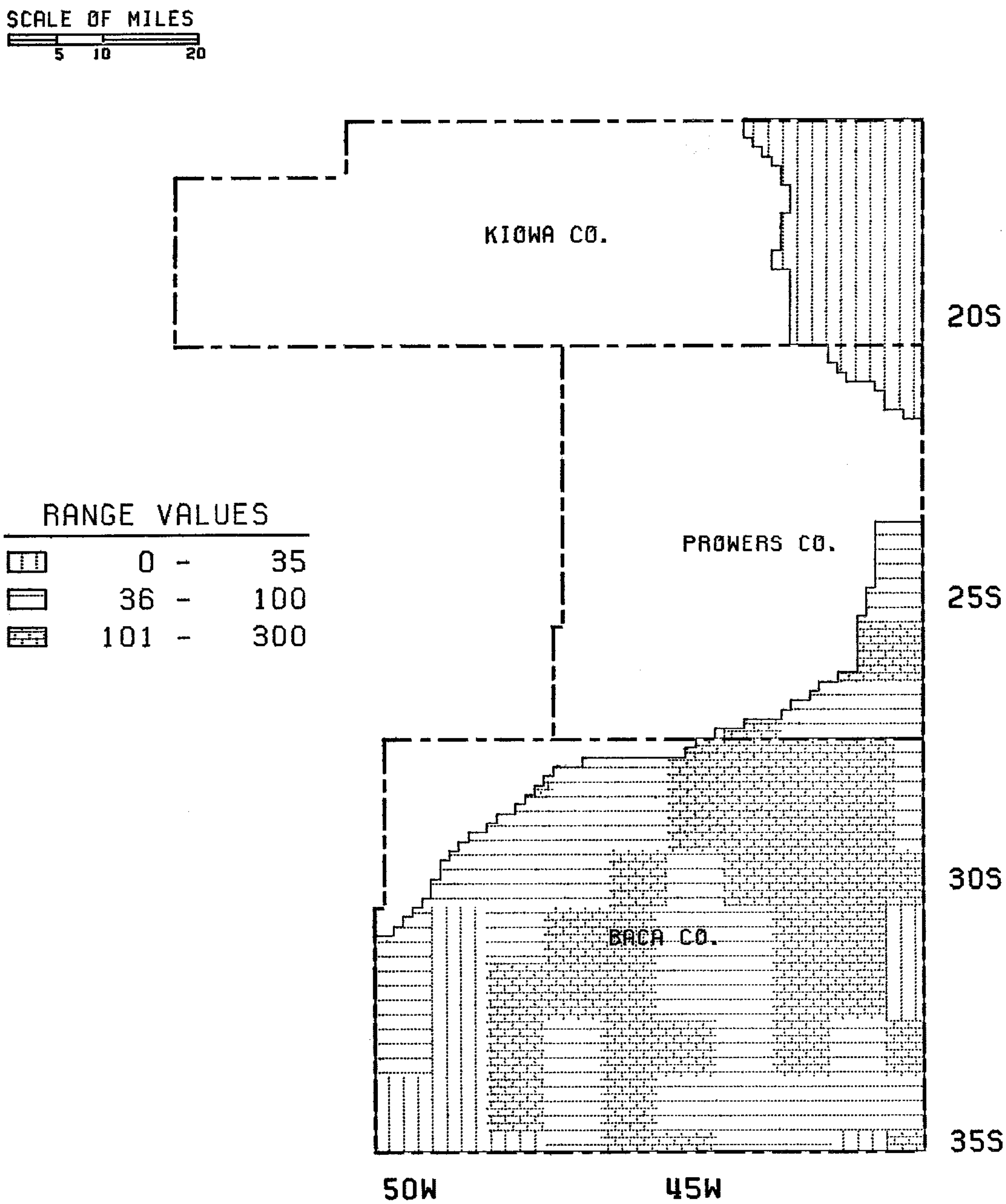
OGALLALA AQUIFER, NORTH-EASTERN COLORADO
TOWNSHIPS BY 2000 DEPTH-ZONES

Figure B3



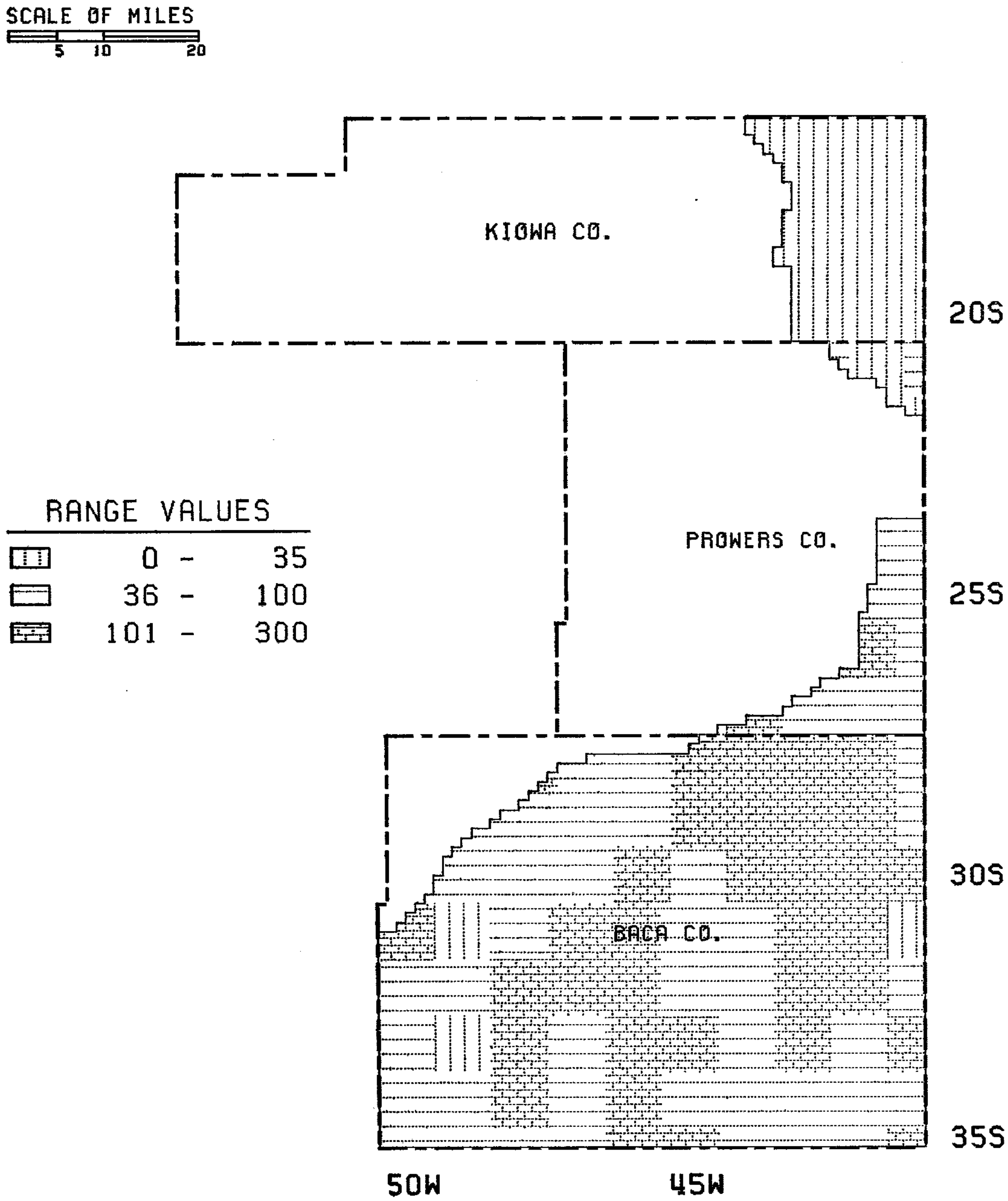
OGALLALA AQUIFER, NORTH-EASTERN COLORADO
TOWNSHIPS BY 2020 DEPTH-ZONES

Figure B4



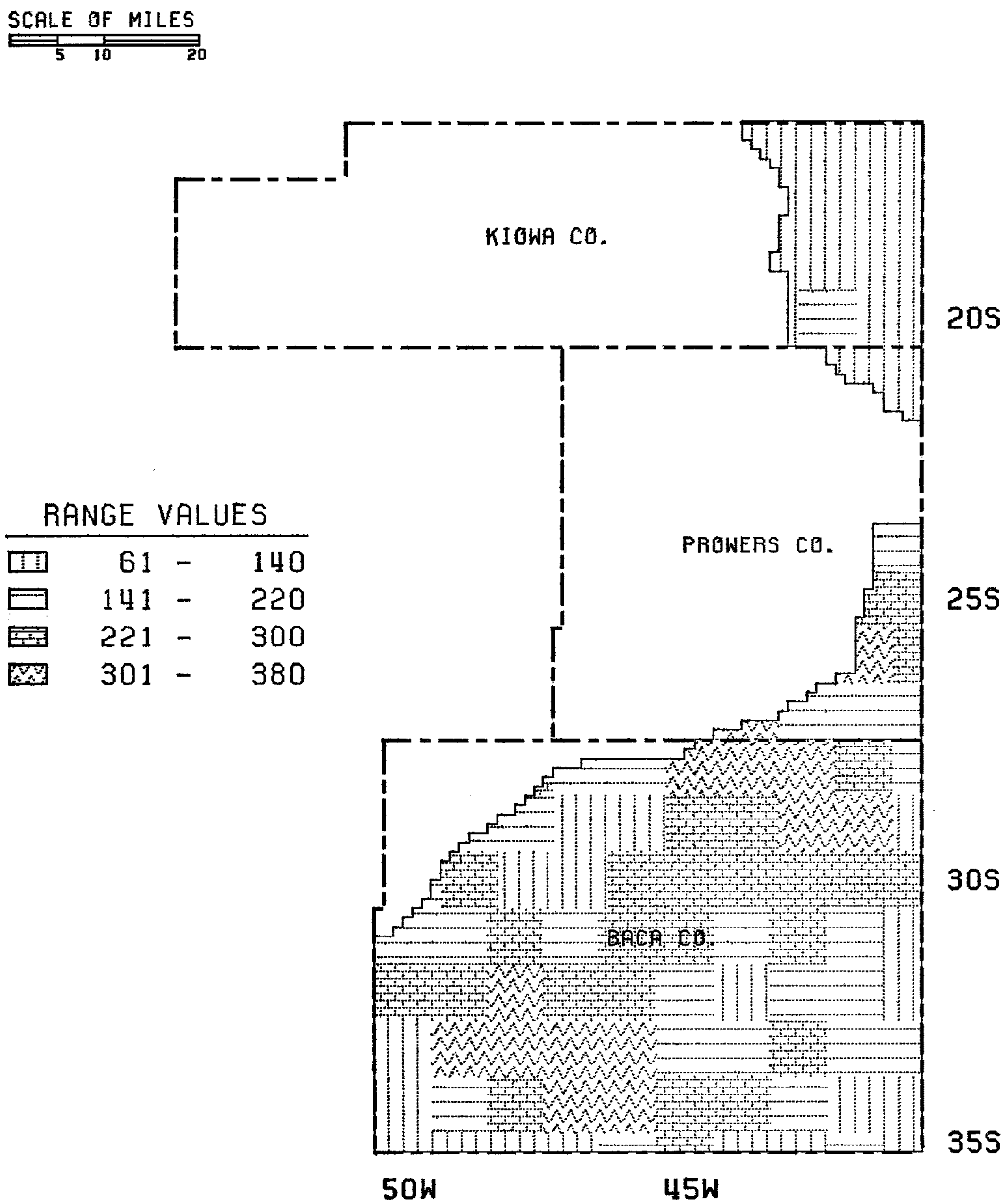
OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2000 SATURATED THICKNESS

Figure B5



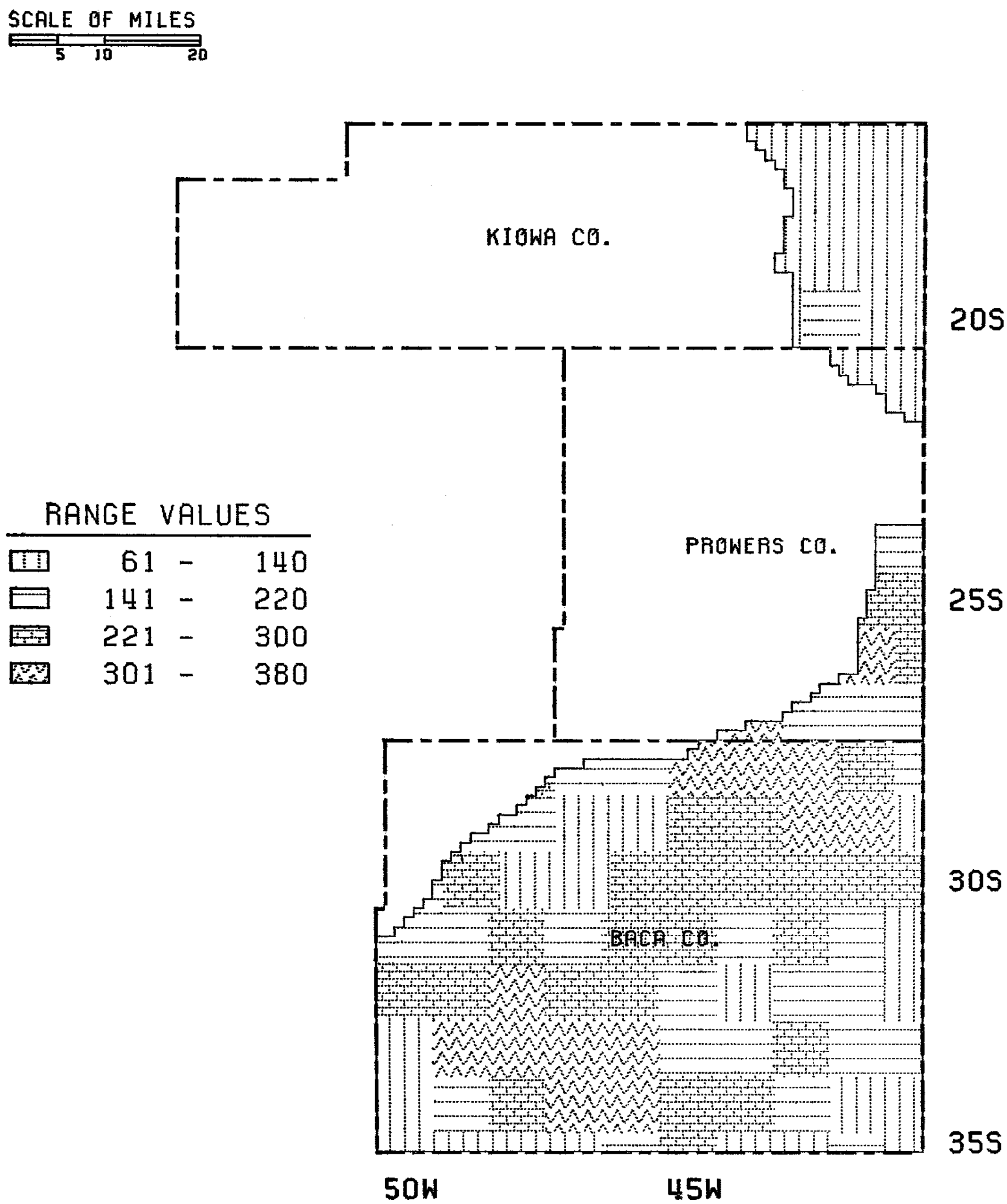
OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2020 SATURATED THICKNESS

Figure B6



OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2000 DEPTH-ZONES

Figure B7



OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2020 DEPTH-ZONES

Figure B8

APPENDIX C -- RESEARCH DETAILS BY SUBAREA, SCENARIO 2

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Table C1 Projected Returns to Land and Management, Scenario 2.

		Returns to Land and Management (Dollars)		
Subarea	Year	Irrigated Crops	Dryland Crops	All Crops
1	1979	1,308,000	3,168,000	4,476,000
	1985	1,818,000	2,880,000	4,698,000
	1990	1,547,000	2,976,000	4,523,000
	2000	2,055,000	3,552,000	5,607,000
	2020	3,146,000	4,704,000	7,868,000
2	1979	6,899,000	12,992,000	19,891,000
	1985	8,102,000	11,783,000	19,885,000
	1990	7,339,000	12,189,000	19,528,000
	2000	8,748,000	14,627,000	23,375,000
	2020	11,903,000	19,646,000	31,549,000
3	1979	10,590,000	22,100,000	32,690,000
	1985	10,811,000	21,284,000	32,095,000
	1990	8,964,000	22,440,000	31,404,000
	2000	11,839,000	28,092,000	39,931,000
	2020	17,676,000	40,453,000	58,129,000
4	1979	11,681,000	1,280,000	12,961,000
	1985	15,563,000	1,185,000	16,748,000
	1990	12,631,000	1,299,000	13,930,000
	2000	16,298,000	1,373,000	17,671,000
	2020	26,574,000	2,266,000	28,840,000
5	1979	16,485,000	11,072,000	27,557,000
	1985	16,169,000	9,858,000	26,027,000
	1990	13,134,000	11,377,000	24,511,000
	2000	16,650,000	15,368,000	32,018,000
	2020	16,697,000	25,451,000	42,148,000
6	1979	1,818,000	5,874,000	7,692,000
	1985	336,000	5,966,000	6,302,000
	1990	-131,000	8,057,000	7,926,000
	2000	1,697,000	13,452,000	15,149,000
	2020	7,258,000	24,500,000	31,758,000
1-6	1979	48,781,000	56,486,000	105,267,000
	1985	52,799,000	52,956,000	105,755,000
	1990	43,484,000	58,338,000	101,822,000
	2000	57,287,000	76,464,000	133,751,000
	2020	83,272,000	117,020,000	200,292,000

Table C2 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 2, Subareas 1-6.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	433,000	422,900	368,300	373,100	248,000
Sorghum	32,300	40,300	31,600	21,800	3,000
Wheat	41,000	0	0	0	50,000
Sunflowers	0	21,700	53,400	11,800	119,100
Sugar Beets	22,500	6,300	6,300	1,700	0
Pinto Beans	22,500	20,900	20,400	19,100	16,500
Alfalfa	47,900	45,100	44,100	41,200	41,200
Total	599,200	557,200	524,100	468,700	477,800
Crop Production					
Corn (mil. bu.)	56.0	59.1	54.2	56.1	43.7
Sorghum (mil. bu.)	2.7	3.4	2.8	2.0	0.2
Wheat (mil. bu.)	1.9	0	0	0	3.7
Sunflowers (mil. cwt.)	0	0.4	1.1	0.3	3.8
Sugar Beets (th. tons)	390.0	115.6	102.2	29.1	0
Pinto Beans (th. cwt.)	366.6	317.5	300.4	273.8	244.9
Alfalfa (th. tons)	179.3	81.9	84.8	60.0	57.9
Value of Production (in millions of 1979 dollars)					
Corn	145.7	181.1	168.8	186.3	152.4
Sorghum	5.9	8.8	7.4	5.7	0.6
Wheat	6.8	0	0	0	14.3
Sunflowers	0	4.5	12.4	3.2	48.1
Sugar Beets	11.7	3.8	3.4	1.0	0
Pinto Beans	8.9	7.7	7.4	7.1	6.9
Alfalfa	9.8	5.1	5.4	3.9	3.8
Total	188.8	211.0	204.8	207.2	225.5

Table C3 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 2, Subarea 1.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	14,500	14,500	14,500	14,500	7,800
Wheat	0	0	0	0	2,700
Sunflowers	0	0	0	0	4,000
Alfalfa	1,500	1,500	1,500	1,500	1,500
Total	16,000	16,000	16,000	16,000	16,000
Crop Production					
Corn (mil. bu.)	1.9	2.0	2.0	2.1	1.5
Wheat (th. bu.)	0	0	0	0	210.6
Sunflowers (th. cwt.)	0	0	0	0	132.0
Alfalfa (th. tons)	5.6	2.2	2.2	2.2	2.2
Value of Production (millions of 1979 dollars)					
Corn	4.9	6.2	6.3	6.7	5.1
Wheat	0	0	0	0	0.8
Sunflowers	0	0	0	0	1.7
Alfalfa	0.3	0.1	0.1	0.1	0.1
Total	5.2	6.3	6.4	6.8	7.7

Table C4 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 2, Subarea 2.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	45,300	45,100	37,600	49,700	24,000
Wheat	0	0	0	0	10,000
Sunflowers	0	0	7,500	0	14,900
Sugar Beets	6,300	6,300	6,300	1,700	0
Pinto Beans	6,300	6,300	6,300	6,300	6,000
Alfalfa	5,100	5,000	5,000	5,000	4,800
Total	63,000	62,700	62,700	62,700	59,700
Crop Production					
Corn (mil. bu.)	5.9	6.3	5.7	7.2	4.5
Wheat (th. bu.)	0	0	0	0	780.0
Sunflowers (th. cwt.)	0	0	160.8	0	491.7
Sugar Beets (th. tons)	119.7	115.6	102.2	29.1	0
Pinto Beans (th. cwt.)	107.1	107.2	105.7	93.4	91.9
Alfalfa (th. tons)	18.5	7.5	7.5	7.5	7.2
Value of Production (in millions of 1979 dollars)					
Corn	15.3	19.3	17.8	24.0	15.8
Wheat	0	0	0	0	2.8
Sunflowers	0	0	1.7	0	6.2
Sugar Beets	3.6	3.8	3.4	1.0	0
Pinto Beans	2.6	2.6	2.6	2.4	2.6
Alfalfa	1.0	0.5	0.5	0.5	0.5
Total	22.5	26.2	26.0	27.9	27.9

Table C5 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 2, Subarea 3.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	89,400	82,200	80,600	79,200	56,500
Sunflowers	0	0	0	0	22,700
Sugar Beets	6,400	0	0	0	0
Pinto Beans	6,400	5,500	5,400	5,300	5,300
Alfalfa	7,800	6,600	6,500	6,400	6,400
Total	110,000	94,300	92,500	90,900	90,900
Crop Production					
Corn (mil. bu.)	11.6	11.5	11.3	11.3	9.4
Sunflowers (th. cwt.)	0	0	0	0	750.0
Sugar Beets (th. tons)	109.1	0	0	0	0
Pinto Beans (th. cwt.)	102.7	75.7	74.8	75.1	77.7
Alfalfa (th. tons)	28.9	9.9	9.8	9.6	9.6
Value of Production (in millions of 1979 dollars)					
Corn	30.0	35.2	35.1	37.7	32.8
Sunflowers	0	0	0	0	9.4
Sugar Beets	3.3	0	0	0	0
Pinto Beans	2.5	1.8	1.8	2.0	2.2
Alfalfa	1.6	0.6	0.6	0.6	0.6
Total	37.4	37.6	37.5	40.3	45.0

Table C6 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 2, Subarea 4.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	127,000	127,900	117,900	109,000	88,300
Wheat	0	0	0	0	5,000
Sunflowers	0	0	0	0	36,200
Alfalfa	13,000	13,700	14,300	15,300	15,500
Total	140,000	141,600	132,200	124,300	145,000
Crop Production					
Corn (mil. bu.)	16.5	18.2	17.9	18.2	16.5
Wheat (th. bu.)	0	0	0	0	405.0
Sunflowers (th. cwt.)	0	0	0	0	1,194.6
Alfalfa (th. tons)	49.3	20.7	34.2	19.1	19.3
Value of Production (in millions of 1979 dollars)					
Corn	43.0	55.8	55.7	60.4	57.6
Wheat	0	0	0	0	1.5
Sunflowers	0	0	0	0	15.1
Alfalfa	2.7	1.3	2.2	1.3	1.3
Total	45.7	57.1	57.9	61.7	75.5

Table C7 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 2, Subarea 5.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	135,600	135,100	102,100	111,000	54,700
Sunflowers	0	0	27,000	0	22,000
Sugar Beets	9,800	0	0	0	0
Pinto Beans	9,800	9,100	8,700	7,500	5,200
Alfalfa	11,800	10,900	10,400	9,000	6,200
Total	167,000	155,100	148,200	127,500	88,100
Crop Production					
Corn (mil. bu.)	17.6	18.9	15.5	16.0	9.4
Sunflowers (th. cwt.)	0	0	581.0	0	611.1
Sugar Beets (th. tons)	161.2	0	0	0	0
Pinto Beans (th. cwt.)	156.8	134.6	119.9	105.3	75.3
Alfalfa (th. tons)	44.1	16.4	15.6	13.5	9.3
Value of Production (in millions of 1979 dollars)					
Corn	45.9	58.0	48.2	53.3	32.6
Sunflowers	0	0	6.3	0	7.7
Sugar Beets	4.8	0	0	0	0
Pinto Beans	3.8	3.3	3.0	2.7	2.1
Alfalfa	2.4	1.0	1.0	0.9	0.6
Total	56.9	62.3	58.5	56.9	43.0

Table C8 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 2, Subarea 6.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	21,200	18,100	15,600	9.700	16,700
Sorghum	32,300	40,300	31,600	21,800	3,000
Wheat	41,000	0	0	0	32,300
Sunflowers	0	21,700	18,900	11,800	19,300
Alfalfa	8,700	7,400	6,400	4,000	6,800
Total	103,200	87,500	72,500	47,400	78,100
Crop Production					
Corn (mil. bu.)	2.5	2.2	1.8	1.3	2.4
Sorghum (mil. bu.)	2.7	3.4	2.8	2.0	0.2
Wheat (th. bu.)	1,930.2	0	0	0	2,522.7
Sunflowers (th. cwt.)	0	404.8	407.8	278.5	638.7
Alfalfa (th. tons)	32.5	25.2	15.5	8.1	10.3
Value of Production (in millions of 1979 dollars)					
Corn	6.6	6.6	5.7	4.2	8.5
Sorghum	5.9	8.8	7.4	5.7	0.6
Wheat	6.8	0	0	0	9.2
Sunflowers	0	4.5	4.4	3.2	8.0
Alfalfa	1.8	1.6	1.0	0.5	0.7
Total	21.1	21.5	18.5	13.6	27.0

Table C9 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 2, Subareas 1-6.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	1,470,700	1,460,400	1,468,400	1,475,900	1,437,500
Sorghum	191,700	124,200	100,700	77,600	75,000
Sunflowers	0	95,300	121,200	162,400	208,200
Corn	12,600	12,600	12,600	12,500	12,600
Hay	8,000	21,200	39,800	16,500	16,500
Total	1,683,000	1,713,700	1,742,700	1,744,900	1,749,800
Crop Production					
Wheat (mil. bu.)	35.0	39.3	43.1	49.1	54.8
Sorghum (mil. bu.)	3.8	2.7	2.3	2.0	2.3
Sunflowers (mil. cwt.)	0	1.0	1.3	1.9	2.9
Corn (th. bu.)	376.5	401.8	427.0	457.1	525.5
Hay (th. tons)	8.0	21.2	39.8	16.5	16.5
Value of Crop Production (in millions of 1979 dollars)					
Wheat	122.3	127.7	141.8	164.8	201.0
Sorghum	8.5	7.0	6.0	5.5	6.7
Sunflowers	0	10.7	14.4	22.0	36.7
Corn	1.0	1.2	1.3	1.5	1.9
Hay	0.4	1.3	2.5	1.1	1.1
Total	132.2	147.9	166.0	194.9	247.4

Table C10 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 2, Subarea 1

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	45,600	45,600	45,600	43,200	43,200
Sunflowers	0	0	0	2,400	2,400
Corn	2,400	2,400	2,400	2,400	2,400
Total	48,000	48,000	48,000	48,000	48,000
Crop Production					
Wheat (mil. bu.)	1.5	1.6	1.7	1.8	2.0
Sunflowers (th. cwt.)	0	0	0	28.8	33.6
Corn (th. bu.)	72.0	76.8	81.6	87.4	99.8
Value of Production (in millions of 1979 dollars)					
Wheat	5.1	5.2	5.6	6.0	7.3
Sunflowers	0	0	0	0.3	0.4
Corn	0.2	0.2	0.3	0.3	0.4
Total	5.3	5.4	5.9	6.6	8.1

Table C11 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 2, Subarea 2.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	192,800	192,800	192,800	182,800	184,200
Sunflowers	0	0	0	10,100	10,200
Corn	10,200	10,200	10,200	10,100	10,200
Total	203,000	203,000	203,000	203,000	204,600
Crop Production					
Wheat (mil. bu.)	6.2	6.8	7.3	7.6	8.5
Sunflowers (th. cwt.)	0	0	0	121.9	143.3
Corn (th. bu.)	304.5	325.0	345.4	369.7	425.7
Value of Production (in millions of 1979 dollars)					
Wheat	21.6	22.0	23.9	25.6	31.3
Sunflowers	0	0	0	1.4	1.8
Corn	0.8	1.0	1.0	1.2	1.5
Total	22.4	23.0	24.9	28.2	34.6

Table C12 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 2, Subarea 3.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	524,900	532,100	533,000	533,700	505,600
Sorghum	27,600	0	0	0	0
Sunflowers	0	28,000	28,000	28,100	56,200
Total	552,500	560,100	561,000	561,800	561,800
Crop Production					
Wheat (mil. bu.)	13.1	14.9	16.2	18.4	20.0
Sorghum (th. bu.)	552.5	0	0	0	0
Sunflowers (th. cwt.)	0	280.0	309.0	337.1	786.6
Value of Production (in millions of 1979 dollars)					
Wheat	45.9	48.6	53.3	61.7	73.3
Sorghum	1.2	0	0	0	0
Sunflowers	0	3.1	3.3	3.8	9.9
Total	47.1	51.7	56.6	65.5	83.2

Table C13 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 2, Subarea 4

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	36,000	32,300	32,300	32,300	32,300
Grass Hay	8,000	20,600	36,500	16,500	16,200
Total	44,000	52,900	68,800	48,800	48,500
Crop Production					
Wheat (mil. bu.)	0.8	0.8	0.9	1.0	1.2
Grass Hay (th. tons)	8.0	20.6	36.5	16.5	16.2
Value of Production (in millions of 1979 dollars)					
Wheat	2.8	2.6	2.9	3.4	4.3
Grass Hay	0.4	1.3	2.3	1.1	1.1
Total	3.2	3.9	5.2	4.5	5.4

Table C14 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 2, Subarea 5.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	328,700	334,500	337,700	347,600	347,000
Sorghum	17,300	0	0	0	0
Sunflowers	0	17,600	17,800	18,300	38,600
Total	346,000	352,100	355,500	365,900	385,600
Crop Production					
Wheat (mil. bu.)	7.2	8.4	9.3	11.0	12.6
Sorghum (th. bu.)	346.0	0	0	0	0
Sunflowers (th. cwt.)	0	176.0	195.5	219.5	540.0
Value of Crop Production (in millions of 1979 dollars)					
Wheat	25.3	27.2	30.7	36.9	46.2
Sorghum	0.8	0	0	0	0
Sunflowers	0	2.0	2.1	2.5	6.8
Total	26.1	29.2	32.8	39.4	53.0

Table C15 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 2, Subarea 6.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	342,700	323,100	327,000	336,300	325,200
Sorghum	146,800	124,200	100,700	77,600	75,000
Sunflowers	0	49,700	75,400	103,500	100,800
Grass Hay	0	600	3,300	0	0
Total	489,500	497,600	506,400	517,400	501,000
Crop Production					
Wheat (mil. bu.)	6.2	6.8	7.7	9.3	10.5
Sorghum (mil. bu.)	2.9	2.7	2.3	2.0	2.3
Sunflowers (th. cwt.)	0	497.0	830.2	1,241.7	1,412.1
Grass Hay (th. tons)	0	0.6	3.3	0	0
Value of Production (in millions of 1979 dollars)					
Wheat	21.6	22.1	25.4	31.2	38.6
Sorghum	6.5	7.0	6.0	5.5	6.7
Sunflowers	0	5.6	9.0	14.0	17.8
Grass Hay	0	a/	0.2	0	0
Total	28.1	34.7	40.6	50.7	63.1

a/ Insignificant

Table C16 Projected Irrigation Water Use, Scenario 2, Subareas 1-6.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	841,990	798,740	658,570	560,380	381,310
Wheat	41,610	0	0	0	36,430
Sugar Beets	52,900	15,060	9,120	2,450	0
Pinto Beans	32,710	24,390	20,000	14,780	12,070
Alfalfa	135,420	63,260	50,760	44,310	41,280
Sorghum	43,580	46,880	35,730	23,670	1,530
Sunflowers	0	19,950	40,870	10,110	111,700
Total	1,148,210	968,280	815,050	655,700	584,320
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.3	22.7	21.5	18.0	18.5
Wheat	12.2	0	0	0	9.7
Sugar Beets	28.2	28.7	17.4	17.3	0
Pinto Beans	17.4	14.0	11.8	9.3	8.8
Alfalfa	33.9	16.8	13.8	12.9	12.0
Sorghum	16.2	14.0	13.6	13.0	6.1
Sunflowers	0	11.0	9.2	10.3	10.8
All Crops	23.0	20.9	18.7	16.8	14.7
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.12	0.10
Wheat (bu.)	0.26	0	0	0	0.13
Sugar Beets (ton)	1.63	1.56	1.07	1.01	0
Pinto Beans (cwt.)	1.07	0.92	0.80	0.65	0.59
Alfalfa (ton)	9.06	9.27	7.18	8.86	8.56
Sorghum (bu.)	0.19	0.17	0.15	0.14	0.09
Sunflowers (cwt.)	0	0.59	0.43	0.44	0.34

Table C17 Projected Irrigation Water Use, Scenario 2, Subarea 1.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	27,810	26,860	22,990	19,230	13,160
Wheat	0	0	0	0	1,580
Alfalfa	3,740	1,570	1,540	1,490	1,430
Sunflowers	0	0	0	0	3,520
Total	31,500	28,430	24,530	20,720	19,690
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.0	22.2	19.0	15.9	20.2
Wheat	0	0	0	0	7.0
Alfalfa	30.2	12.7	12.4	12.0	11.6
Sunflowers	0	0	0	0	10.6
All Crops	23.7	21.3	18.4	15.5	14.8
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)-	0.18	0.16	0.14	0.11	0.11
Wheat (bu.)	0	0	0	0	0.09
Alfalfa (ton)	8.04	8.44	8.26	8.02	7.71
Sunflowers (cwt.)	0	0	0	0	0.32

Table C18 Projected Irrigation Water Use, Scenario 2, Subarea 2.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	87,980	84,890	71,020	71,260	40,480
Wheat	0	0	0	0	6,390
Sugar Beets	16,800	15,060	9,120	2,450	0
Pinto Beans	9,450	9,410	8,600	4,860	4,380
Alfalfa	14,630	5,850	5,730	5,560	5,090
Sunflowers	0	0	5,430	0	14,300
Total	128,860	115,210	99,900	84,130	70,640
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.3	22.6	22.6	17.2	20.2
Wheat	0	0	0	0	7.7
Sugar Beets	32.0	28.8	17.5	16.7	0
Pinto Beans	18.0	18.0	16.5	9.3	8.8
Alfalfa	34.8	14.0	13.7	13.3	12.7
Sunflowers	0	0	8.7	0	11.5
All Crops	24.5	22.1	19.1	16.1	14.2
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.12	0.11
Wheat (bu.)	0	0	0	0	0.10
Sugar Beets (ton)	1.68	1.56	1.07	1.01	0
Pinto Beans (cwt.)	1.06	1.05	0.98	0.62	0.57
Alfalfa (ton)	9.29	9.33	9.13	8.87	8.53
Sunflowers (cwt.)	0	0	0.41	0	0.35

Table C19 Projected Irrigation Water Use, Scenario 2, Subarea 3.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	170,630	152,540	128,950	106,100	77,570
Sugar Beets	14,980	0	0	0	0
Pinto Beans	8,560	4,610	4,380	4,130	3,910
Alfalfa	20,350	7,000	6,720	6,400	6,160
Sunflowers	0	0	0	0	19,990
Total	214,520	164,105	140,050	116,630	107,630
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.0	22.3	19.2	16.1	16.5
Sugar Beets	28.0	0	0	0	0
Pinto Beans	16.0	10.0	9.7	9.3	8.8
Alfalfa	31.7	12.7	12.4	12.0	11.6
Sunflowers	0	0	0	0	10.6
All Crops	23.5	20.9	18.2	15.4	14.2
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.14	0.11	0.10
Sugar Beets (ton)	1.65	0	0	0	0
Pinto Beans (cwt.)	1.00	0.73	0.70	0.66	0.60
Alfalfa (ton)	8.45	8.45	8.26	8.02	7.71
Sunflowers (cwt.)	0	0	0	0	0.32

Table C20 Projected Irrigation Water Use, Scenario 2, Subarea 4.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	243,680	245,150	219,180	194,270	148,990
Alfalfa	33,060	14,450	14,770	15,340	14,910
Sunflowers	0	0	0	0	36,300
Total	276,740	259,600	233,950	209,610	200,200
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.0	23.0	22.3	21.4	20.2
Alfalfa	30.2	12.7	12.4	12.0	11.6
Sunflowers	0	0	0	0	10.6
All Crops	23.7	22.0	21.2	20.2	16.6
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.13	0.11
Alfalfa (ton)	8.04	8.39	5.19	9.62	9.25
Sunflowers (cwt.)	0	0	0	0	0.32

Table C21 Projected Irrigation Water Use, Scenario 2, Subarea 5.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	262,400	256,570	193,730	155,920	79,010
Sugar Beets	21,120	0	0	0	0
Pinto Beans	14,700	10,370	7,020	5,790	3,780
Alfalfa	34,150	12,610	11,360	8,980	5,970
Sunflowers	0	0	18,580	0	14,760
Total	332,370	279,550	230,690	170,690	103,520
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.2	22.8	22.8	16.8	17.3
Sugar Beets	25.9	0	0	0	0
Pinto Beans	18.0	13.7	9.7	9.3	8.8
Alfalfa	34.8	13.9	13.1	12.0	11.6
Sunflowers	0	0	8.3	0	8.0
All Crops	23.8	21.6	18.7	16.1	14.1
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.16	0.15	0.12	0.10
Sugar Beets (ton)	1.57	0	0	0	0
Pinto Beans (cwt.)	1.13	0.92	0.70	0.66	0.60
Alfalfa (ton)	9.28	9.25	8.72	8.02	7.71
Sunflowers (cwt.)	0	0	0.38	0	0.29

Table C22 Projected Irrigation Water Use, Scenario 2, Subarea 6.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	49,490	32,730	22,700	13,600	22,100
Wheat	41,610	0	0	0	28,460
Alfalfa	29,490	21,780	10,640	6,540	7,720
Sorghum	43,580	46,880	35,730	23,670	1,530
Sunflowers	0	19,950	16,860	10,110	22,830
Total	164,170	121,340	85,930	53,920	82,640
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	28.0	21.7	17.5	16.7	15.8
Wheat	12.2	0	0	0	10.6
Alfalfa	40.8	35.3	20.0	19.7	13.5
Sorghum	16.2	14.0	13.6	13.0	6.1
Sunflowers	0	11.0	10.7	10.2	14.1
All Crops	19.1	16.6	14.2	13.7	12.7
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.23	0.18	0.15	0.13	0.11
Wheat (bu.)	0.26	0	0	0	0.14
Alfalfa (ton)	10.88	10.38	8.22	9.67	9.02
Sorghum (bu.)	0.19	0.16	0.15	0.14	0.09
Sunflowers (cwt.)	0	0.59	0.50	0.44	0.43

Table C23 Projected Resource Use, Scenario 2, Subareas 1-6.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	5,571	4,813	3,463	2,401	2,006
Electricity Use for Irrigation (million KWH)	441	392	345	285	254
Natural Gas Use for Irrigation (1000 MCF)	4,279	3,659	2,406	1,503	1,200
Irrigation Pumps:					
Electric	3,048	2,925	2,858	2,798	2,786
Natural Gas	1,719	1,671	1,466	1,169	1,184
Total	4,767	4,596	4,324	3,967	3,970
Farm Consumption of:					
Diesel Fuel (1000 gal.)	13,951	13,572	13,298	13,056	12,505
Gasoline (1000 gal.)	2,739	2,566	2,457	2,350	2,248
NH3 (tons)	81,862	88,693	90,617	97,439	106,551
Other Fertilizer (tons)	46,504	44,586	41,986	42,548	37,077
Irrigated Farm Labor (man-years)	1,332	1,174	1,065	969	841
Dryland Farm Labor (man-years)	1,344	1,362	1,376	1,389	1,392
Total Crop Labor (man-years)	2,676	2,536	2,441	2,358	2,233

Table C24 Projected Resource Use, Scenario 2, Subarea 1.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	95	84	75	57	51
Electricity Use for Irrigation (million KWH)	18	16	15	12	11
Natural Gas Use for Irrigation (1000 MCF)	35	31	25	17	14
Irrigation Pumps:					
Electric	112	112	112	112	112
Natural Gas	12	12	12	12	12
Total	124	124	124	124	124
Farm Consumption of:					
Diesel Fuel (1000 gal.)	387	381	381	381	359
Gasoline (1000 gal.)	74	73	71	69	68
NH3 (tons)	2,423	2,676	2,808	3,069	3,221
Other Fertilizer (tons)	1,222	1,277	1,306	1,362	1,066
Irrigated Farm Labor (man-years)	33	32	31	31	27
Dryland Farm Labor (man-years)	38	38	38	38	38
Total Crop Labor (man-years)	71	70	69	69	65

Table C25 Projected Resource Use, Scenario 2, Subarea 2.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	407	271	293	236	186
Electricity Use for Irrigation (million KWH)	67	62	53	45	37
Natural Gas Use for Irrigation (1000 MCF)	187	167	118	87	63
Irrigation Pumps:					
Electric	365	364	364	364	350
Natural Gas	55	54	54	54	48
Total	420	418	418	418	398
Farm Consumption of:					
Diesel Fuel (1000 gal.)	1,716	1,697	1,663	1,679	1,508
Gasoline (1000 gal.)	334	330	318	290	267
NH3 (tons)	9,020	9,950	10,323	11,814	12,118
Other Fertilizer (tons)	4,851	4,986	4,599	5,236	3,710
Irrigated Farm Labor (man-years)	177	169	156	152	114
Dryland Farm Labor (man-years)	162	162	162	162	164
Total Crop Labor (man-years)	339	331	318	314	278

Table C26 Projected Resource Use, Scenario 2, Subarea 3.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	881	710	580	447	375
Electricity Use for Irrigation (million KWH)	96	78	68	57	49
Natural Gas Use for Irrigation (1000 MCF)	583	467	366	266	219
Irrigation Pumps:					
Electric	653	560	546	533	533
Natural Gas	203	177	177	177	177
Total	856	737	723	710	710
Farm Consumption of:					
Diesel Fuel (1000 gal.)	3,804	3,635	3,623	3,613	3,559
Gasoline (1000 gal.)	721	653	637	624	613
NH3 (tons)	20,476	21,770	22,995	25,466	27,947
Other Fertilizer (tons)	8,024	7,076	7,093	7,273	6,030
Irrigated Farm Labor (man-years)	242	187	182	174	162
Dryland Farm Labor (man-years)	442	448	448	450	450
Total Crop Labor (man-years)	684	635	630	624	612

Table C27 Projected Resource Use, Scenario 2, Subarea 4.

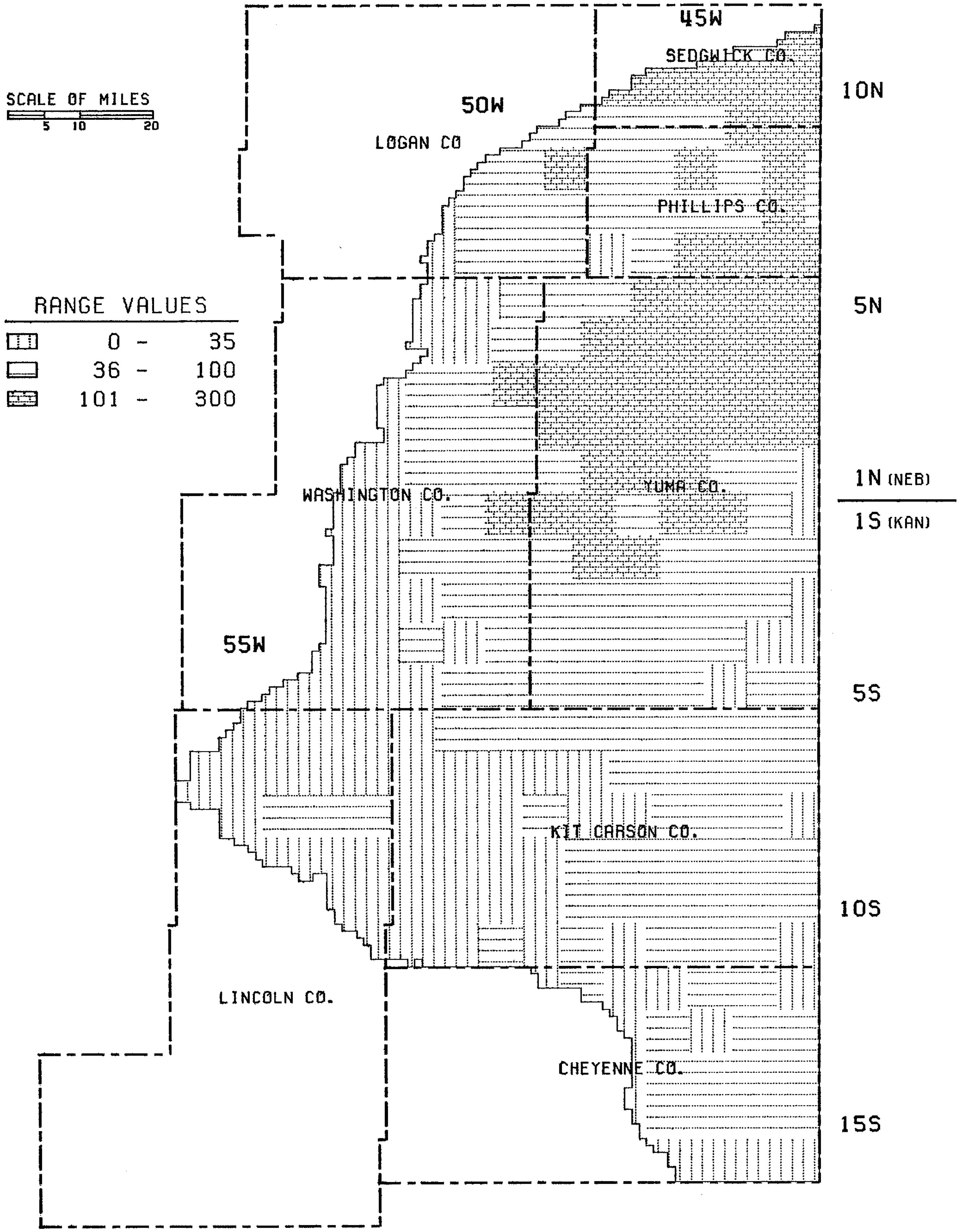
	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	741	736	640	511	498
Electricity Use for Irrigation (million KWH)	142	140	132	118	112
Natural Gas Use for Irrigation (1000 MCF)	270	272	199	114	122
Irrigation Pumps:					
Electric	1,001	1,046	1,097	1,194	1,194
Natural Gas	95	95	95	82	95
Total	1,096	1,141	1,192	1,276	1,299
Farm Consumption of:					
Diesel Fuel (1000 gal.)	1,490	1,474	1,466	1,350	1,408
Gasoline (1000 gal.)	345	349	330	311	315
NH3 (tons)	13,434	14,685	14,601	15,236	18,437
Other Fertilizer (tons)	14,651	15,897	16,292	16,226	15,325
Irrigated Farm Labor (man-years)	290	284	268	248	261
Dryland Farm Labor (man-years)	32	34	40	32	32
Total Crop Labor (man-years)	322	318	308	280	293

Table C28. Projected Resource Use, Scenario 2, Subarea 5.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	2,047	1,876	1,293	856	457
Electricity Use for Irrigation (million KWH)	90	77	61	43	29
Natural Gas Use for Irrigation (1000 MCF)	1,832	1,698	1,142	746	377
Irrigation Pumps:					
Electric	632	558	525	442	349
Natural Gas	675	654	633	554	339
Total	1,307	1,212	1,158	996	688
Farm Consumption of:					
Diesel Fuel (1000 gal.)	3,455	3,287	3,140	3,125	2,692
Gasoline (1000 gal.)	696	619	581	539	468
NH3 (tons)	21,138	22,700	22,490	23,546	21,840
Other Fertilizer (tons)	12,186	11,670	9,589	10,254	5,948
Irrigated Farm Labor (man-years)	423	356	312	288	167
Dryland Farm Labor (man-years)	277	282	284	293	308
Total Crop Labor (man-years)	700	638	596	581	475

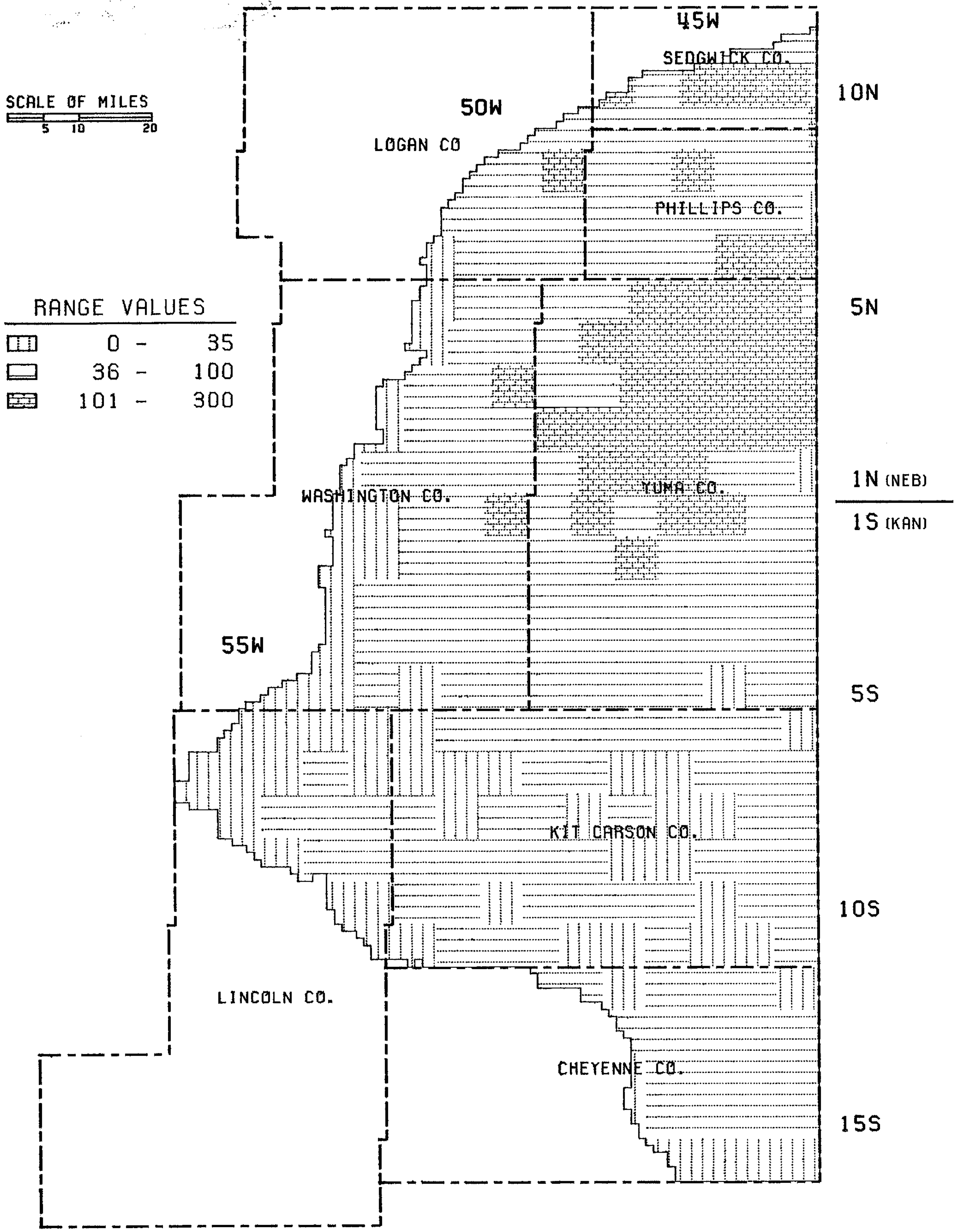
Table C29 Projected Resource Use, Scenario 2, Subarea 6.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	1,400	1,038	583	294	439
Electricity Use for Irrigation (million KWH)	28	19	16	10	16
Natural Gas Use for Irrigation (1000 MCF)	1,372	1,024	556	273	405
Irrigation Pumps:					
Electric	285	285	214	153	248
Natural Gas	679	679	495	290	513
Total	964	964	709	443	761
Farm Consumption of:					
Diesel Fuel (1000 gal.)	3,099	3,098	3,025	2,908	2,979
Gasoline (1000 gal.)	569	542	520	490	517
NH3 (tons)	15,371	16,912	17,400	18,308	22,988
Other Fertilizer (tons)	5,570	3,680	3,107	2,197	4,998
Irrigated Farm Labor (man-years)	166	146	116	76	110
Dryland Farm Labor (man-years)	392	398	404	414	400
Total Crop Labor (man-years)	558	544	520	490	510



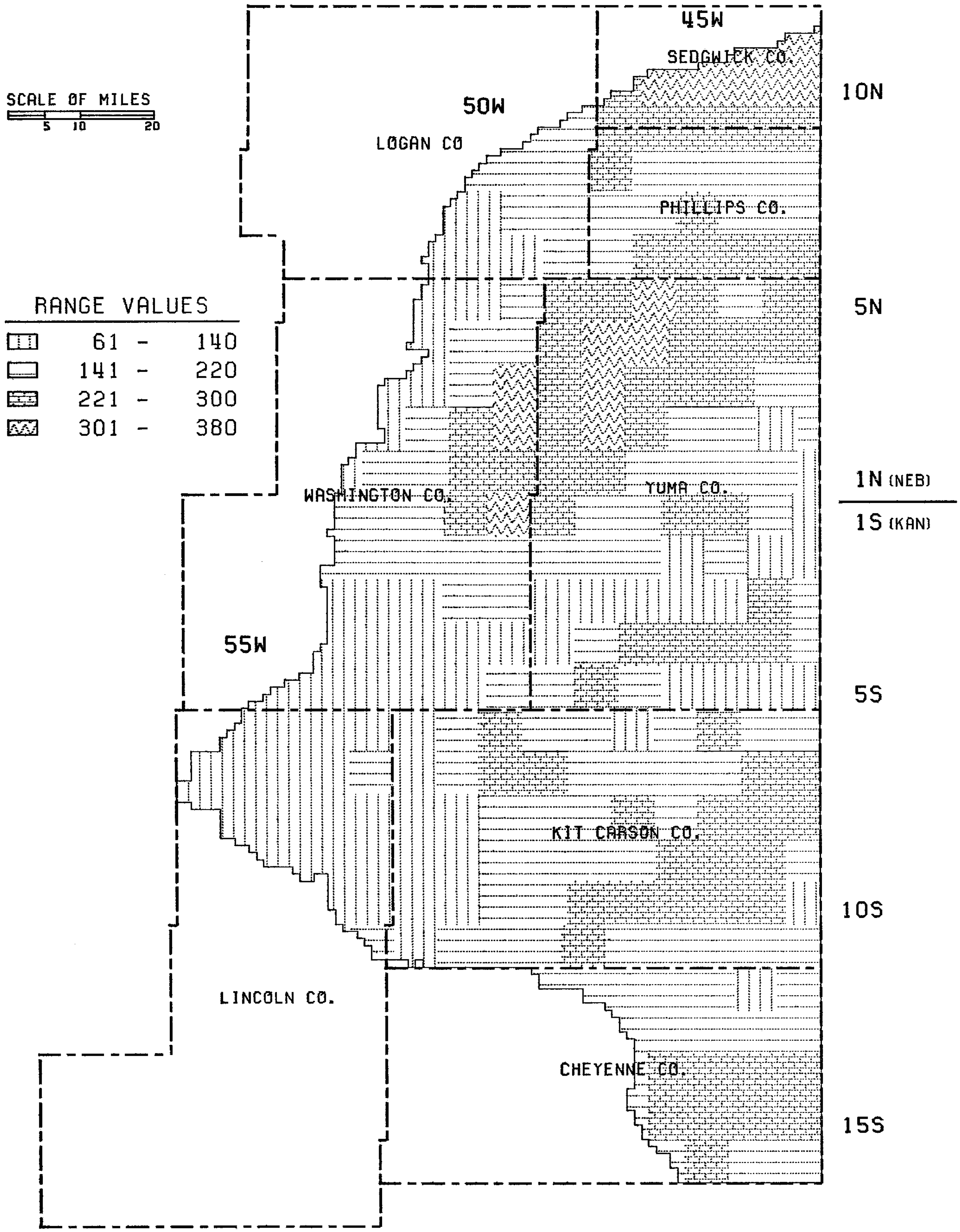
OGALLALA AQUIFER, NORTH-EASTERN COLORADO
TOWNSHIPS BY 2000 SATURATED THICKNESS 2

Figure C1



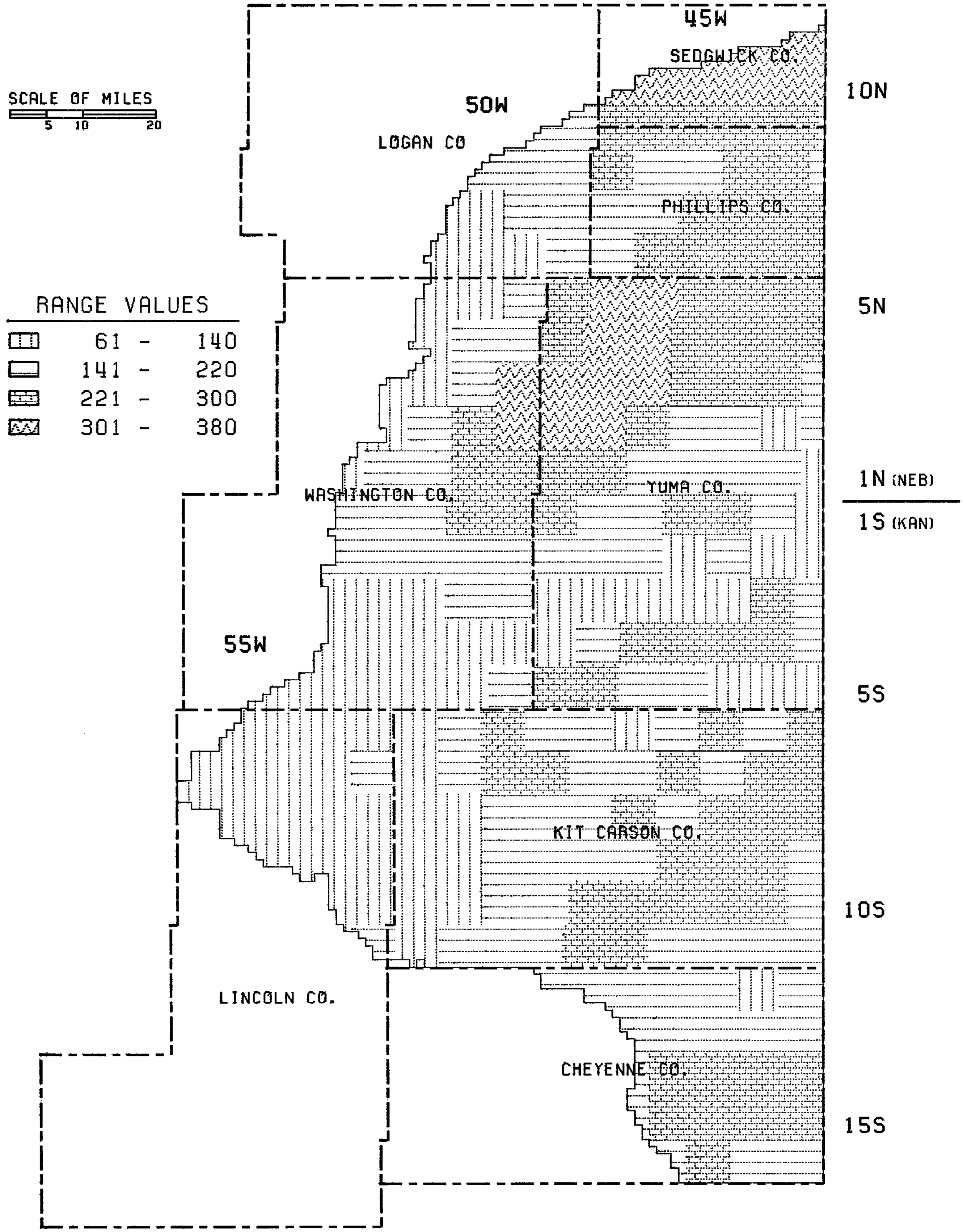
OGALLALA AQUIFER, NORTH-EASTERN COLORADO
TOWNSHIPS BY 2020 SATURATED THICKNESS 2

Figure C2



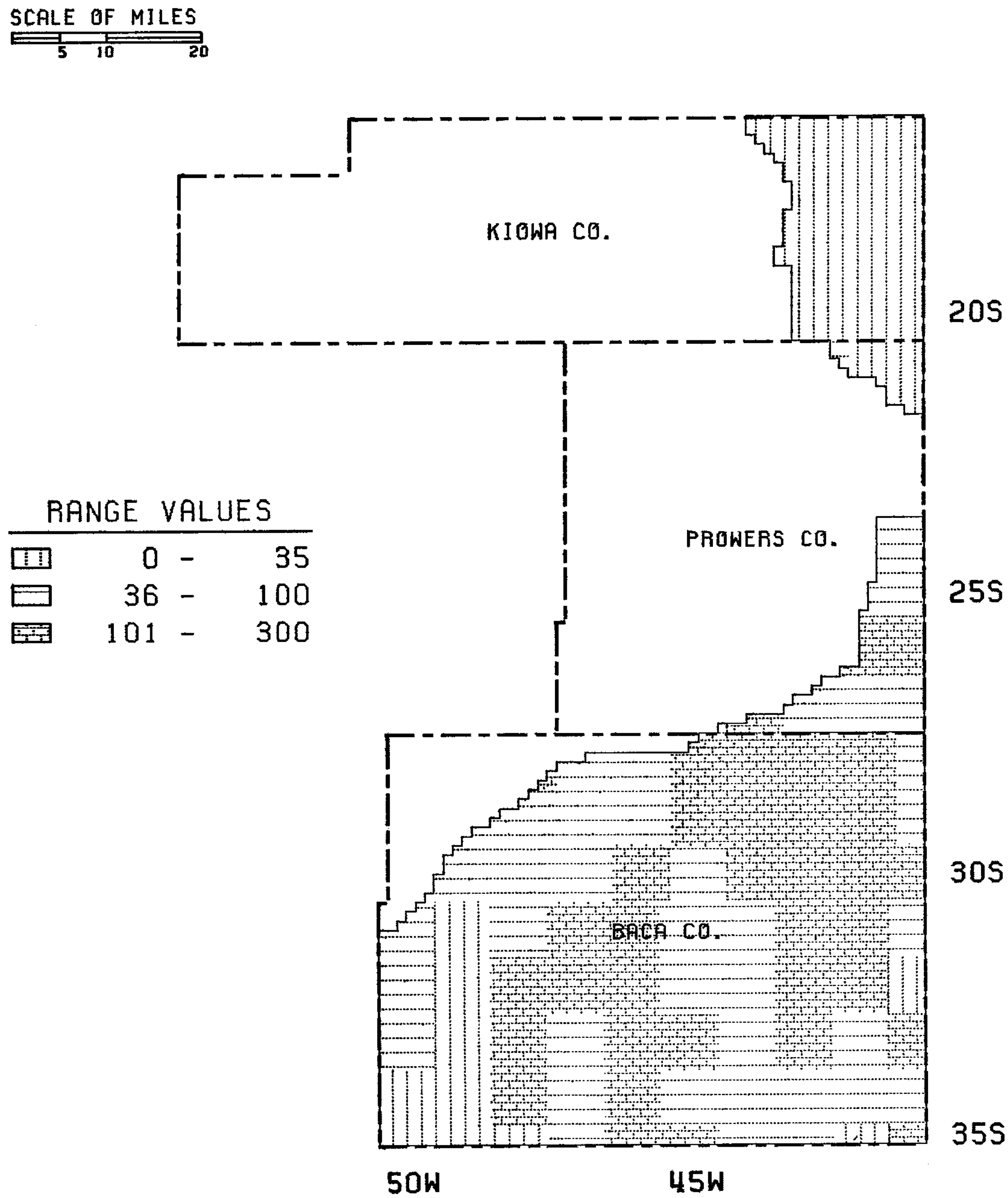
OGALLALA AQUIFER, NORTH-EASTERN COLORADO
TOWNSHIPS BY 2000 DEPTH-ZONES 2

Figure C3



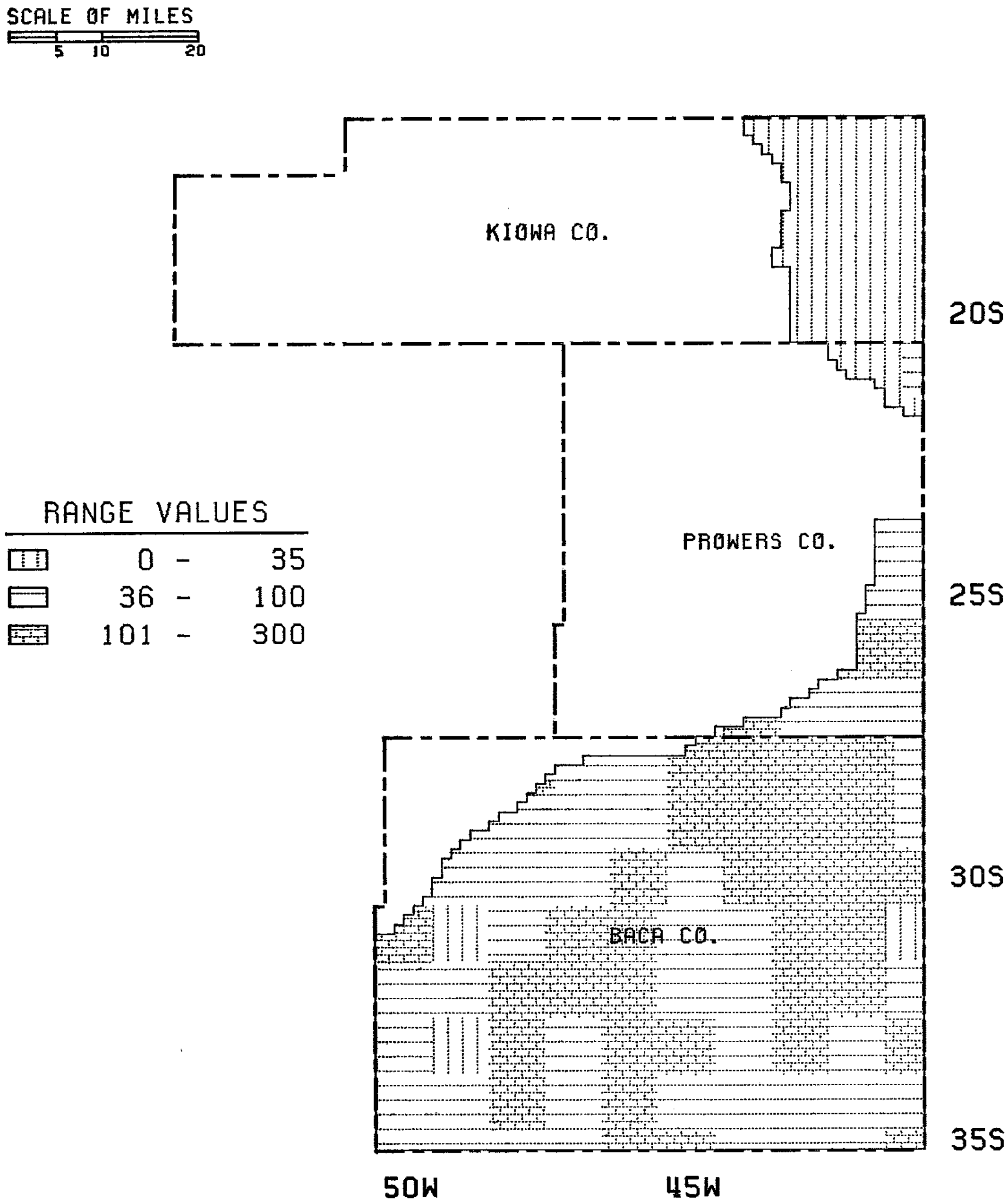
OGALLALA AQUIFER, NORTH-EASTERN COLORADO
TOWNSHIPS BY 2020 DEPTH-ZONES 2

Figure C4

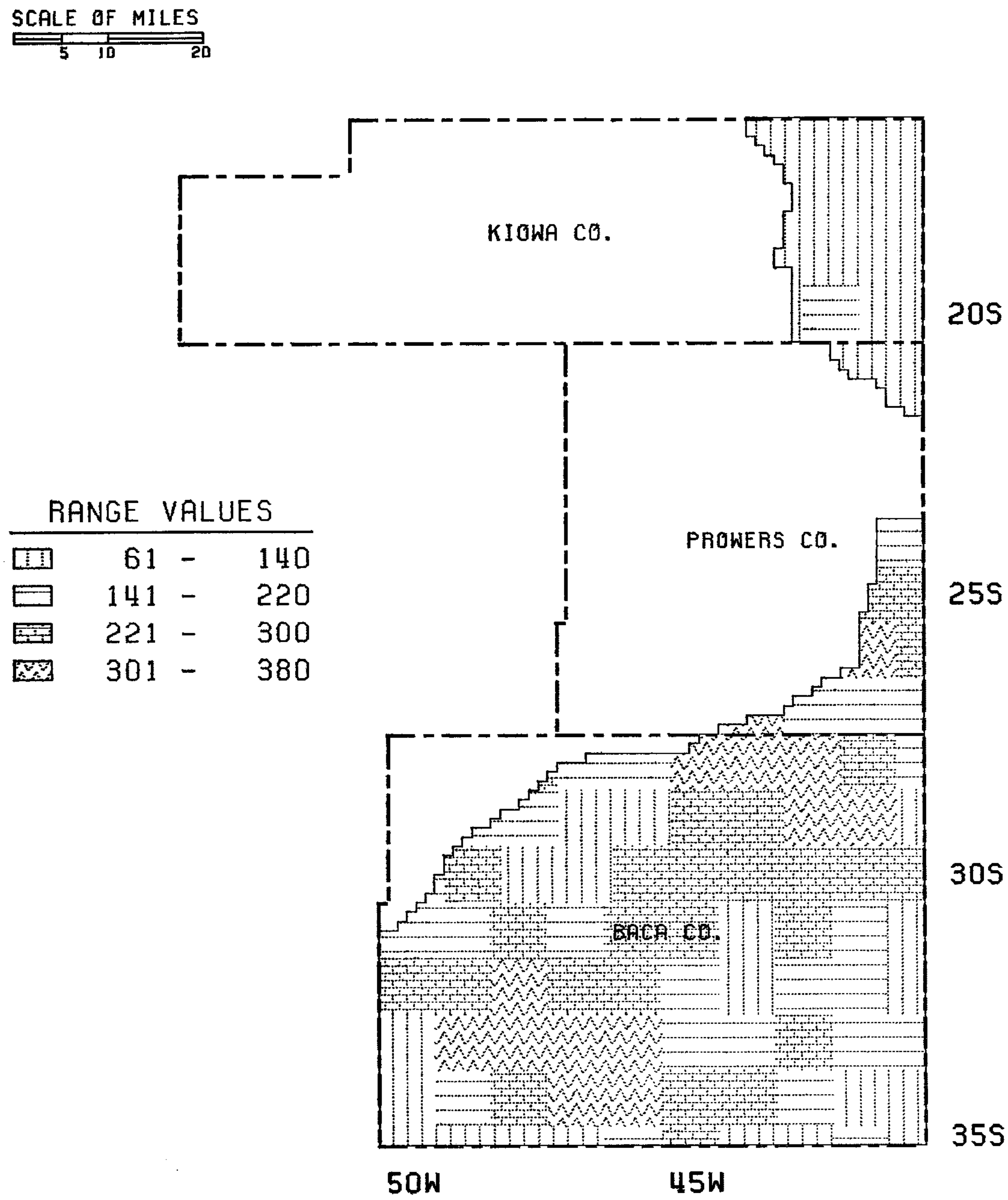


OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2000 SATURATED THICKNESS 2

Figure C5

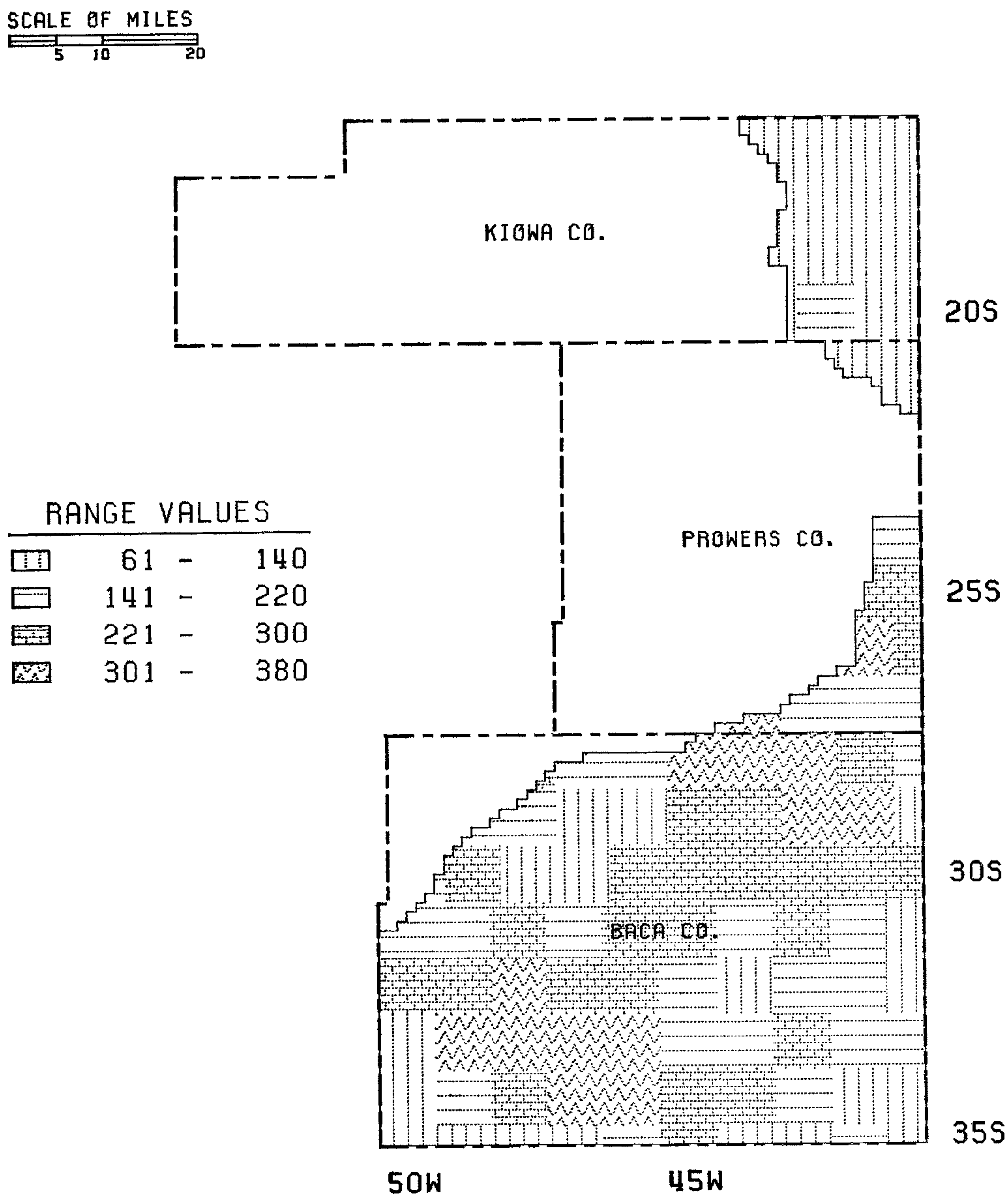


OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2020 SATURATED THICKNESS 2
Figure C6



OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2000 DEPTH-ZONES 2

Figure C7



OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2020 DEPTH-ZONES 2

Figure C8

APPENDIX D -- RESEARCH DETAILS BY SUBAREA, SCENARIOS 5A AND 5B

List of Tables

Table D1 Land Restored to Irrigation with Imported Water and the Amount of Water Required.

	Land Restored (acres)		Water Application Rate (acre ft./acre)		Total Water Required (acre feet)	
Subarea	2000	2020	2000	2020	2000	2020
Scenario 5A						
1	0	0			0	0
2	300	9,200	1.90	1.69	570	15,550
3	12,200	28,800	1.83	1.69	22,330	48,670
4	800	3,200	1.83	1.73	1,460	5,540
5	30,200	90,400	1.88	1.65	56,780	149,160
6	53,500	21,800	1.62	1.45	86,670	31,610
Total	97,000	153,400	1.73	1.64	167,810	250,080
Scenario 5B						
1	0	0			0	0
2	300	3,300	1.34	1.18	400	3,900
3	19,100	19,100	1.28	1.18	24,450	22,540
4	41,300	20,600	1.70	1.38	70,210	28,430
5	39,500	78,900	1.34	1.18	52,930	93,100
6	55,800	25,100	1.14	1.06	63,600	26,600
Total	156,000	147,000	1.36	1.19	211,590	174,570

Table D2 Projected Increases in Irrigated Crop Acreage, Production, and Value of Production, Scenarios 5A and 5B, Subareas 1-6.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Crop Acreage				
Corn	51,340	112,657	98,902	80,097
Sugar Beets	30	86	8	0
Pinto Beans	30	0	3,468	6,103
Sorghum	24,650	1,630	25,663	964
Wheat	0	17,830	0	10,934
Sunflowers	13,350	9,912	13,891	37,353
Alfalfa	7,660	11,285	13,949	11,549
Total	97,000	153,400	156,000	147,000
Crop Production				
Corn (th. bu.)	9,026	21,022	14,942	13,757
Sugar Beets (tons)	580	1,720	137	0
Pinto Beans (th. cwt.)	520	0	494	5,168
Sorghum (th. bu.)	2,292	165	2,354	64
Wheat (th. bu.)	0	1,390	0	854
Sunflowers (th. cwt.)	358	327	328	1,130
Alfalfa (tons)	36,750	54,900	22,117	16,796
Value of Production (in thousands of 1979 dollars)				
Corn	30,859	73,365	50,506	48,566
Sugar Beets	20	64	5	0
Pinto Beans	14	0	904	1,732
Sorghum	6,465	486	6,757	192
Wheat	0	5,089	0	3,108
Sunflowers	4,040	4,116	3,705	14,248
Alfalfa	2,408	3,689	1,461	1,139
Total	43,806	86,809	63,338	68,985

Table D3 Projected Increases in Irrigated Crop Acreage, Production, Value of Production, Scenarios 5A and 5B, Subarea 2.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Crop Acreage				
Corn	215	7,011	238	1,326
Sugar Beets	30	86	8	0
Pinto Beans	30	0	30	332
Wheat	0	0	0	553
Sunflowers	0	1,368	0	824
Alfalfa	25	735	24	265
Total	300	9,200	300	3,300
Crop Production				
Corn (th. bu.)	36	1,311	34	249
Sugar Beets (tons)	580	1,720	137	0
Pinto Beans (cwt.)	520	0	445	5,085
Wheat (th. bu.)	0	0	0	43
Sunflowers (th. cwt.)	0	45	0	27
Alfalfa (tons)	110	3,600	36	398
Value of Production (in thousands of 1979 dollars)				
Corn	120	4,575	115	879
Sugar Beets	20	65	5	0
Pinto Beans	14	0	8	99
Wheat	0	0	0	157
Sunflowers	0	569	0	343
Alfalfa	7	242	2	27
Total	161	5,450	130	1,505

Table D4 Projected Increases in Irrigated Crop Acreage, Production, and Value of Production, Scenarios 5A and 5B, Subarea 3.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Crop Acreage				
Corn	11,340	25,600	16,641	11,871
Pinto Beans	0	0	1,114	1,114
Wheat	0	1,170	0	0
Sunflowers	0	0	0	4,770
Alfalfa	860	2,030	1,345	1,345
Total	12,200	28,800	19,100	19,100
Crop Production				
Corn (th. bu.)	1,894	4,787	2,374	1,975
Pinto Beans (th. cwt.)	0	0	16	16
Wheat (th. bu.)	0	91	0	0
Sunflowers (th. cwt.)	0	0	0	158
Alfalfa (tons)	3,900	10,200	2,018	2,018
Value of Production (in thousands of 1979 dollars)				
Corn	6,288	16,707	8,025	6,972
Pinto Beans (th	0	0	292	318
Wheat	0	334	0	0
Sunflowers	0	0	0	1,986
Alfalfa	257	684	133	137
Total	6,545	17,725	8,450	9,413

Table D5 Projected Increases in Irrigated Crop Acreage, Production, and Value of Production, Scenarios 5A and 5B, Subarea 4.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Crop Acreage				
Corn	725	2,876	36,216	12,545
Sunflowers	0	24	0	5,853
Alfalfa	75	300	5,084	2,202
Total	800	3,200	41,300	20,600
Crop Production				
Corn (th. bu.)	121	537	6,048	2,344
Sunflowers (th. cwt.)	0	0.8	0	193
Alfalfa (tons)	340	1,500	6,347	2,742
Value of Production (in thousands of 1979 dollars)				
Corn	402	1,874	20,439	8,275
Sunflowers	0	10	0	2,437
Alfalfa	22	101	420	186
Total	424	1,985	20,859	10,898

Table D6 Projected Increases in Irrigated Crop Acreage, Production, and Value of Production, Scenarios 5A and 5B, Subarea 5.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Crop Acreage				
Corn	28,080	72,700	34,388	48,988
Pinto Beans	0	0	2,324	4,657
Wheat	0	8,260	0	0
Sunflowers	0	3,070	0	19,703
Alfalfa	2,120	6,370	2,788	5,552
Total	30,200	90,400	39,500	78,900
Crop Production				
Corn (th. bu.)	5,251	13,595	4,957	8,418
Pinto Beans (th. cwt.)	0	0	33	67
Wheat (th. bu.)	0	644	0	0
Sunflowers (th. cwt.)	0	101	0	547
Alfalfa (tons)	9,700	30,300	4,182	8,328
Value of Production (in thousands of 1979 dollars)				
Corn	18,326	47,446	16,754	29,717
Pinto Beans	0	0	604	1,315
Wheat	0	2,358	0	0
Sunflowers	0	1,276	0	6,896
Alfalfa	635	2,037	276	565
Total	18,961	53,117	17,634	38,493

Table D7 Projected Increases in Irrigated Crop Acreage, Production, and Value of Production, Scenarios 5A and 5B, Subarea 6.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Crop Acreage				
Corn	10,980	4,470	11,419	5,367
Sorghum	24,650	1,630	25,663	964
Wheat	0	8,400	0	10,381
Sunflowers	13,350	5,450	13,891	6,203
Alfalfa	4,520	1,850	4,708	2,185
Total	53,500	21,800	55,800	25,100
Crop Production				
Corn (th. bu.)	1,724	792	1,530	771
Sorghum (th. bu.)	2,292	165	2,354	64
Wheat (th. bu.)	0	655	0	811
Sunflowers (th. cwt.)	358	179	328	205
Alfalfa (tons)	22,700	9,300	9,534	3,310
Value of Production (in thousands of 1979 dollars)				
Corn	5,723	2,763	5,173	2,723
Sorghum	6,465	486	6,757	192
Wheat	0	2,397	0	2,951
Sunflowers	4,040	2,261	3,705	2,586
Alfalfa	1,487	625	630	224
Total	17,715	8,532	16,265	8,676

Table D8 Projected Decreases in Dryland Crop Acreage, Production, and Value of Production, Scenarios 5A and 5B, Subareas 1-6.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Crop Acreage Decreases				
Wheat	37,745	64,865	46,103	53,526
Sunflowers	6,417	8,370	7,054	7,512
Corn	8	230	8	83
Sorghum	3,930	1,635	4,185	1,879
Grassland Hay	800	3,200	4,800	4,500
Total	48,900	78,300	62,150	67,500
Crop Production Decreases				
Wheat (th. bu.)	1,138	2,419	1,409	1,970
Sunflowers (th. cwt.)	77	117	85	104
Corn (bu.)	332	9,545	274	3,424
Sorghum (th. bu.)	99	49	105	57
Grassland Hay (tons)	800	3,200	4,800	4,500
Value of Crop Production Decreases (in thousands of 1979 dollars)				
Wheat	3,883	8,702	4,718	7,168
Sunflowers	869	1,477	957	1,325
Corn	1	33	1	12
Sorghum	279	146	303	169
Grassland Hay	52	215	317	305
Total	5,084	10,573	6,296	8,979

Table D9 Projected Decreases in Dryland Crop Acreage, Production, and Value of Production, Scenarios 5A and 5B, Subarea 2.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Crop Acreage Decreases				
Wheat	135	4,140	135	1,485
Sunflowers	7	230	7	82
Corn	8	230	8	83
Total	150	4,600	150	1,650
Crop Production Decreases				
Wheat (th. bu.)	6	192	6	69
Sunflowers (cwt.)	84	3,220	90	1,155
Corn (bu.)	332	9,545	274	3,424
Value of Production Decreases (in thousands of 1979 dollars)				
Wheat	19	705	19	251
Sunflowers	1	41	1	15
Corn	1	3	1	12
Total	21	779	21	278

Table D10 Projected Decreases in Dryland Crop Acreage, Production, and Value of Production, Scenarios 5A and 5B, Subarea 3.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Crop Acreage Decrease				
Wheat	5,795	12,960	9,072	8,595
Sunflowers	305	1,440	478	955
Total	6,100	14,400	9,550	9,550
Crop Production Decrease				
Wheat (th. bu.)	200	512	313	340
Sunflowers (th. cwt.)	4	20	6	13
Value of Crop Production Decrease (in thousands of 1979 dollars)				
Wheat	732	1,720	1,048	1,236
Sunflowers	41	254	65	168
Total	773	1,974	1,113	1,404

Table D11 Projected Decreases in Dryland Crop Acreage, Production, and Value of Production, Scenarios 5A and 5B, Subarea 4.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Crop Acreage Decrease				
Grassland Hay	800	3,200	4,800	4,500
Crop Production Decrease				
Grassland Hay (tons)	800	3,200	4,800	4,500
Value of Production Decrease (in thousands of 1979 dollars)				
Grassland Hay	52	215	317	305

Table D12 Projected Decreases in Dryland Crop Acreage, Production, and Value of Production, Scenarios 5A and 5B, Subarea 5.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Crop Acreage Decrease				
Wheat	14,345	40,680	18,762	35,500
Sunflowers	755	4,520	988	3,950
Total	15,100	45,200	19,750	39,450
Crop Production Decrease				
Wheat (th. bu.)	452	1,485	591	1,296
Sunflowers (th. cwt.)	9	63	12	55
Value of Production Decrease (in thousands of 1979 dollars)				
Wheat	1,518	5,434	1,980	4,717
Sunflowers	102	797	134	697
Total	1,620	6,231	2,114	5,414

Table D13 Projected Decreases in Dryland Crop Acreage, Production, and Value of Production, Scenarios 5A and 5B, Subarea 6.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Crop Acreage Decrease				
Wheat	17,470	7,085	18,134	8,146
Sorghum	3,930	1,635	4,185	1,879
Sunflowers	5,350	2,180	5,581	2,525
Total	26,750	10,900	27,900	12,550
Crop Production Decrease				
Wheat (th. bu.)	480	230	499	265
Sorghum (th. bu.)	99	49	105	57
Sunflowers (th. cwt.)	64	31	67	35
Value of Production Decrease (in thousands of 1979 dollars)				
Wheat	1,614	843	1,671	964
Sorghum	279	385	303	169
Sunflowers	725	146	757	445
Total	2,618	1,374	2,731	1,578

Table D14 Projected Increases in Irrigation Water Use, Scenarios 5A and 5B, Subareas 1-6.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Water Use (acre feet)				
Corn	98,136	193,241	151,940	117,821
Sugar Beets	74	202	11	0
Pinto Beans	36	0	2,687	4,475
Sorghum	28,901	2,133	28,173	490
Wheat	0	13,609	0	9,652
Sunflowers	17,611	11,700	11,807	30,598
Alfalfa	23,052	29,195	16,972	11,534
Total	167,810	250,080	211,590	174,570

Table D15 Projected Increases in Irrigation Water Use, Scenarios 5A and 5B, Subarea 2.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Water Use (acre feet)				
Corn	394	12,036	340	2,232
Sugar Beets	74	202	11	0
Pinto Beans	36	0	23	243
Wheat	0	0	0	355
Sunflowers	0	1,402	0	790
Alfalfa	68	1,874	26	280
Total	572	15,514	400	3,900

Table D16 Projected Increases in Irrigation Water Use, Scenarios 5A and 5B, Subarea 3.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Water Use (acre feet)				
Corn	20,223	43,093	22,242	16,209
Pinto Beans	0	0	863	817
Wheat	0	682	0	0
Sunflowers	0	0	0	4,214
Alfalfa	2,207	4,940	1,345	1,300
Total	22,430	48,715	24,450	22,540

Table D17 Projected Increases in Irrigation Water Use, Scenarios 5A and 5B, Subarea 4.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Water Use (acre feet)				
Corn	1,293	4,841	65,126	21,131
Sunflowers	0	21	0	5,170
Alfalfa	177	675	5,084	2,129
Total	1,470	5,537	70,210	28,430

Table D18 Projected Increases in Irrigation Water Use, Scenarios 5A and 5B, Subarea 5.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Water Use (acre feet)				
Corn	51,246	124,196	48,341	71,183
Pinto Beans	0	0	1,801	3,415
Wheat	0	5,507	0	0
Sunflowers	0	3,147	0	13,135
Alfalfa	5,759	15,925	2,788	5,367
Total	57,005	148,775	52,930	93,100

Table D19 Projected Increases in Irrigated Water Use, Scenarios 5A and 5B, Subarea 6.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Water Use (acre feet)				
Corn	24,980	9,312	15,891	7,066
Sorghum	28,964	2,133	28,178	490
Wheat	0	7,420	0	9,297
Sunflowers	17,911	7,130	11,807	7,289
Alfalfa	14,841	5,781	7,729	2,458
Total	86,696	31,776	63,600	26,600

Table D20 Changes in Projected Resource Use, Scenarios 5A and 5B, Subareas 1-6.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Total Energy Use for Irrigation (billion BTU)	96.2	134.8	121.3	94.9
Electricity Use for Irrigation (million KWH)	28.2	39.5	35.6	27.9
Irrigation Pumps	757	1,187	1,218	1,144
Farm Consumption of:				
Diesel Fuel (1000 gal.)	590	1,011	1,159	972
Gasoline (1000 gal.)	170	290	293	249
NH_3 (tons)	7,413	16,162	12,436	12,920
Other Fertilizer (tons)	6,777	14,410	9,720	7,563
Irrigated Farm Labor (man-years)	203.2	335.3	284.7	256.4
Dryland Farm Labor (man-years)	-38.9	-61.9	-48.4	-53.0
Total Crop Labor (man-years)	164.3	273.4	236.3	203.4

Table D21 Changes in Projected Resource Use, Scenarios 5A and 5B, Subarea 2.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Total Energy Use for Irrigation (billion BTU)	0.3	8.2	0.2	2.1
Electricity Use for Irrigation (million KWH)	0.1	2.4	0.1	0.6
Irrigation Pumps	2	61	2	22
Farm Consumption of:				
Diesel Fuel (1000 gal.)	3	68	2	20
Gasoline (1000 gal.)	1	18	1	5
NH_3 (tons)	25	976	27	231
Other Fertilizer (tons)	27	807	21	147
Irrigated Farm Labor (man-years)	0.8	21.7	0.6	5.6
Dryland Farm Labor (man-years)	-0.1	-3.7	-0.1	-1.3
Total Crop Labor (man-years)	0.7	18.0	0.5	4.3

Table D22 Changes in Projected Resource Use, Scenarios 5A and 5B, Subarea 3.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Total Energy Use for Irrigation (billion BTU)	13.0	26.3	14.0	12.1
Electricity Use for Irrigation (million KWH)	3.8	7.7	4.1	3.6
Irrigation Pumps	95	225	149	149
Farm Consumption of:				
Diesel Fuel (1000 gal.)	80	182	126	100
Gasoline (1000 gal.)	25	59	38	34
NH_3 (tons)	1,280	3,697	1,603	1,561
Other Fertilizer (tons)	1,147	2,996	1,100	772
Irrigated Farm Labor (man-years)	25.4	58.8	37.1	34.2
Dryland Farm Labor (man-years)	-4.9	-11.5	-7.6	-7.6
Total Crop Labor (man-years)	20.5	47.3	29.5	26.6

Table D23 Changes in Projected Resource Use, Scenarios 5A and 5B, Subarea 4.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Total Energy Use for Irrigation (billion BTU)	0.7	3.1	40.2	15.3
Electricity Use for Irrigation (million KWH)	0.2	0.9	11.8	4.5
Irrigation Pumps	6	25	323	161
Farm Consumption of:				
Diesel Fuel (1000 gal.)	4	14	361	155
Gasoline (1000 gal.)	2	6	89	38
NH_3 (tons)	93	418	4,653	2,450
Other Fertilizer (tons)	78	354	4,635	1,738
Irrigated Farm Labor (man-years)	1.7	6.7	82.9	37.4
Dryland Farm Labor (man-years)	-0.4	-1.8	-2.6	-2.5
Total Crop Labor (man-years)	1.3	4.9	80.3	34.9

Table D24 Changes in Projected Resource Use, Scenarios 5A and 5B, Subarea 5.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Total Energy Use for Irrigation (billion BTU)	32.4	80.2	30.4	50.2
Electricity Use for Irrigation (million KWH)	9.5	23.5	8.9	14.7
Irrigation Pumps	236	706	308	616
Farm Consumption of:				
Diesel Fuel (1000 gal.)	238	653	312	553
Gasoline (1000 gal.)	63	177	80	137
NH_3 (tons)	3,170	9,643	3,312	7,255
Other Fertilizer (tons)	2,839	8,879	2,274	3,874
Irrigated Farm Labor (man-years)	74.7	210.4	76.4	144.3
Dryland Farm Labor (man-years)	-12.1	-36.2	-15.8	-31.6
Irrigated Farm Labor (man-years)	62.6	174.2	60.9	112.7

Table D25 Changes in Projected Resource Use, Scenarios 5A and 5B, Subarea 6.

	Scenario 5A		Scenario 5B	
	2000	2020	2000	2020
Total Energy Use for Irrigation (billion BTU)	49.8	17.1	36.5	15.2
Electricity Use for Irrigation (million KWH)	14.6	5.0	10.7	4.5
Irrigation Pumps	418	170	436	196
Farm Consumption of:				
Diesel Fuel (1000 gal.)	266	93	358	144
Gasoline (1000 gal.)	80	30	85	35
NH_3 (tons)	2,845	1,428	2,841	1,423
Other Fertilizer (tons)	2,686	1,374	1,690	1,032
Irrigated Farm Labor (man-years)	100.6	37.7	87.4	34.9
Dryland Farm Labor (man-years)	-21.4	-8.7	-22.3	-10.0
Total Crop Labor (man-years)	79.2	29.0	65.1	24.9

APPENDIX E -- RESEARCH DETAILS BY SUBAREA, SCENARIO 6

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Table E1 Projected Returns to Land and Management, Scenario 6.

Subarea	Year	Returns to Land and Management (Dollars) Irrigated Crops	Dryland Crops	All Crops
1	1979	1,308,000	3,168,000	4,476,000
	1985	94,000	2,614,000	2,708,000
	1990	-633,000	2,525,000	1,892,000
	2000	-363,000	2,800,000	2,437,000
	2020	0	3,472,000	3,472,000
2	1979	6,899,000	12,992,000	19,891,000
	1985	1,880,000	11,151,000	13,031,000
	1990	-484,000	10,060,000	9,576,000
	2000	-960,000	11,385,000	10,425,000
	2020	0	14,538,000	14,538,000
3	1979	10,590,000	22,100,000	32,690,000
	1985	1,047,000	14,592,000	15,639,000
	1990	-1,691,000	11,650,000	9,959,000
	2000	-1,313,000	13,211,000	11,898,000
	2020	0	18,219,000	18,219,000
4	1979	11,681,000	1,280,000	12,961,000
	1985	-451,000	922,000	507,000
	1990	-5,913,000	630,000	-5,283,000
	2000	-3,602,000	742,000	-2,860,000
	2020	0	1,089,000	1,089,000
5	1979	16,485,000	11,072,000	27,557,000
	1985	-423,000	7,152,000	6,729,000
	1990	-3,911,000	5,862,000	1,951,000
	2000	-2,523,000	7,479,000	4,956,000
	2020	0	11,170,000	11,170,000
6	1979	1,818,000	5,874,000	7,692,000
	1985	-3,985,000	4,224,000	239,000
	1990	-4,108,000	4,262,000	154,000
	2000	-2,236,000	6,452,000	4,216,000
	2020	0	11,904,000	11,904,000
1-6	1979	48,781,000	56,486,000	105,267,000
	1985	-1,802,000	40,655,000	38,853,000
	1990	-16,740,000	34,989,000	18,249,000
	2000	-10,997,000	42,069,000	31,072,000
	2020	0	60,392,000	60,392,000

Table E2 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 6, Subareas 1-6.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	433,000	273,100	0	0	0
Sorghum	32,300	600	0	0	0
Wheat	41,000	158,900	169,300	40,200	0
Sunflowers	0	2,000	38,900	19,200	0
Sugar Beets	22,500	15,000	8,800	2,300	0
Pinto Beans	22,500	20,900	18,000	10,500	0
Alfalfa	47,900	0	0	0	0
Total	599,200	470,500	235,000	72,200	0
Crop Production					
Corn (mil. bu.)	56.0	37.1	0	0	0
Sorghum (mil. bu.)	2.7	0.05	0	0	0
Wheat (mil. bu.)	1.9	7.7	9.4	3.0	0
Sunflowers (th. cwt.)	0	36.4	714.1	303.7	0
Sugar Beets (th. tons)	390.0	266.8	161.4	43.7	0
Pinto Beans (th. cwt.)	366.6	340.9	277.0	163.2	0
Alfalfa (th. tons)	179.3	0	0	0	0
Value of Production (in millions of 1979 dollars)					
Corn	145.7	96.5	0	0	0
Sorghum	5.9	0.1	0	0	0
Wheat	6.8	27.1	33.3	10.7	0
Sunflowers	0	0.4	7.2	3.1	0
Sugar Beets	11.7	8.1	4.8	1.3	0
Pinto Beans	8.9	8.1	6.6	4.0	0
Alfalfa	9.8	0	0	0	0
Total	188.8	140.3	51.9	19.1	0

Table E3 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 6, Subarea 1.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	14,500	12,400	0	0	0
Wheat	0	2,700	2,200	0	0
Alfalfa	1,500	0	0	0	0
Total	16,000	15,100	2,200	0	0
Crop Production					
Corn (mil. bu.)	1.9	1.7	0	0	0
Wheat (mil. bu.)	0	0.1	0.1	0	0
Alfalfa (th. tons)	5.6	0	0	0	0
Value of Production (in millions of 1979 dollars)					
Corn	4.9	4.4	0	0	0
Wheat	0	0.5	0.4	0	0
Alfalfa	0.3	0	0	0	0
Total	5.9	4.9	0.4	0	0

Table E4 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 6, Subarea 2.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	45,300	26,600	0	0	0
Wheat	0	16,800	20,100	6,100	0
Sunflowers	0	0	0	1,100	0
Sugar Beets	6,300	6,300	5,500	2,100	0
Pinto Beans	6,300	6,300	6,100	4,400	0
Alfalfa	5,100	0	0	0	0
Total	63,000	56,000	31,700	13,700	0
Crop Production					
Corn (mil. bu.)	5.9	3.6	0	0	0
Wheat (mil. bu.)	0	0.8	1.0	0.3	0
Sunflowers (th. cwt.)	0	0	0	15.9	0
Sugar Beets (th. tons)	119.7	118.4	104.8	40.4	0
Pinto Beans (th. cwt.)	107.1	106.0	103.8	73.7	0
Alfalfa (th. tons)	18.9	0	0	0	0
Value of Production (in millions of 1979 dollars)					
Corn	15.3	9.4	0	0	0
Wheat	0	2.9	3.6	1.2	0
Sunflowers	0	0	0	0.2	0
Sugar Beets	3.6	3.6	3.1	1.2	0
Pinto Beans	2.6	2.5	2.5	1.8	0
Alfalfa	1.0	0	0	0	0
Total	22.5	18.4	9.2	4.4	0

Table E5 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 6, Subarea 3.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	89,400	53,200	0	0	0
Wheat	0	29,100	42,000	11,700	0
Sunflowers	0	0	1,700	0	0
Sugar Beets	6,400	4,200	1,400	0	0
Pinto Beans	6,400	5,500	4,600	2,400	0
Alfalfa	7,800	0	0	0	0
Total	110,000	92,000	49,700	14,100	0
Crop Production					
Corn (mil. bu.)	11.6	7.2	0	0	0
Wheat (mil. bu.)	0	1.5	2.5	1.0	0
Sunflowers (th. cwt.)	0	0	35.6	0	0
Sugar Beets (th. tons)	109.1	72.2	24.0	0	0
Pinto Beans (th. cwt.)	102.7	88.6	71.0	36.6	0
Alfalfa (th. tons)	28.9	0	0	0	0
Value of Production (in millions of 1979 dollars)					
Corn	30.0	18.8	0	0	0
Wheat	0	5.1	8.8	3.6	0
Sunflowers	0	0	0.4	0	0
Sugar Beets	3.3	2.2	0.7	0	0
Pinto Beans	2.5	2.1	1.7	0.9	0
Alfalfa	1.6	0	0	0	0
Total	37.4	28.2	11.6	4.5	0

Table E6 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 6, Subarea 4.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	127,000	134,000	0	0	0
Wheat	0	0	40,500	4,800	0
Sunflowers	0	0	13,500	1,600	0
Alfalfa	13,000	0	0	0	0
Total	140,000	134,000	54,000	6,400	0
Crop Production					
Corn (mil. bu.)	16.5	18.2	0	0	0
Wheat (mil. bu.)	0	0	2.2	0.3	0
Sunflowers (th. cwt.)	0	0	283.5	36.0	0
Alfalfa (th. tons)	49.3	0	0	0	0
Value of Production (in millions of 1979 dollars)					
Corn	43.0	47.3	0	0	0
Wheat	0	0	7.7	1.0	0
Sunflowers	0	0	2.8	0.4	0
Alfalfa	2.7	0	0	0	0
Total	45.7	47.3	10.5	1.4	0

Table E7 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 6, Subarea 5.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	135,600	46,100	0	0	0
Wheat	0	84,500	61,900	16,900	0
Sunflowers	0	0	6,500	7,400	0
Sugar Beets	9,800	4,500	1,900	200	0
Pinto Beans	9,800	9,100	7,300	3,700	0
Alfalfa	11,800	0	0	0	0
Total	167,000	144,200	77,600	28,200	0
Crop Production					
Corn (mil. bu.)	17.6	6.3	0	0	0
Wheat (mil. bu.)	0	4.3	3.5	1.4	0
Sunflowers (th. cwt.)	0	0	137.5	115.6	0
Sugar Beets (th. tons)	161.2	76.2	32.6	3.3	0
Pinto Beans (th. cwt.)	156.8	146.3	102.2	52.9	0
Alfalfa (th. tons)	44.1	0	0	0	0
Value of Production (in millions of 1979 dollars)					
Corn	45.9	16.3	0	0	0
Wheat	0	14.9	12.3	4.8	0
Sunflowers	0	0	1.4	1.1	0
Sugar Beets	4.8	2.3	1.0	0.1	0
Pinto Beans	3.8	3.5	2.4	1.3	0
Alfalfa	2.4	0	0	0	0
Total	56.9	37.0	17.1	7.3	0

Table E8 Projected Irrigated Crop Acreage, Production, and Value of Production, Scenario 6, Subarea 6.

	1979	1985	1990	2000	2020
Crop Acreage					
Corn	21,200	800	0	0	0
Sorghum	32,300	600	0	0	0
Wheat	41,000	25,800	2,600	700	0
Sunflowers	0	2,000	17,200	9,100	0
Alfalfa	8,700	0	0	0	0
Total	103,200	29,200	19,800	9,800	0
Crop Production					
Corn (mil. bu.)	2.5	0.1	0	0	0
Sorghum (mil. bu.)	2.7	0.05	0	0	0
Wheat (mil. bu.)	1.9	1.0	0.1	0.04	0
Sunflowers (th. cwt.)	0	36.4	257.9	136.2	0
Alfalfa (th. tons)	32.5	0	0	0	0
Value of Production (in millions of 1979 dollars)					
Corn	6.6	0.3	0	0	0
Sorghum	5.9	0.1	0	0	0
Wheat	6.8	3.7	0.5	0.1	0
Sunflowers	0	0.4	2.6	1.4	0
Alfalfa	1.8	0	0	0	0
Total	21.1	4.5	3.1	1.5	0

Table E9 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 6, Subareas 1-6.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	1,470,000	1,541,000	1,643,300	1,724,000	1,633,600
Sorghum	191,700	176,900	152,600	130,100	81,200
Sunflowers	0	0	0	0	172,200
Corn	12,600	12,500	12,700	13,200	14,500
Grass Hay	8,000	19,100	19,600	19,600	16,500
Total	1,683,000	1,750,300	1,828,200	1,886,900	1,918,000
Crop Production					
Wheat (mil. bu.)	35.0	38.7	43.6	49.2	51.4
Sorghum (mil. bu.)	3.8	3.8	3.3	3.0	2.0
Sunflowers (mil. cwt.)	0	0	0	0	2.0
Corn (th. bu.)	376.5	389.3	404.8	437.0	522.9
Grass Hay (th. tons)	8.0	19.1	19.6	19.6	16.5
Value of Production (in millions of 1979 dollars)					
Wheat	122.3	135.7	152.7	172.0	179.8
Sorghum	8.5	8.2	7.4	5.3	4.5
Sunflowers	0	0	0	0	19.9
Corn	1.0	1.0	1.0	1.1	1.4
Grass Hay	0.4	1.0	1.0	1.1	0.9
Total	132.2	145.9	162.1	179.5	206.5

Table E10 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 6, Subarea 1.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	45,600	46,000	52,400	53,400	50,400
Sunflowers	0	0	0	0	2,800
Corn	2,400	2,400	2,500	2,600	2,800
Total	48,000	48,400	54,900	56,000	56,000
Crop Production					
Wheat (mil. bu.)	1.5	1.5	1.8	2.0	2.0
Sunflowers (th. cwt.)	0	0	0	0	32.5
Corn (th. bu.)	72.0	74.4	78.7	86.5	100.8
Value of Production (in millions of 1979 dollars)					
Wheat	5.1	5.4	6.4	6.9	7.1
Sunflowers	0	0	0	0	0.3
Corn	0.2	0.2	0.2	0.2	0.3
Total	5.3	5.6	6.6	7.1	7.7

Table E11 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 6, Subarea 2.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	192,800	196,400	208,500	217,100	211,100
Sunflowers	0	0	0	0	11,700
Corn	10,200	10,100	10,200	10,600	11,700
Total	203,000	206,500	218,700	227,700	234,500
Crop Production					
Wheat (mil. bu.)	6.2	6.6	7.3	8.0	8.4
Sunflowers (th. cwt.)	0	0	0	0	136.0
Corn (th. bu.)	304.5	314.9	326.1	350.5	422.1
Value of Production (in millions of 1979 dollars)					
Wheat	21.6	23.1	25.5	28.1	29.5
Sunflowers	0	0	0	0	1.4
Corn	0.8	0.8	0.8	0.9	1.1
Total	22.4	23.9	26.3	29.0	32.0

Table E12 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 6, Subarea 3.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	524,900	533,300	554,100	570,500	546,600
Sorghum	27,600	28,000	28,400	30,000	0
Sunflowers	0	0	0	0	60,700
Total	552,500	561,300	582,500	600,500	607,300
Crop Production					
Wheat (mil. bu.)	13.1	14.1	15.5	17.1	17.8
Sorghum (mil. bu.)	0.6	0.6	0.6	0.7	0
Sunflowers (th. cwt.)	0	0	0	0	698.0
Value of Production (in millions of 1979 dollars)					
Wheat	45.9	49.6	54.3	59.9	62.2
Sorghum	1.2	1.3	1.4	1.5	0
Sunflowers	0	0	0	0	7.0
Total	47.1	50.9	55.7	61.4	69.2

Table E13 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 6, Subarea 4.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	36,000	32,300	32,300	33,000	33,000
Grass Hay	8,000	16,200	16,200	16,500	16,500
Total	44,000	48,500	48,500	49,500	49,500
Crop Production					
Wheat (mil. bu.)	0.8	0.8	0.8	0.9	1.0
Grass Hay (th. tons)	8.0	16.2	16.2	16.5	16.5
Value of Production (in millions of 1979 dollars)					
Wheat	2.8	2.6	2.8	3.1	3.5
Grass Hay	0.4	0.8	0.8	0.9	0.9
Total	3.2	3.4	3.6	4.0	4.4

Table E14 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 6, Subarea 5.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	328,700	340,000	372,500	395,600	386,700
Sorghum	17,300	17,600	18,300	19,900	0
Sunflowers	0	0	0	0	42,900
Total	346,000	357,600	390,800	415,500	429,600
Crop Production					
Wheat (mil. bu.)	7.2	8.0	9.3	10.7	11.6
Sorghum (mil. bu.)	0.3	0.4	0.4	0.5	0
Sunflowers (th. cwt.)	0	0	0	0	498.4
Value of Production (in millions of 1979 dollars)					
Wheat	25.3	28.1	32.6	37.4	40.6
Sorghum	0.8	0.8	0.9	1.0	0
Sunflowers	0	0	0	0	5.0
Total	26.1	28.9	33.5	38.4	45.6

Table E15 Projected Dryland Crop Acreage, Production, and Value of Production, Scenario 6, Subarea 6.

	1979	1985	1990	2000	2020
Crop Acreage					
Wheat	342,700	393,800	423,500	454,400	405,800
Sorghum	146,800	131,300	105,900	80,200	81,200
Sunflowers	0	0	0	0	54,100
Grass Hay	0	2,900	3,400	3,100	0
Total	489,500	528,000	532,800	537,700	541,100
Crop Production					
Wheat (mil. bu.)	6.2	7.7	8.9	10.5	10.6
Sorghum (mil. bu.)	2.9	2.8	2.3	1.8	2.0
Sunflowers (th. cwt.)	0	0	0	0	622.2
Grass Hay (th. tons)	0	2.9	3.4	3.1	0
Value of Production (in millions of 1979 dollars)					
Wheat	21.6	26.9	31.1	36.6	36.9
Sorghum	6.5	6.1	5.1	4.1	4.5
Sunflowers	0	0	0	0	6.2
Grass Hay	0	0.2	0.2	0.2	0
Total	28.1	33.2	36.4	40.9	47.6

Table E16 Projected Irrigation Water Use, Scenario 6, Subareas 1-6.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	841,990	526,860	0	0	0
Wheat	41,610	110,560	126,920	29,480	0
Sugar Beets	52,900	37,890	21,910	6,020	0
Pinto Beans	32,710	27,910	20,840	11,760	0
Sunflowers	0	2,360	32,370	9,130	0
Alfalfa	135,402	0	0	0	0
Sorghum	43,580	640	0	0	0
Total	1,148,210	706,220	202,040	56,390	0
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.3	23.2	0	0	0
Wheat	12.2	8.3	9.0	8.8	0
Sugar Beets	28.2	30.3	29.9	31.4	0
Pinto Beans	17.4	16.0	13.9	13.4	0
Sunflowers	0	14.2	10.0	5.7	0
Alfalfa	33.9	0	0	0	0
Sorghum	16.2	12.8	0	0	0
All Crops	23.0	18.0	10.3	9.4	0
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.17	0	0	0
Wheat (bu.)	0.26	0.17	0.16	0.12	0
Sugar Beets (ton)	1.63	1.70	1.63	1.65	0
Pinto Beans (cwt.)	1.07	0.98	0.90	0.86	0
Sunflowers (cwt.)	0	0.78	0.54	0.36	0
Alfalfa (ton)	9.06	0	0	0	0
Sorghum (bu.)	0.19	0.17	0	0	0

Table E17 Projected Irrigation Water Use, Scenario 6, Subarea 1.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	27,810	23,740	0	0	0
Wheat	0	1,810	1,460	0	0
Alfalfa	3,740	0	0	0	0
Total	31,550	25,550	1,460	0	0
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.0	23.0	0	0	0
Wheat	0	8.0	8.0	0	0
Alfalfa	30.2	0	0	0	0
All Crops	23.7	20.5	8.0	0	0
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.17	0	0	0
Wheat (bu.)	0	0.15	0.16	0	0
Alfalfa (ton)	8.04	0	0	0	0

Table E18 Projected Irrigation Water Use, Scenario 6, Subarea 2.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	87,980	52,580	0	0	0
Wheat	0	12,000	13,120	4,090	0
Sunflowers	0	0	0	360	0
Sugar Beets	16,800	16,160	13,590	5,520	0
Pinto Beans	9,450	8,120	7,850	5,320	0
Alfalfa	14,630	0	0	0	0
Total	128,860	88,860	34,550	15,290	0
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.3	23.7	0	0	0
Wheat	0	8.6	7.8	8.0	0
Sunflowers	0	0	0	4.0	0
Sugar Beets	32.0	30.9	29.9	32.0	0
Pinto Beans	18.0	15.5	15.3	14.5	0
Alfalfa	34.8	0	0	0	0
All Crops	24.5	19.0	13.1	13.4	0
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.17	0	0	0
Wheat (bu.)	0	0.17	0.15	0.15	0
Sunflowers (cwt.)	0	0	0	0.27	0
Sugar Beets (ton)	1.68	1.64	1.56	1.64	0
Pinto Beans (cwt.)	1.06	0.92	0.91	0.86	0
Alfalfa (ton)	9.29	0	0	0	0

Table E19 Projected Irrigation Water Use, Scenario 6, Subarea 3.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	170,630	102,010	0	0	0
Wheat	0	19,380	27,980	7,790	0
Sunflowers	0	0	1,700	0	0
Sugar Beets	14,980	9,850	3,260	0	0
Pinto Beans	8,560	7,300	5,520	2,660	0
Alfalfa	20,350	0	0	0	0
Total	214,520	138,540	38,460	10,450	0
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.0	23.0	0	0	0
Wheat	0	8.0	8.0	8.0	0
Sunflowers	0	0	12.0	0	0
Sugar Beets	28.0	28.0	28.0	0	0
Pinto Beans	16.0	15.8	14.5	13.3	0
Alfalfa	31.7	0	0	0	0
All Crops	23.5	18.1	9.3	8.9	0
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.17	0	0	0
Wheat (bu.)	0	0.16	0.13	0.09	0
Sunflowers (cwt.)	0	0	0.57	0	0
Sugar Beets (ton)	1.65	1.64	1.63	0	0
Pinto Beans (cwt.)	1.00	1.00	0.93	0.87	0
Alfalfa (ton)	8.45	0	0	0	0

Table E20 Projected Irrigation Water Use, Scenario 6, Subarea 4.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	243,680	256,620	0	0	0
Wheat	0	0	43,880	5,200	0
Sunflowers	0	0	13,500	1,600	0
Alfalfa	33,060	0	0	0	0
Total	276,740	256,620	57,380	6,800	0
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.0	23.0	0	0	0
Wheat	0	0	13.0	13.0	0
Sunflowers	0	0	12.0	12.0	0
Alfalfa	30.2	0	0	0	0
All Crops	23.7	23.0	12.8	12.8	0
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.17	0	0	0
Wheat (bu.)	0	0	0.24	0.22	0
Sunflowers (cwt.)	0	0	0.57	0.53	0
Alfalfa (ton)	8.04	0	0	0	0

Table E21 Projected Irrigation Water Use, Scenario 6, Subarea 5.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	262,400	89,860	0	0	0
Wheat	0	58,570	37,880	11,610	0
Sunflowers	0	0	7,620	3,150	0
Sugar Beets	21,120	11,880	5,060	500	0
Pinto Beans	14,700	12,490	7,480	3,780	0
Alfalfa	34,150	0	0	0	0
Total	332,370	172,800	58,040	19,040	0
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	23.2	23.3	0	0	0
Wheat	0	8.3	7.3	8.2	0
Sunflowers	0	0	14.0	5.1	0
Sugar Beets	25.9	32.0	32.0	32.1	0
Pinto Beans	18.0	16.5	12.2	12.2	0
Alfalfa	34.8	0	0	0	0
All Crops	23.8	14.4	9.0	0	0
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.18	0.17	0	0	0
Wheat (bu.)	0	0.17	0.13	0.10	0
Sunflowers (cwt.)	0	0	0.67	0.33	0
Sugar Beets (ton)	1.57	1.87	1.86	1.83	0
Pinto Beans (cwt.)	1.13	1.02	0.88	0.86	0
Alfalfa (ton)	9.28	0	0	0	0

Table E22 Projected Irrigation Water Use, Scenario 6, Subarea 6.

	1979	1985	1990	2000	2020
Water Use (acre feet)					
Corn	49,490	2,050	0	0	0
Sorghum	43,580	640	0	0	0
Wheat	41,610	18,800	2,600	790	0
Sunflowers	0	2,360	9,550	4,020	0
Alfalfa	29,490	0	0	0	0
Total	164,170	23,850	12,150	4,810	0
Water Use Per Irrigated Acre (acre inch/acre)					
Corn	28.0	32.0	0	0	0
Sorghum	16.2	14.0	0	0	0
Wheat	12.2	8.7	12.0	14.0	0
Sunflowers	0	14.3	6.7	5.3	0
Alfalfa	40.8	0	0	0	0
All Crops	19.1	9.8	7.4	5.9	0
Water Use Per Unit of Yield (acre inch/unit)					
Corn (bu.)	0.23	0.25	0	0	0
Sorghum (bu.)	0.19	0.17	0	0	0
Wheat (bu.)	0.26	0.22	0.24	0.25	0
Sunflowers (cwt.)	0	0.78	0.44	0.35	0
Alfalfa (ton)	10.88	0	0	0	0

Table E23 Projected Resource Use, Scenario 6, Subareas 1-6

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	5,571	2,144	489	179	0
Electricity Use for Irrigation (million KWH)	441	364	108	26	0
Natural Gas Use for Irrigation (1000 MCF)	4,279	950	188	96	0
Irrigation Pumps:					
Electric	3,048	2,849	2,389	1,311	0
Natural Gas	1,719	1,606	1,266	642	0
Total	4,767	4,455	3,655	1,953	0
Farm Consumption of:					
Diesel Fuel (1000 gal.)	13,951	12,458	10,507	9,936	9,650
Gasoline (1000 gal.)	2,739	2,419	1,823	1,601	1,527
NH_3 (tons)	81,862	64,286	41,029	38,858	41,320
Other Fertilizer (tons)	46,504	36,975	12,572	4,473	1,290
Irrigated Farm Labor (man-years)	1,332	886	318	101	0
Dryland Farm Labor (man-years)	1,344	1,391	1,455	1,501	1,529
Total Crop Labor (man-years)	2,676	2,277	1,733	1,602	1,529

Table E24 Projected Resource Use, Scenario 6, Subarea 1.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	95	58	3	0	0
Electricity Use for Irrigation (million KWH)	18	16	1	0	0
Natural Gas Use for Irrigation (1000 MCF)	35	4	0	0	0
Irrigation Pumps:					
Electric	112	112	96	49	0
Natural Gas	12	12	10	6	0
Total	124	124	106	55	0
Farm Consumption of:					
Diesel Fuel (1000 gal.)	387	363	283	280	280
Gasoline (1000 gal.)	74	73	47	45	45
NH_3 (tons)	2,423	2,454	1,344	1,410	1,574
Other Fertilizer (tons)	1,222	1,144	152	37	42
Irrigated Farm Labor (man-years)	33	28	2	0	0
Dryland Farm Labor (man-years)	38	39	44	45	45
Total Crop Labor (man-years)	71	67	46	45	45

Table E25 Projected Resource Use, Scenario 6, Subarea 2.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	407	207	83	35	0
Electricity Use for Irrigation (million KWH)	67	48	21	9	0
Natural Gas Use for Irrigation (1000 MCF)	187	45	12	5	0
Irrigation Pumps:					
Electric	365	364	364	269	0
Natural Gas	55	54	45	25	0
Total	420	418	409	294	0
Farm Consumption of:					
Diesel Fuel (1000 gal.)	1,716	1,554	1,326	1,250	1,172
Gasoline (1000 gal.)	334	313	257	215	188
NH_3 (tons)	9,020	5,970	3,518	3,251	3,277
Other Fertilizer (tons)	4,851	4,036	2,082	943	176
Irrigated Farm Labor (man-years)	177	136	62	28	0
Dryland Farm Labor (man-years)	162	165	175	182	188
Total Crop Labor (man-years)	339	301	237	210	188

Table E26 Projected Resource Use, Scenario 6, Subarea 3.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	881	413	85	22	0
Electricity Use for Irrigation (million KWH)	96	75	22	5	0
Natural Gas Use for Irrigation (1000 MCF)	583	165	10	5	0
Irrigation Pumps:					
Electric	653	560	470	244	0
Natural Gas	203	177	140	75	0
Total	856	737	610	319	0
Farm Consumption of:					
Diesel Fuel (1000 gal.)	3,804	3,512	3,163	3,109	3,109
Gasoline (1000 gal.)	721	662	549	501	486
NH_3 (tons)	20,476	12,904	8,264	7,930	8,502
Other Fertilizer (tons)	8,024	6,388	2,638	801	0
Irrigated Farm Labor (man-years)	242	169	61	17	0
Dryland Farm Labor (man-years)	442	449	466	480	486
Total Crop Labor (man-years)	684	618	527	497	486

Table E27 Projected Resource Use, Scenario 6, Subarea 4.

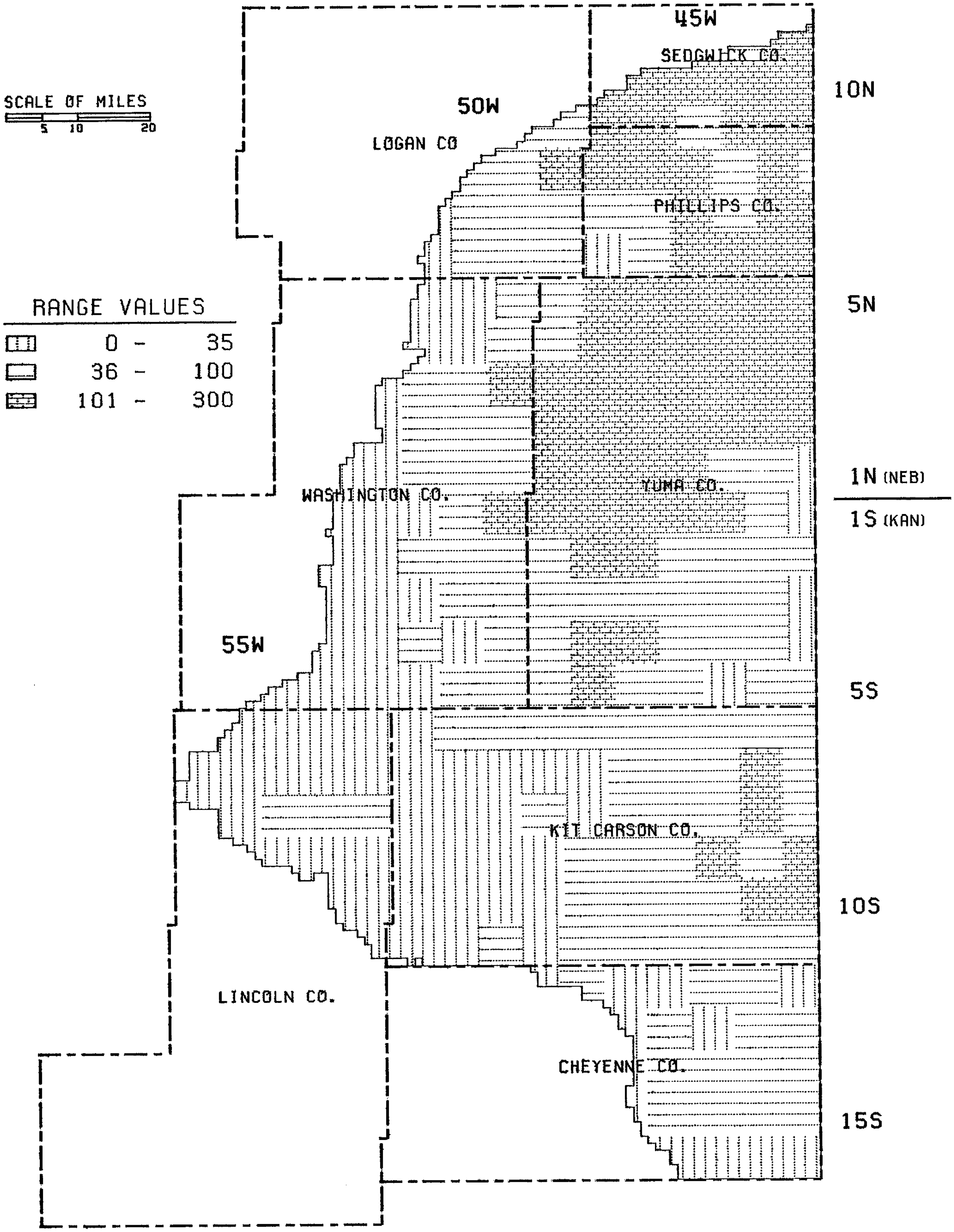
	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	741	515	109	10	0
Electricity Use for Irrigation (million KWH)	142	151	32	3	0
Natural Gas Use for Irrigation (1000 MCF)	270	0	0	0	0
Irrigation Pumps:					
Electric	1,001	1,046	804	413	0
Natural Gas	95	95	76	42	0
Total	1,096	1,141	880	455	0
Farm Consumption of:					
Diesel Fuel (1000 gal.)	1,490	1,378	488	266	236
Gasoline (1000 gal.)	345	353	114	41	31
NH_3 (tons)	13,434	14,647	2,957	741	462
Other Fertilizer (tons)	14,651	15,201	3,587	1,340	1,072
Irrigated Farm Labor (man-years)	290	274	65	8	0
Dryland Farm Labor (man-years)	32	32	32	33	33
Total Crop Labor (man-years)	322	306	97	41	33

Table E28 Projected Resource Use, Scenario 6, Subarea 5.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	2,047	801	122	71	0
Electricity Use for Irrigation (million KWH)	90	67	28	8	0
Natural Gas Use for Irrigation (1000 MCF)	1,832	602	89	46	0
Irrigation Pumps:					
Electric	632	558	478	236	0
Natural Gas	675	654	500	261	0
Total	1,307	1,212	978	497	0
Farm Consumption of:					
Diesel Fuel (1000 gal.)	3,455	2,786	2,391	2,245	2,148
Gasoline (1000 gal.)	696	572	432	371	344
NH_3 (tons)	21,138	15,590	11,431	11,309	12,030
Other Fertilizer (tons)	12,186	8,914	3,885	1,191	0
Irrigated Farm Labor (man-years)	423	249	108	38	0
Dryland Farm Labor (man-years)	277	286	313	332	344
Total Crop Labor (man-years)	700	535	421	370	344

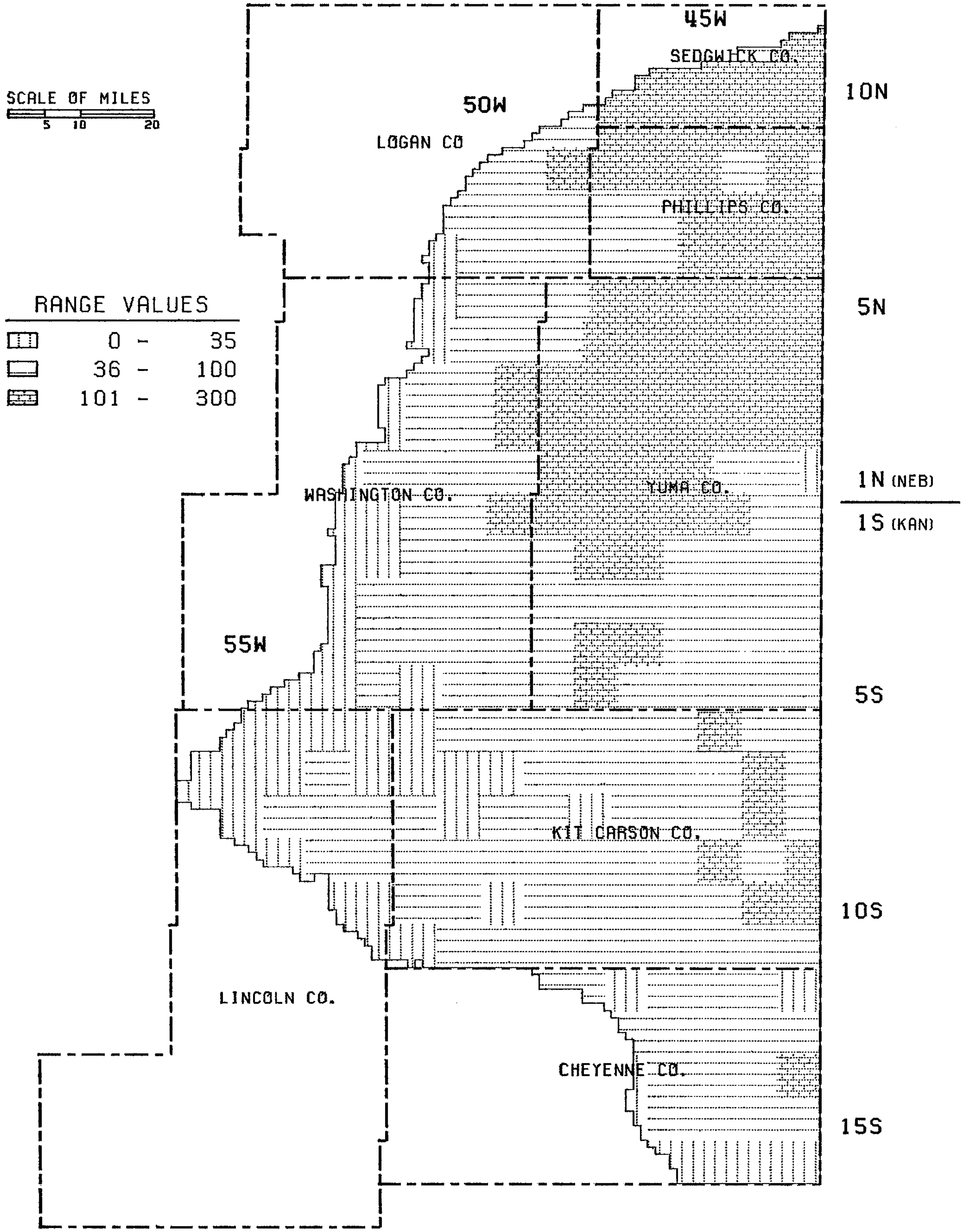
Table E29 Projected Resource Use, Scenario 6, Subarea 6.

	1979	1985	1990	2000	2020
Total Energy Use for Irrigation (billion BTU)	1,400	150	87	41	0
Electricity Use for Irrigation (million KWH)	28	7	4	1	0
Natural Gas Use for Irrigation (1000 MCF)	1,372	134	77	40	0
Irrigation Pumps:					
Electric	285	209	177	100	0
Natural Gas	679	614	495	233	0
Total	964	823	672	333	0
Farm Consumption of:					
Diesel Fuel (1000 gal.)	3,099	2,865	2,856	2,786	2,705
Gasoline (1000 gal.)	569	446	428	428	433
NH_3 (tons)	15,371	12,721	13,515	14,217	15,475
Other Fertilizer (tons)	5,570	1,292	228	161	0
Irrigated Farm Labor (man-years)	166	30	20	10	0
Dryland Farm Labor (man-years)	392	420	425	429	433
Total Crop Labor (man-years)	558	450	445	439	433



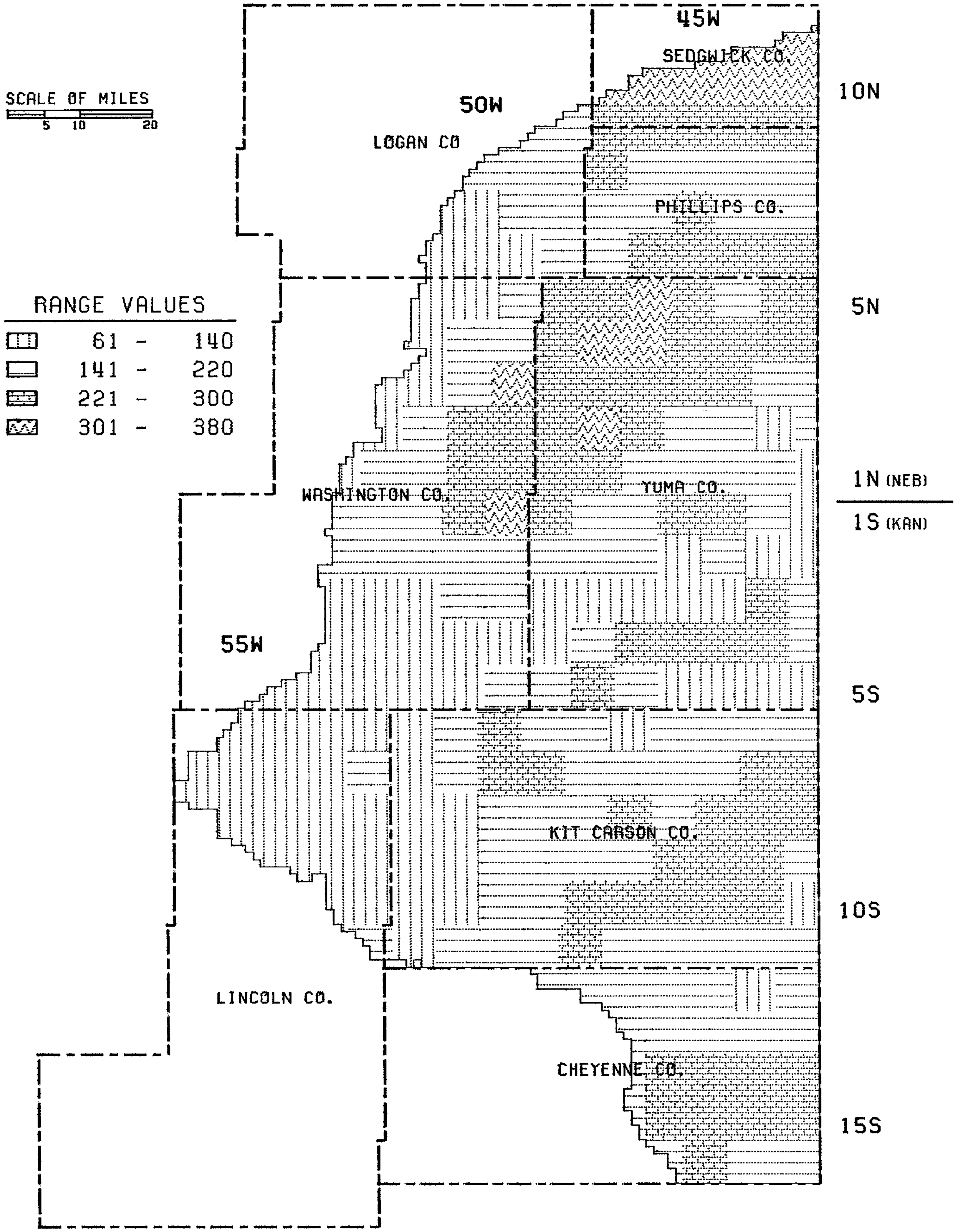
ØGALLALA AQUIFER, NØRTH-EASTERN CØLØRADØ
TØWNSHIPS BY 2000 SATURATED THICKNESS 6

Figure E1



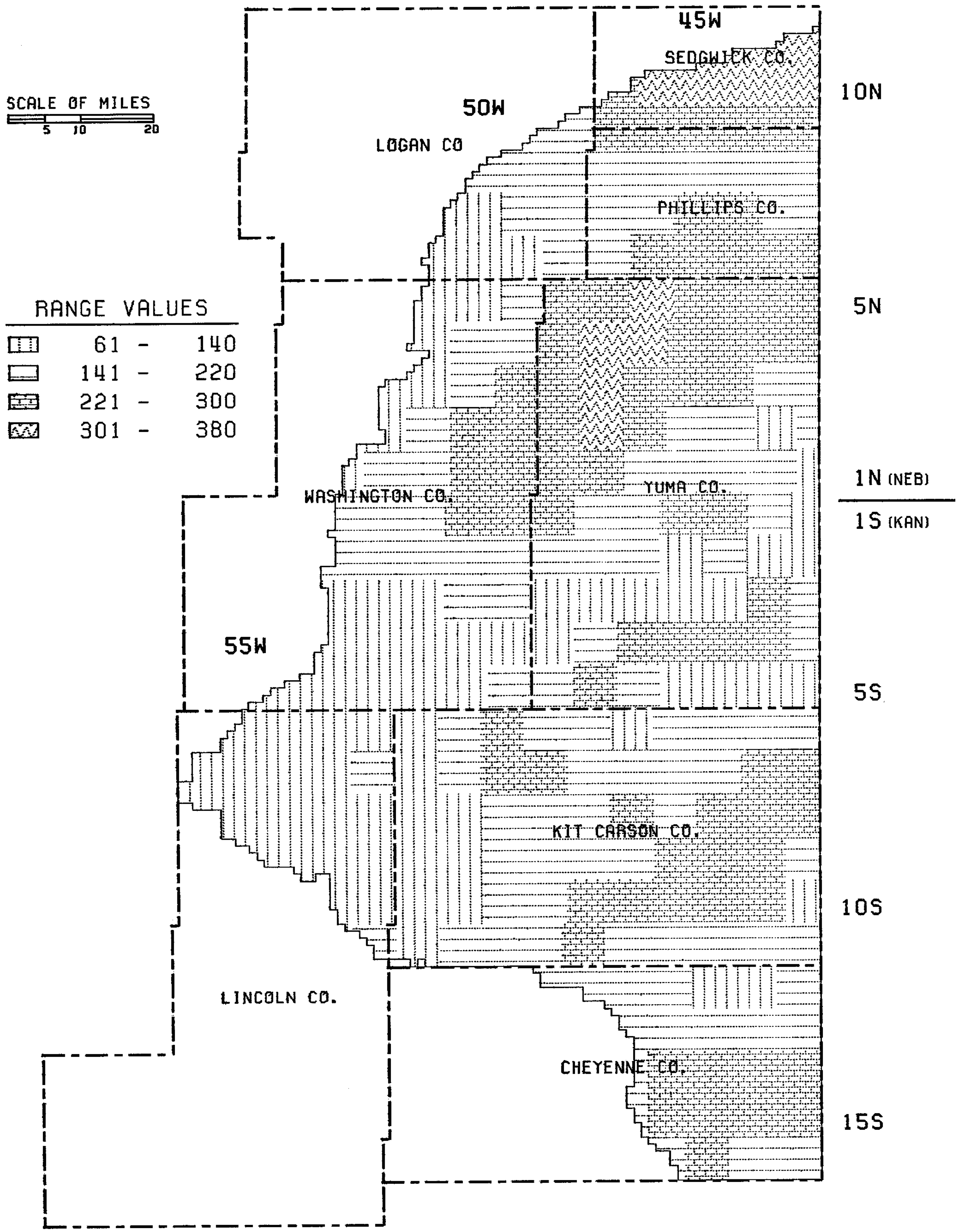
OGALLALA AQUIFER, NORTH-EASTERN COLORADO
TOWNSHIPS BY 2020 SATURATED THICKNESS 6

Figure E2



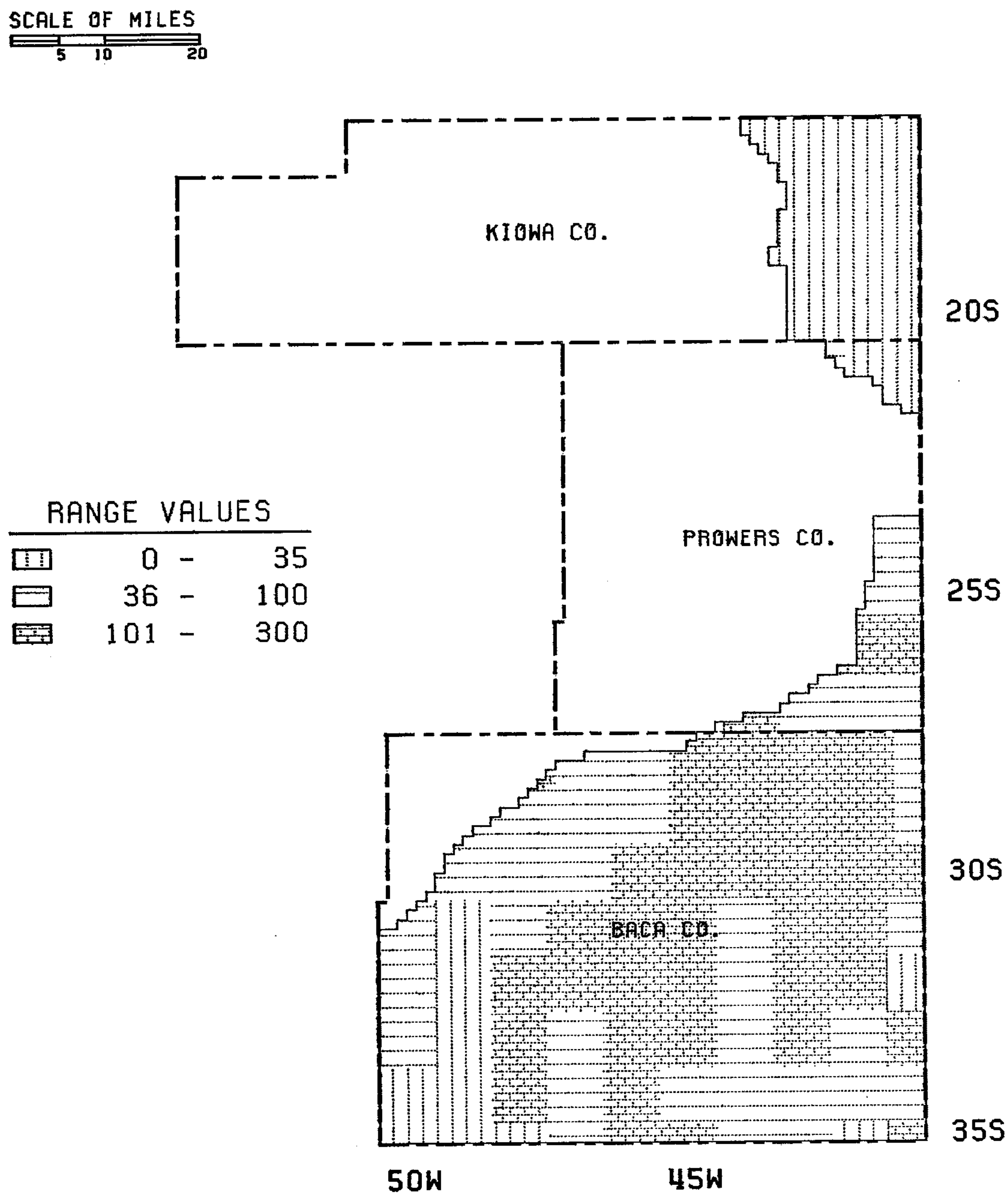
OGALLALA AQUIFER, NORTH-EASTERN COLORADO
TOWNSHIPS BY 2000 DEPTH-ZONES 6

Figure E3



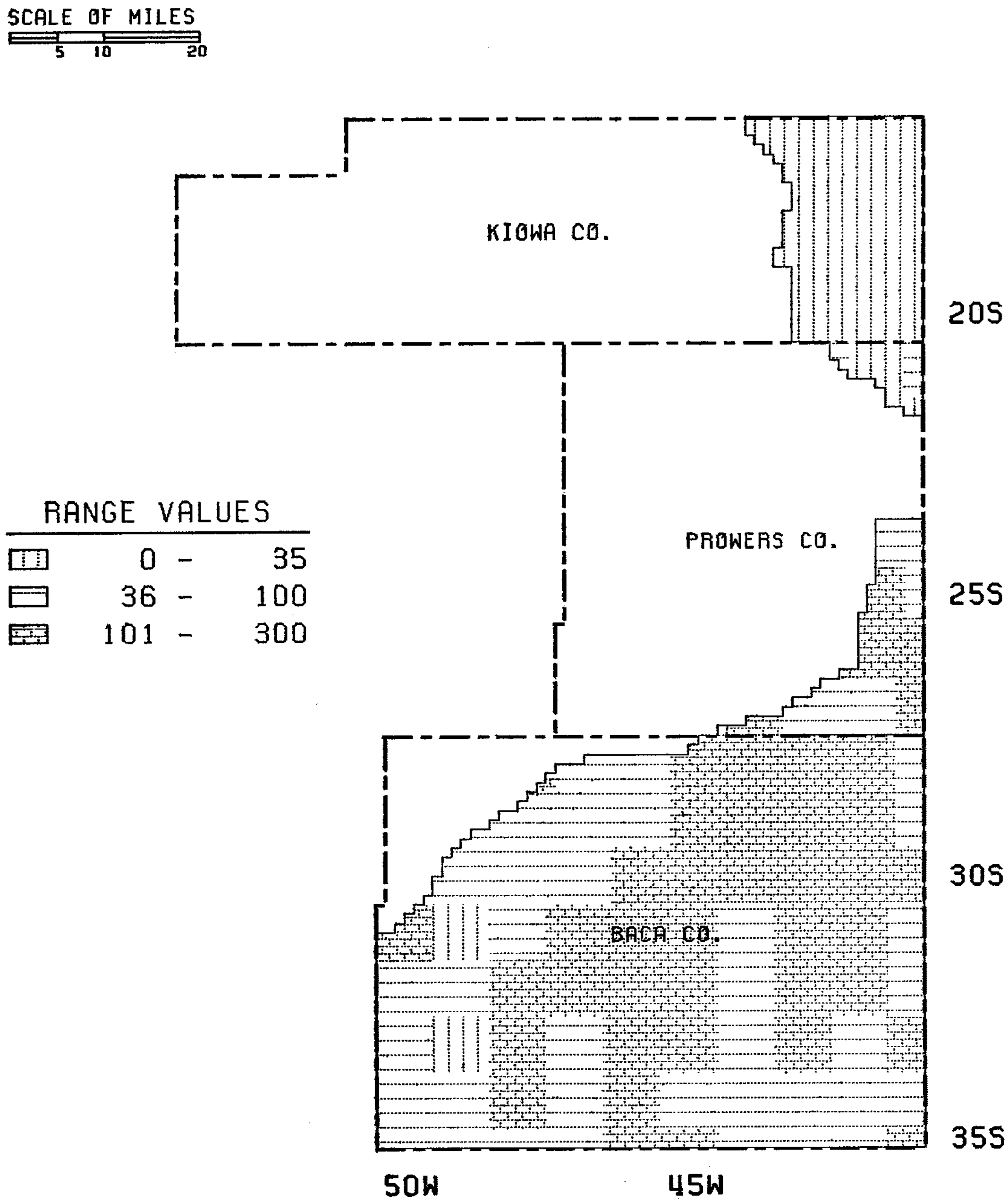
OGALLALA AQUIFER, NORTH-EASTERN COLORADO
TOWNSHIPS BY 2020 DEPTH-ZONES 6

Figure E4



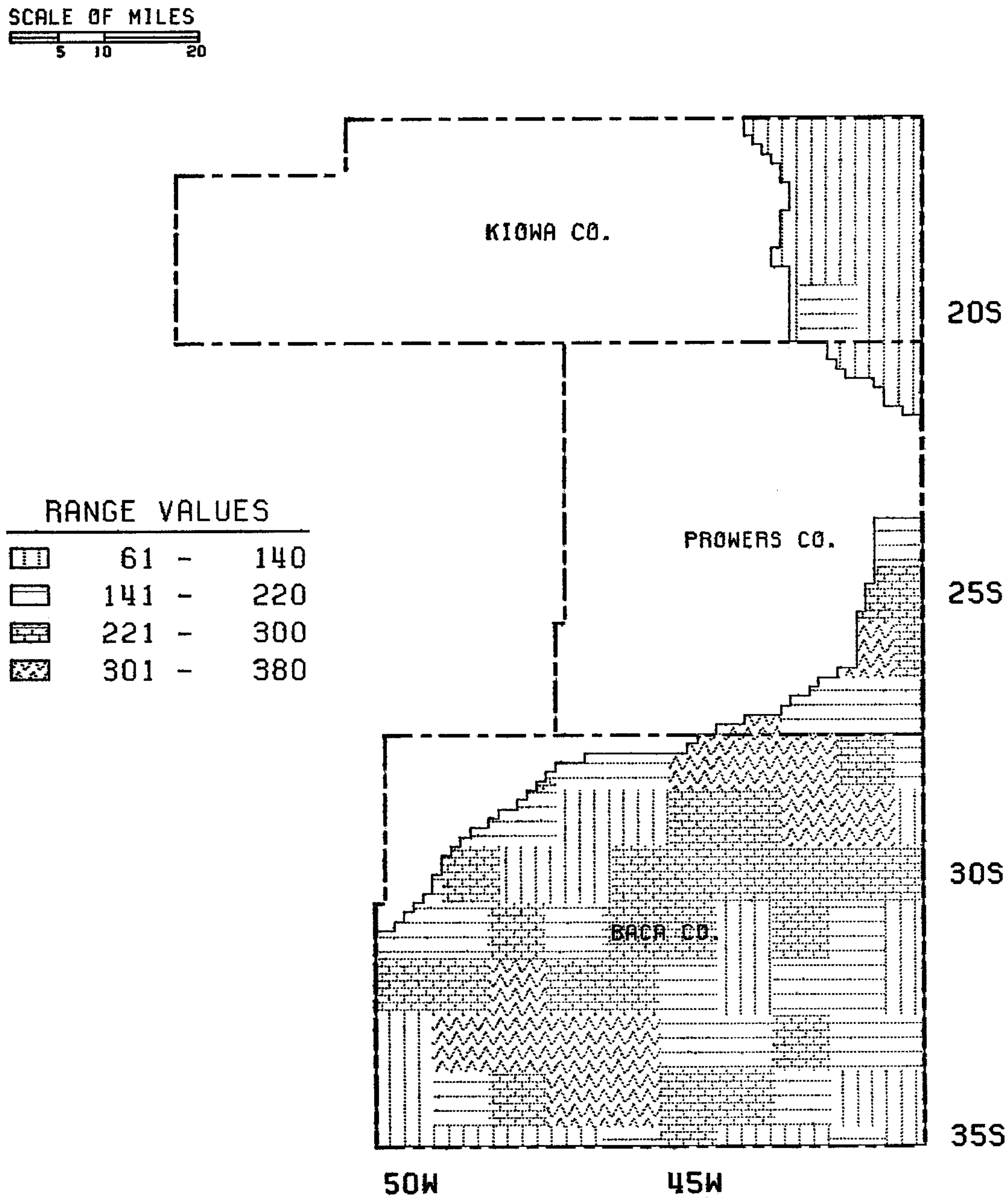
OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2000 SATURATED THICKNESS 6

Figure E5



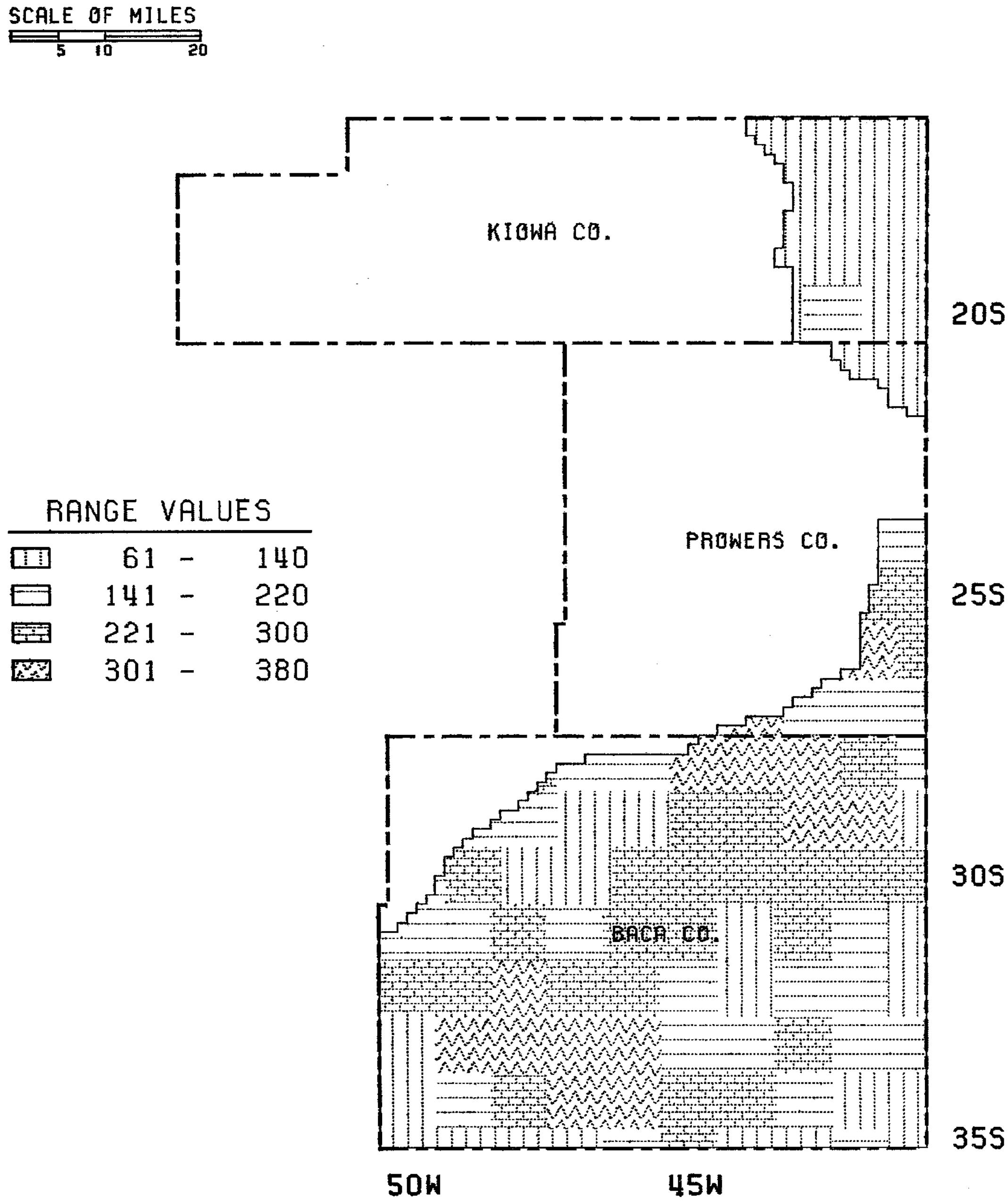
OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2020 SATURATED THICKNESS 6

Figure E6



OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2000 DEPTH-ZONES 6

Figure E7



OGALLALA AQUIFER, SOUTH-EASTERN COLORADO
TOWNSHIPS BY 2020 DEPTH-ZONES 6

Figure E8

APPENDIX F -- FARM MANAGEMENT QUESTIONNAIRE

OGALLALA-HIGH PLAINS STUDY
COLORADO STATE UNIVERSITY

FARM MANAGEMENT QUESTIONNAIRE - INDIVIDUAL ANSWERS ARE CONFIDENTIAL

Date ______________ ID ______________

1. Land Use - 1979

Total Land in Farm ______________

Cropland Harvested - Irrigation ______________

Dryland ______________

Dryland Fallow ______________

Grazing Land - Irrigated ______________

Range land ______________

Other land ______________

2. Crops Grown - 1979

Crop	Acres	Irrig or Dry	Yield
Winter Wheat			
Sorghum Grain			
Corn Grain			
Corn Silage			
Pinto Beans			
Sugar Beets			
Alfalfa Hay			
Grass Hay			

Rotation - Irrigated Land ______________

Soil Texture ______________

Dryland ______________

Soil Texture ______________

3. Field Operations

Crop ________________ Field Preparation ______________________________

____

____

____

Fertilizer ____

____

Varieties Planted ____

Seed Rate ______________________________ Row Spacing ________________

Herbicide ______________________________ Insecticide ________________

No. of Cultivations ____

Irrig. Method ______________________ No. of Irrigations ______________

Water Applied ____

Irrig. Labor ____

Harvest Sequence ____

Use of Plant Residue ____

Crop ________________ Field Preparation ______________________________

____

____

____

Fertilizer ____

____

Varieties Planted ____

Seed Rate ______________________________ Row Spacing ________________

Herbicide ______________________________ Insecticide ________________

No. of Cultivations ____

Irrig. Method ______________________ No. of Irrigations ______________

Water Applied ____

Irrig. Labor ____

Harvest Sequence ____

Use of Plant Residue ____

4. Irrigation Facilities
No. of Irrigation Wells __________

		1	2	3
Approx. location		Sec. ___ T. ___ R. ___	Sec. ___ T. ___ R. ___	Sec. ___ T. ___ R. ___
Year of installation				
Power source				
Motor Size				
Power or fuel cost	1977			
	1978			
	1979			
Acres irrigated				
Crops Grown	1977			
	1978			
	1979			
Dist. system				
Operating pressure				
M & R cost/year: Pumping plant				
Dist. system				
Last pumping plant overhaul (date, descrip, cost)				
Last dist. system change (date, descrip, cost)				
Depth of water				
Discharge rate				

Have you had to adjust your irrigation practices to a decrease in water supply over the past 3 years?

Do you anticipate any change in your irrigation practices?

5. Field Machinery

Tractors

Make, Model & Year	Fuel	Special Equip (cab, 4 WD, 3-pt., loader)

Other

Item	No.	Size	Make & Model
Plow			
Ripper			
Chisel-disk			
Field cult.			
One-way			
Rod weeder			
Offset disk			
Tandem disk			
Roller-harrow			
Rotary hoe			
Spike tooth			
Land plane			
Bedder			
Grain drill			
Corn planter			
Bean planter			
Beet planter			
Sprayer			
Corn cult.			
Bean cult.			
Beet cult.			
Beet thinner			
Swather			
Baler			
Bale stacker			
Loose-hay stacker			
Field chopper			
PU head			
Corn head			

5. Field Machinery (continued)

Item	No.	Size	Make & Model
Beet topper			
Beet harvester			
Bean cutter			
Grain combine			
Sm. grain header			
Corn header			
Bean combine			
Grain cart			
Grain auger			
Grain dryer			
Trucks			

6. Buildings and Improvements

Item	Brief Description (incl. size)
Machinery storage	
Shop	
Grain bins	
Feed lot	

7. Livestock

No. of beef cows ____________
Cattle on feed ____________
Other breeding stock ____________

No. of animals sold annually ____________

No. of dairy cows ____________
Annual milk production ____________

Feed used:	Own production	Purchased
Hay		
Silage		
Corn grain:		

8. Labor

a. Operator's Labor:

% of time spent on field work ______________________

% of time spent on livestock work ______________________

% of time spent on planning, supervision, and marketing ______________

Off-farm employment ______________________

b. Permanent Help:

No. of workers ______________________

% of time on crop work ______________________

% of time with livestock ______________________

c. Seasonal Help:

Job Description	No. of Workers	Time Worked

d. Custom Work Hired:

Operation	Rate Charged

9. Overhead Costs (estimates for a normal year):

Building maint. & repair ______________________

Fence maint. & repair ______________________

Insurance: crop ______________________

comp. ______________________

Property taxes ______________________

Management & accounting ______________________

10. Transaction Analysis

A. Sales

<u>Commodity</u> (incl. crops & livestock) <u>Purchaser</u>

B. Purchases

<u>Input</u> (incl. machinery, fert & chem, feed) <u>Supplier</u>

APPENDIX G -- CODE FOR VARIABLE NAMES IN THE LINEAR PROGRAM, SUBAREA 2

Code for Variable Names in the Linear Program, Subarea 2.

Row Number and Name		Meaning (Units)
1.	OBJFUN	Objective function (dollars)
2.	GPWAPR	Gated pipe system water use in April (acre inch)
3.	GPWMAY	Gated pipe system water use in May (acre inch)
4.	GPWJUN	Gated pipe system water use in June (acre inch)
5.	GPWJUL	Gated pipe system water use in July (acre inch)
6.	GPWAUG	Gated pipe system water use in August (acre inch)
7.	GPWSEP	Gated pipe system water use in September (acre inch)
8.	LPWAPR	Low pressure system water use in April (acre inch)
9.	LPWMAY	Low pressure system water use in May (acre inch)
10.	LPWJUN	Low pressure system water use in June (acre inch)
11.	LPWJUL	Low pressure system water use in July (acre inch)
12.	LPWAUG	Low pressure system water use in August (acre inch)
13.	LPWSEP	Low pressure system water use in September (acre inch)
14.	HPWAPR	High pressure system water use in April (acre inch)
15.	HPWMAY	High pressure system water use in May (acre inch)
16.	HPWJUN	High pressure system water use in June (acre inch)
17.	HPWJUL	High pressure system water use in July (acre inch)
18.	HPWAUG	High pressure system water use in August (acre inch)
19.	HPWSEP	High pressure system water use in September (acre inch)
20.	RBYDSL	Buy diesel fuel (gallons)
21.	RBYGAS	Buy gasoline (gallons)
22.	RBYNH3	Buy anhydrous ammonia (pounds of material)
23.	RBYFER	Buy fertilizer (pounds of material)
24.	RNPWC	Non-power water costs (acre inches)
25.	GPALFE	Alfalfa seeding under gated pipe (acres)
26.	LPALFE	Alfalfa seeding under low pressure (acres)
27.	HPALFE	Alfalfa seeding under high pressure (acres)
28.	RSLSB	Sell sugar beets (tons)
29.	RSLPB	Sell pinto beans (cwt.)
30.	RSLCG	Sell corn grain (bu.)
31.	RSLWH	Sell wheat (bu.)
32.	RSLSG	Sell sorghum (bu.)

Code for Variable Names in the Linear Program, Subarea 2. (continued)

Row Number and Name		Meaning (Units)
33.	RSLSF	Sell sunflowers (cwt.)
34.	RSLHAY	Sell hay (tons)
35.	PUMAPR	Total water pumped in April (acre inches)
36.	PUMMAY	Total water pumped in May (acre inches)
37.	PUMJUN	Total water pumped in June (acre inches)
38.	PUMJUL	Total water pumped in July (acre inches)
39.	PUMAUG	Total water pumped in August (acre inches)
40.	PUMSEP	Total water pumped in September (acre inches)
41.	IRRLND	Amount of irrigable land (acres)
42.	GPLND	Amount of land irrigated by gated pipe (acres)
43.	LPLND	Amount of land irrigated by low pressure system (acres)
44.	HPLND	Amount of land irrigated by high pressure system (acres)
45.	BTLND	Amount of land in sugar beets (acres)
46.	BNLND	Amount of land in pinto beans (acres)
47.	SFLND	Amount of land in sunflowers (acres)
48.	ALFLND	Amount of land in alfalfa (acres)
49.	DRYLND	Amount of irrigable land farmed as dryland (acres)
50.	DRYNETY	Total dryland net income (dollars)
51.	LABOR	Total labor and management time (hours)
52.	RWTRSB	Total water pumped for sugar beets (acre inches)
53.	RWTRPB	Total water pumped for pinto beans (acre inches)
54.	RWTRCG	Total water pumped for corn (acre inches)
55.	RWTRWH	Total water pumped for wheat (acre inches)
56.	RWTRSG	Total water pumped for sorghum (acre inches)
57.	RWTRSF	Total water pumped for sunflowers (acre inches)
58.	RWTRAL	Total water pumped for alfalfa (acre inches)
59	ZWATER	Total water pumped (acre inches)

Code for Variable Names in the Linear Program, Subarea 2.

Column Number and Name	Meaning (Units)
1. GPWCAP	Gated pipe water cost in April ($/acre inch)
2. GPWCMA	Gated pipe water cost in May ($/acre inch)
3. GPWCJN	Gated pipe water cost in June ($/acre inch)
4. GPWCJL	Gated pipe water cost in July ($/acre inch)
5. GPWCAG	Gated pipe water cost in August ($/acre inch)
6. GPWCSP	Gated pipe water cost in September ($/acre inch)
7. LPWCAP	Low pressure system water cost in April ($/acre inch)
8. LPWCMA	Low pressure system water cost in May ($/acre inch)
9. LPWCJN	Low pressure system water cost in June ($/acre inch)
10. LPWCJL	Low pressure system water cost in July ($/acre inch)
11. LPWCAG	Low pressure system water cost in August ($/acre inch)
12. LPWCSP	Low pressure system water cost in September ($/acre inch)
13. HPWCAP	High pressure system water cost in April ($/acre inch)
14. HPWCMA	High pressure system water cost in May ($/acre inch)
15. HPWCJN	High pressure system water cost in June ($/acre inch)
16. HPWCJL	High pressure system water cost in July ($/acre inch)
17. HPWCAG	High pressure system water cost in August ($/acre inch)
18. HPWCSP	High pressure system water cost in September ($/acre inch)
19. CBYDSL	Buy diesel fuel ($/gallon)
20. CBYGAS	Buy gasoline ($/gallon)
21. CBYNH3	Buy anhydrous ammonia ($/pound)
22. CBYFER	Buy fertilizer ($/pound)
23. CNPWC	Non-power water cost ($/acre inch)
24. CSLSB	Sell sugar beets ($/ton)
25. CSLPB	Sell pinto beans ($/cwt.)
26. CSLCG	Sell corn grain ($/bu.)
27. CSLWH	Sell wheat ($/bu.)
28. CSLSG	Sell sorghum ($/bu.)
29. CSLSF	Sell sunflowers ($/cwt.)
30. CSLHAY	Sell hay ($/ton)
31. SBGP3	Sugar beets, gated pipe, full irrigation
32. SBGP2	Sugar beets, gated pipe, two-thirds irrigation

Code for Variable Names in the Linear Program, Subarea 2. (continued)

Column Number and Name	Meaning (Units)
33. SBGP1	Sugar beets, gated pipe, one-third irrigation
34. SBLP3	Sugar beets, low pressure, full irrigation
35. SBLP2	Sugar beets, low pressure, two-thirds irrigation
36. SBLP1	Sugar beets, low pressure, one-third irrigation
37. SBHP3	Sugar beets, high pressure, full irrigation
38. SBHP2	Sugar beets, high pressure, two-thirds irrigation
39. SBHP1	Sugar beets, high pressure, one-third irrigation
40. PBGP3	Pinto beans, gated pipe, full irrigation
41. PBGP2	Pinto beans, gated pipe, two-thirds irrigation
42. PBGP1	Pinto beans, gated pipe, one-third irrigation
43. PBLP3	Pinto beans, low pressure, full irrigation
44. PBLP2	Pinto beans, low pressure, two-thirds irrigation
45. PBLP1	Pinto beans, low pressure, one-third irrigation
46. PBHP3	Pinto beans, high pressure, full irrigation
47. PBHP2	Pinto beans, high pressure, two-thirds irrigation
48. PBHP1	Pinto beans, high pressure, one-third irrigation
49. PBDRY	Pinto beans, dryland
50. CGGP3	Corn grain, gated pipe, full irrigation
51. CGGP2	Corn grain, gated pipe, two-thirds irrigation
52. CGGP1	Corn grain, gated pipe, one-third irrigation
53. CGLP3	Corn grain, low pressure, full irrigation
54. CGLP2	Corn grain, low pressure, two-thirds irrigation
55. CGLP1	Corn grain, low pressure, one-third irrigation
56. CGHP3	Corn grain, high pressure, full irrigation
57. CGHP2	Corn grain, high pressure, two-thirds irrigation
58. CGHP1	Corn grain, high pressure, one-third irrigation
59. CGDRY	Corn grain, dryland
60. WHGP3	Wheat, gated pipe, full irrigation
61. WHGP2	Wheat, gated pipe, two-thirds irrigation
62. WHGP1	Wheat, gated pipe, one-third irrigation
63. WHLP3	Wheat, low pressure, full irrigation
64. WHLP2	Wheat, low pressure, two-thirds irrigation

Code for Variable Names in the Linear Program, Subarea 2.

Column Number and Name	Meaning (Units)
65. WHLP1	Wheat, low pressure, one-third irrigation
66. WHHP3	Wheat, high pressure, full irrigation
67. WHHP2	Wheat, high pressure, two-thirds irrigation
68. WHHP1	Wheat, high pressure, one-third irrigation
69. WHDRY	Wheat, dryland
70. SGGP3	Sorghum, gated pipe, full irrigation
71. SGGP2	Sorghum, gated pipe, two-thirds irrigation
72. SGGP1	Sorghum, gated pipe, one-third irrigation
73. SGLP3	Sorghum, low pressure, full irrigation
74. SGLP2	Sorghum, low pressure, two-thirds irrigation
75. SGLP1	Sorghum, low pressure, one-third irrigation
76. SGHP3	Sorghum, high pressure, full irrigation
77. SHGP2	Sorghum, high pressure, two-thirds irrigation
78. SHGP1	Sorghum, high pressure, one-third irrigation
79. SGDRY	Sorghum, dryland
80. SFGP3	Sunflowers, gated pipe, full irrigation
81. SFGP2	Sunflowers, gated pipe, two-thirds irrigation
82. SFGP1	Sunflowers, gated pipe, one-third irrigation
83. SFLP3	Sunflowers, low pressure, full irrigation
84. SFLP2	Sunflowers, low pressure, two-thirds irrigation
85. SFLP1	Sunflowers, low pressure, one-third irrigation
86. SFHP3	Sunflowers, high pressure, full irrigation
87. SFHP2	Sunflowers, high pressure, two-thirds irrigation
88. SFHP1	Sunflowers, high pressure, one-third irrigation
89. SFDRY	Sunflowers, dryland
90. ALFGP3	Alfalfa hay, gated pipe, full irrigation
91. ALFGP2	Alfalfa hay, gated pipe, two-thirds irrigation
92. ALFGP1	Alfalfa hay, gated pipe, one-third irrigation
93. ALFLP3	Alfalfa hay, low pressure, full irrigation
94. ALFLP2	Alfalfa hay, low pressure, two-thirds irrigation
95. ALFLP1	Alfalfa hay, low pressure, one-third irrigation
96. ALFHP3	Alfalfa hay, high pressure, full irrigation

Code for Variable Names in the Linear Program, Subarea 2. (continued)

Column Number and Name		Meaning (Units)
97.	ALFHP2	Alfalfa hay, high pressure, two-thirds irrigation
98.	ALFHP1	Alfalfa hay, high pressure, one-third irrigation
99.	AESTGP	Alfalfa seeding under gated pipe
100.	AESTLP	Alfalfa seeding under low pressure
101.	AESTHP	Alfalfa seeding under high pressure
102.	HAYDRY	Grass hay, dryland
103.	RHS	Right-hand side values