IMPACT OF AVAILABILITY OF WATER AND COST OF ENERGY INPUTS ON AGRICULTURAL PRODUCTION IN THE OKLAHOMA PANHANDLE

By

Harry P. Mapp, Jr.
Department of Agricultural Economics

OKLAHOMA STATE UNIVERSITY

OKLAHOMA WATER RESOURCES RESEARCH INSTITUTE
Period Covered by Research Investigation:
October 1, 1978 through September 30, 1980

TABLE OF CONTENTS

INTRODUCTION

The Oklahoma Panhandle, which is composed of Cimarron, Texas and Beaver counties, is a 5,680 square mile semi-arid area in western Oklahoma. Part of the High Plains, the Panhandle is an eastward sloping plateau with its highest point in extreme northwest Cimarron County at an altitude of 4,978 feet and its lowest point at the Cimarron River on the eastern edge of Beaver County at an altitude of 1990 feet (Figure 1). Principal crops in the area include grain sorghum, corn and alfalfa which are produced to supply feed for the large beef feedlots in the area and wheat which is produced primarily for the export market.

Prior to 1950, crop production in the area was almost exclusively dryland wheat and grain sorghum. With the discovery of a significant quantity of high quality groundwater underlying most of the region came the development of irrigated production practices.

Development of agricultural crop production under irrigated conditions has contributed to increased economic activity in the Oklahoma Panhandle and surrounding regions. Acres irrigated in the Oklahoma Panhandle increased from 11,500 in 1950 to 427,000 in 1973 and totaled 405,700 in 1979 (Table 1). Despite this increase in irrigated crop production, only about 17 percent of the soils classified as irrigable were being irrigated in 1979 (Table 2). Rapid growth in irrigation has also occurred in surrounding portions of Kansas, Texas, New Mexico and Colorado. The primary source of irrigation water in the Oklahoma Panhandle is the Ogallala Formation, a major under-

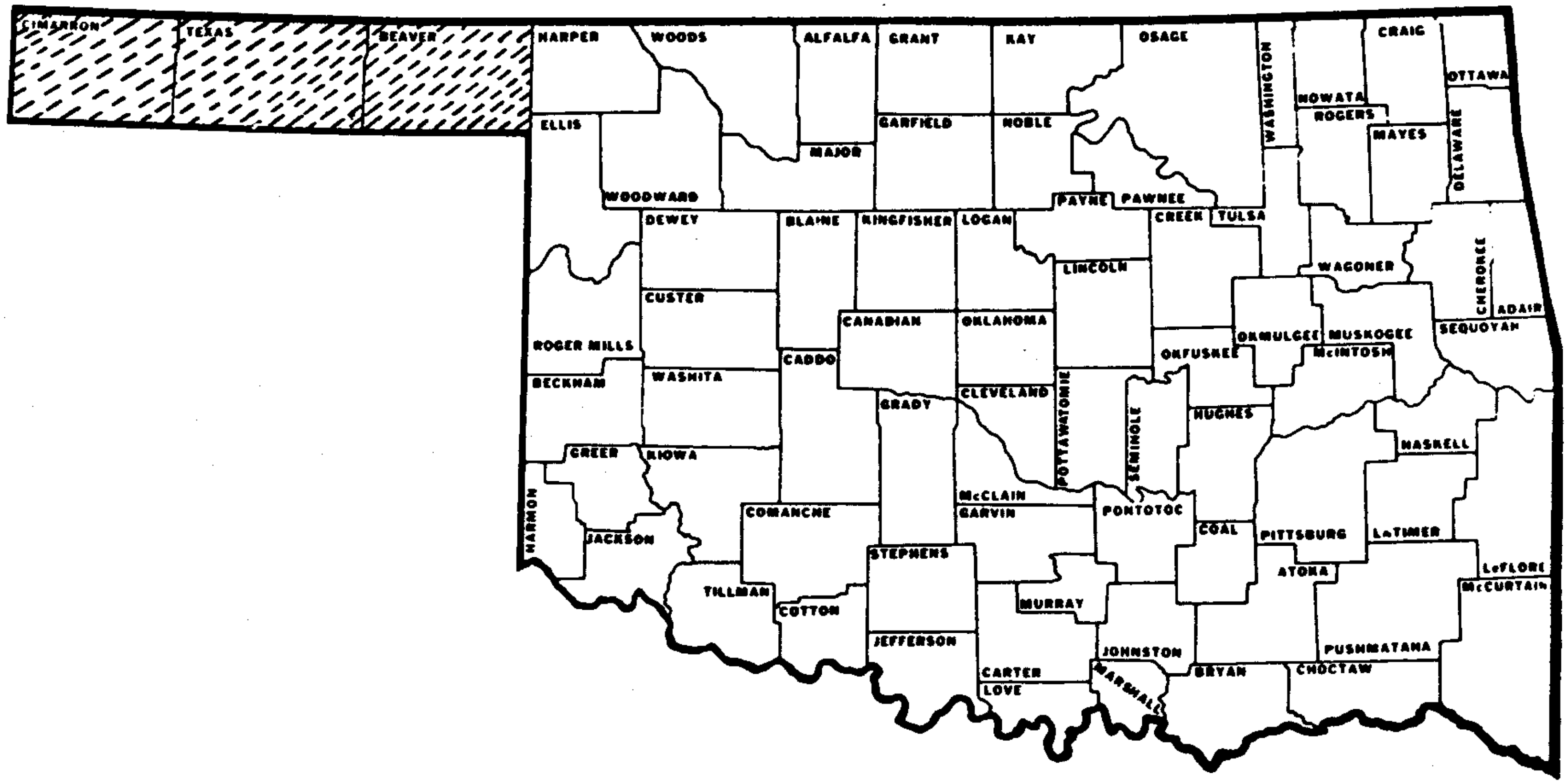

Figure 1. Map of Oklahoma Showing the Area of Study

TABLE 1

IRRIGATION STATISTICS--OKLAHOMA PANHANDLE

Year	No. Farms	Total Acres	No. Farms Gravity System	Acres Gravity System	No. Farms Sprinkler System	Acres Sprinkler System	Number Irrigation Wells	Total Acres Irrigated (Groundwater)
1979	1,223	405,679	898	297,649	350	97,215	2,227	403,619
1977	1,155	385,900	896	301,650	259	85,700	2,172	384,000
1975	1,094	404,610	901	329,460	193	75,150	2,112	402,550
1973	1,530	427,000	1,360	324,500	175	102,500	2,207	422,680
1971	1,375	356,360	1,165	302,938	255	54,422	1,846	344,040
1969	960	315,518	835	282,618	141	32,900	1,634	312,518
1967	1,150	263,000	1,010	224,850	145	38,150	1,358	261,000
1965	745	138,000	586	122,000	104	16,000	972	135,500
1963	304	84,500	241	72,560	75	11,940	409	83,020
1959	275	71,500		65,820	46	5,680	365	69,520
1958	279	69,575		62,623	53	6,960		67,375
1957	267	76,500		68,360	49	8,140	359	75,225
1956	266	71,200		64,700	41	6,500	336	70,100
1955	212	34,247		32,030		2,317		32,797
1954		24,680		23,758		922		23,580
1952		13,000						
1950	53	11,500						

Source: Schwab, Delbert. Irrigation Survey Oklahoma. Department of Agricultural Engineering, Oklahoma State University, Various Issues.

TABLE 2

SOIL CLASSIFICATIONS--OKLAHOMA PANHANDLE

		Panhandle Acreage	Acreage Overlying the Aquifer	Irrigable Acreage Overlying the Aquifer	Totals
Not Suitable for Irrigation	Acres	1,247,688	1,080,412		
	%	34.52	31.71		
Clay Soils Irrigable by Surface Systems	Acres	1,171,396	1,159,766	1,159,766	
	%	32.41	34.03	49.84	<u>Clay Totals</u>
Clay Soils Irrigable by Surface and Center Pivot Systems	Acres	367,780	357,820	357,820	1,517,596
	%	10.50	10.50	15.38	65.21
Sandy Soils Irrigable by Surface and Center Pivot Systems	Acres	400,876	390,159	390,159	
	%	11.09	11.45	16.76	<u>Sandy Soils</u> 809,591 34.79
Sandy Soils Irrigable by Center Pivot Systems	Acres	426,614	419,432	419,432	
	%	11.80	12.31	18.02	
Totals	Acres	3,614,350	3,407,609	2,327,197	2,327,197
	%	100	100	100	100

Source: Thompson, Mark. <u>Soils and Groundwater Resource Situations in the Oklahoma Panhandle</u>. Unpublished paper, Department of Agricultural Economics, Oklahoma State University, Stillwater, 1978.

ground aquifer supporting irrigation water throughout much of the Great Plains.

Under natural conditions, the aquifer underlying the Oklahoma Panhandle is near equilibrium, with natural recharge approximately equal to natural discharge. However, the rapid development of irrigated crop production has resulted in overdraft of the aquifer, with withdrawals greatly exceeding natural recharge and return percolation of irrigation water. The result has been a gradual decline in the water table within the aquifer. The declining water table interacts with rapidly increasing costs of energy inputs, particularly natural gas being utilized by most irrigation systems in the Oklahoma Panhandle and, other things equal, reduces the profitability of irrigated crop production. Continued declines in the water level within the aquifer threaten the capital intensive irrigated agricultural economy of the area.

PROBLEM STATEMENT AND OBJECTIVES OF ANALYSIS

Despite continued overdraft of the Ogallala Formation and water level declines of two to three feet per year in many areas, physical exhaustion of the aquifer is not of major concern. The characteristics of the aquifer make physical exhaustion virtually impossible. Economic exhaustion of the aquifer is a very real possiblity - one that has already occurred for some irrigators in some parts of the Oklahoma Panhandle. Economic exhaustion occurs when net returns from the production of the best dryland crop alternative exceed the net returns of the most profitable irrigated crop activity.

Several factors are interacting to reduce the economic life of the aquifer. Rapid water withdrawals lower the water table and increase the vertical lift of the water to the surface. In addition, declines in saturated thickness of the aquifer reduce the well yield, measured in gallons per minute, which increases the time required to apply a specified quantity of water onto the crops. Reduced well yield and increased feet of lift interact to increase the cost of pumping irrigation water and reduce the profitability of irrigated crop production.

During the past couple of years, irrigators in the area have experienced rapidly rising prices for natural gas, the primary fuel for irrigation engines in the area. Even though natural gas remains a cheaper energy source than electricity or diesel fuel, recent price increases have further reduced the profitability of irrigated crop production and shortened the economic life of the underground aquifer.

The adjustment from irrigated to dryland production, though likely to be gradual, may result in serious economic disruptions in the area. The severity of the problems depends upon the time horizon over which economic exhaustion occurs and the adjustments in production practices that may mitigate the adverse effects of the depletion of the scarce water resource.

The objectives of this study were to analyze the potential impact of the declining water supply on irrigated and dryland production of the principal crops in the Oklahoma Panhandle and to evaluate the potential impact of increases in the price of natural gas relative to other inputs on the economic life of the underground aquifer.1/ Specific objectives

---

1/Although the general objectives are somewhat similar, this study should not be confused with the Six-States High Plains Ogallala Aquifer Area Study (referred to as the High Plains Project) funded by the U.S. Department of Commerce through the Economic Development Administration. Major portions of this OWRT study were completed prior to initiation of state-level research under the High Plains Project.

include:

1. To develop costs and returns estimates for dryland crops and for irrigated crops under alternative water pumping and application efficiency assumptions and for alternative fuel prices.
2. To estimate the effects of the declining water supply and adjustments in production practices on the amount of water that can be economically withdrawn from the underground aquifer for alternative water resource situations.
3. To estimate the amount of substitution resulting from increases in the price of natural gas relative to other inputs and to evaluate the impact of these substitutions on water use and aggregate output in the area.

A recursive regional linear programming model is developed to project changes in total irrigated and dryland acreages and the rate of decline in the water table for alternative soil and water resource situations, estimate acreages under dryland and irrigated production by crop, and estimate net returns within the region for the alternatives evaluated. The next section of this report reviews the methodology used in the analysis, including a discussion of the model, data requirements, constraints and activities.

MODEL DEVELOPMENT AND DATA REQUIREMENTS

Model Development

A recursive linear programming (RLP) model was developed to analyze the impact of the declining water supply and an increasing price of natural gas on irrigated and dryland crop production within the study area. The RLP model is an adaptation of a static linear programming (LP) model. Changing conditions of time necessitate revision of the LP model for time period t + 1, based upon the solution for period t and conditions that exist in period t + 1. The revision may involve the objective function, the input-output coefficients, the right hand side restrictions, or any combination thereof.

The three-county Oklahoma Panhandle area overlying the Ogallala aquifer is treated as a single producing unit, stratified by different soil and water resource situations which are associated with different costs and returns for the crop produced in the area. The RLP production model shown in the flow diagram of Figure 2 has two computational portions. The first portion is a linear programming model which maximizes net returns above total costs, subject to a set of resource restrictions specified for period t. In the second portion, changes in irrigation pumping costs and resource restrictions are estimated and certain parameters of the LP model are revised for the subsequent t + 1 period.

In any production period t, the inputs to the model are (1) the soil and water resource base and the appropriate set of production restrictions represented by vector B_t, (2) the various crop enterprises and selling and buying activities represented by matrix P_t, (3) the associated input-output coefficients of the activities in P_t represented by matrix A, and (4) the

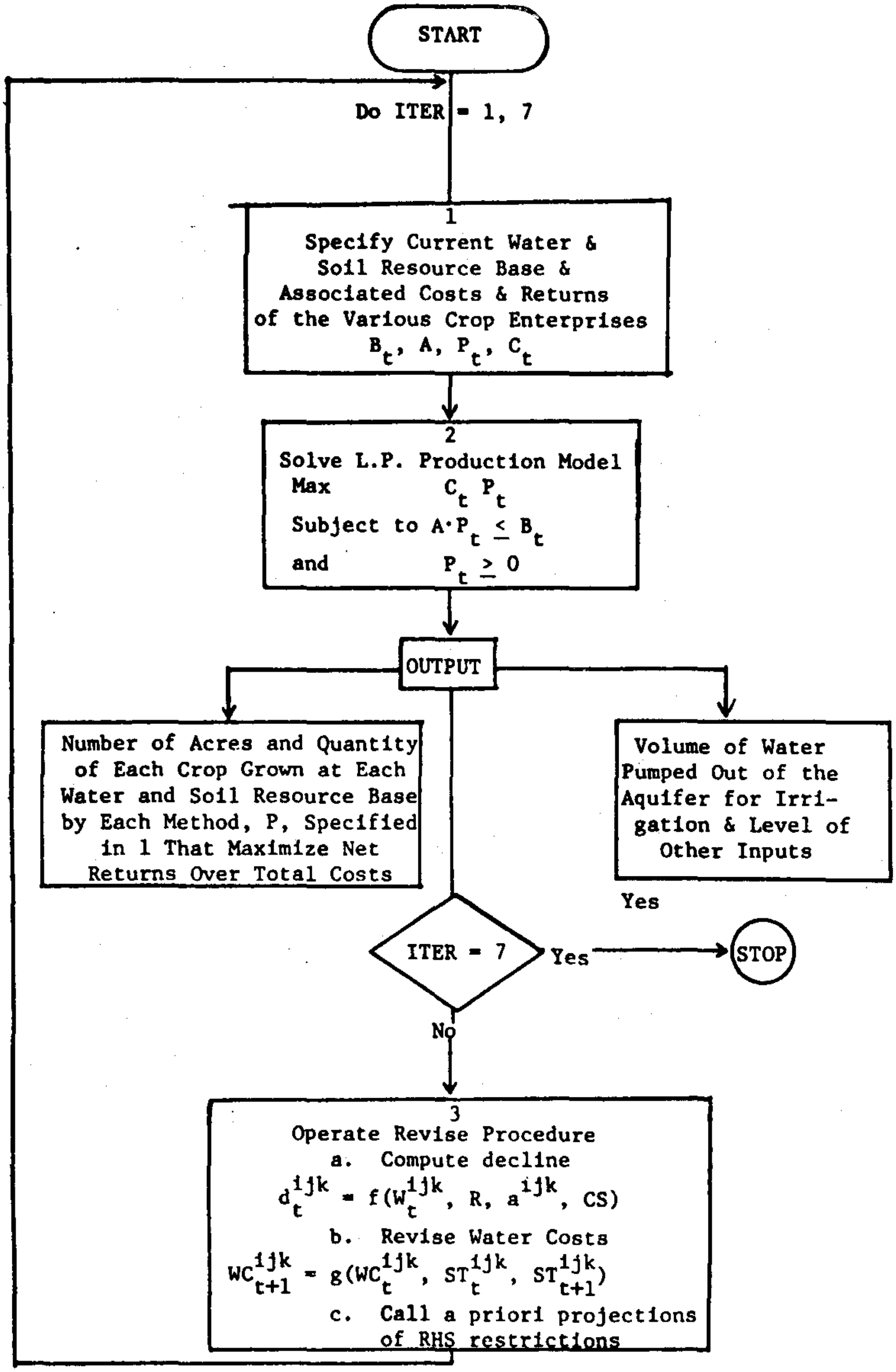

Figure 2. The Recursive Linear Programming Model

net returns accruing from the activities in P_t represented by vector C_t (Figure 2).

The results calculated by the model include (1) the number of dryland acres and the acres irrigated for the various crops grown on each soil and water resource situation under different levels of irrigation water application, (2) the volume of water pumped from each soil and water resource situation, (3) the level of other inputs used, specifically capital and labor, and (4) the total net returns from all enterprises.

In the second part of the model, several calculations are made to update and specify the parameters of the LP model for period t + 1. First, the volume of water pumped from a soil and water resource situation is denoted as W_t^{ijk}, (where i = 75,150, 225, represents the three depths to water; j = 50, 150, ..., 550, represents the six saturated thicknesses and k = c, s, represents either clay or sandy soil). The decline of a static water level d_t^{ijk}, at the end of production period t is calculated as a function of the volume of water pumped W_t^{ijk}, the recirculation coefficient[2], R = 0.2, the appropriate surface (land) area a^{ijk}, and the coefficient of storage[3], CS = 0.1. Implicitly, we have:

$$(1) \quad d_t^{ijk} = f\ (W_t^{ijk},\ R,\ a^{ijk},\ CS).$$

It should be noted that in this study industrial and municipal pumpage is assumed to be offset by recharge from precipitation and return irrigation flow.

---

[2] The recirculation coefficient is defined as the percentage of water applied that percolates back through to the water table (Hart, et al.).

[3] The coefficient of storage indicates that the volume of water the aquifer releases by gravity is only 10 percent of the volume of the saturated material (Hart, et al.).

Based on the decline in the static water level, a new saturated thickness ST_{t+1}^{ijk} is computed and new water costs WC_{t+1}^{ijk} are derived from the previous water cost WC_{t}^{ijk} and the new saturated thickness ST_{t}^{ijk}. Implicitly we have:

$$(2) \quad WC_{t+1}^{ijk} = g(WC_{t}^{ijk}, ST_{t}^{ijk}, ST_{t+1}^{ijk})$$

These water costs are used to update the cost of the water buying activities in P_t by revising the appropriate elements of vector C_t. Most of the right hand side restrictions in vector B_t are upper limits to crop production in the soil and water resource situations. *A priori* projections are used to revise the production restrictions in vector B_t in each new production period. Detailed explanations concerning the *a priori* projections and water cost revisions are given in a later section of this report.

When this process is completed, the inputs of the production model are updated and the model is ready to generate the production pattern for period t + 1. The complete process is iterated for t = 7 periods, the first four periods representing a span of five years each, and the last three periods representing a span of ten years each. The model is run once for 1977 benchmark conditions and then the initial conditions for 1980 are specified. Then t is made to represent the five year period 1980-84. When t + 7, the calendar year period is 2020-29 and the production has been depicted for a period of one-half century.

DATA REQUIREMENTS

The Soil Classification Scheme

The Soil Conservation Service (SCS) county soil surveys provide the basic data. The soils of each county were divided into irrigable and non-irrigable groups using the irrigated capability units as the criterion of classification. Non-irrigable soils account for 34 percent of the total land base in the area. Irrigable soils were subdivided into clay and sandy soils and further subdivided according to suitability for irrigation by alternative irrigation systems. Clay soils that are deep, well drained, and nearly level (0 to 3 percent slope) are best suited for surface irrigation systems. Sandy soils characterized by poor drainage and moderate to steep slope are best suited for center pivot systems. Clay soils irrigable by surface systems comprise 50 percent of the land overlying the aquifer; clay soils irrigable by surface and center pivot systems comprise 15 percent; sandy soils only irrigable by center pivot comprise 18 percent; and sandy soils irrigable by both methods comprise 17 percent of the acreage overlying the aquifer. These soil groups were identified and color coded on a map of each county. To simplify, clay soils were combined, assumed to be irrigated by surface systems, and accounted for 65 percent of the irrigable acreage. Sandy soils were combined, assumed to be irrigated by center pivot systems, and accounted for 35 percent of the total irrigable acreage.

The Soil and Water Resource Situation Strata

Hydrologic maps of each county were used to inventory the water resources (Hart, Hoffman, Goemaat). Two maps for each county were utilized. The saturated thickness maps indicated the number of feet of water saturated material in the aquifer. The depth to water maps indicated the distance from the ground to the static water level. By superimposing the depth to water maps over the saturated thickness maps, the land overlying the aquifer was divided into 35 distinct water resource situations. The water resource maps were then placed over the soil maps and the areas were planimetered to determine the number of acres of each soil category at each depth to water and saturated thickness interval. These 70 soil and water resource situations were reduced to 26 situations by disregarding categories representing very small portions of the study area and by combining the original hydrologic data into fewer water resource strata. The acres represented by each soil and water resource situation, and their respective percentages of the total, are presented in Tables 3 and 4.

When soil type, depth to water, and saturated thickness are considered, there are 26 categories which serve as upper limit land restrictions in the model. The number of acres in each of the 26 soil and water resource situations constitute the land base on which the total crop production activities take place. They are entered in the B_t vector as right hand side restrictions in the LP model.

The Quantity of Crops Produced

The Water Resources Council has developed projections of agricultural production from 1980-2020. The projections, referred to as OBERS projections are based on domestic supply-demand relationships and foreign export conditions that existed in the 1950-72 period. The projections represent an attempt, imperfect though it may be, to forecast the economic future with the specification of assumptions and methodology introducing considerable objectivity into the process.[4/]

[4/] The Water Resources Council has a number of OBERS projections on hand as a result of different assumptions of fertility levels, export trends, and updated information. OBERS C, developed in 1967 assumed a high fertility rate and low export level. OBERS E in 1972 assumed a low fertility rate and a low export level. OBERS E', 1975, assumed a low fertility rate but a high export level and has the highest production projections of the three. The OBERS E' projections were utilized in this analysis.

TABLE 3

SOIL AND WATER RESOURCE SITUATION ACREAGES

Depth to Water (ft)	Soil Type	Saturated Thickness (ft) 50	150	250	350	450	550
	All	172381	202447	113302	52545	-	-
75	Clay	74579	111120	31790	19670	-	-
	Sandy	97802	91327	81512	32768	-	-
	All	-	413816	148898	204677	137965	445831
150	Clay	-	273768	104070	162672	120935	218783
	Sandy	-	139048	44828	42005	17030	227048
	All	-	73451	40763	146556	174565	-
225	Clay	-	70701	38955	127216	172247	-
	Sandy	-	2750	14558	21658	2318	-

---

[1] Blank areas constituted such a small part of the study area that they were combined with adjacent categories.

TABLE 4

SOIL AND WATER RESOURCE SITUATION PERCENTAGES

Depth to Water (ft)	Soil Type	Saturated Thickness (ft) 50	150	250	350	450	550
	All	07.4	08.6	04.8	02.2		
75	Clay	03.2	04.7	01.3	00.8		
	Sandy	04.2	03.9	03.5	01.4		
	All		17.7	06.3	08.7	05.9	19.
150	Clay		11.8	04.4	05.9	05.1	09.
	Sandy		05.9	01.9	01.8	00.7	09.
	All		03.1	01.7	06.2	07.5	
225	Clay		03.0	01.2	05.4	07.4	
	Sandy		00.1	00.5	00.8	00.0	

The broad assumptions underlying the methodology of the OBERS E' projections are: (1) a replacement fertility level, (2) an increase of private output per manhour of 2.9 percent annually, (3) reasonably full employment (4 percent unemployment), (4) no foreign conflicts, and (5) production will migrate to areas of economic opportunities and away from slow growth or declining areas.

Domestic consumption is based on a functional relationship between per capita demand and real income levels for each commodity. Total real disposable income, expressed in constant dollars, is projected to increase at 4.1 percent annually in 1980, and 3.8 percent annually from 1981 to 2020. As real income increases, income elasticity for food decreases; i.e., consumption increasing at a decreasing rate.

Export projections are based on estimated world consumption requirements and the corresponding portion the U.S. is estimated to contribute. World population growth is expected to be 2 percent per year, and export projections are based on the assumption of continued growth in demand and a return to trends established prior to 1972.

Expected crop yield changes involve complex biological relationships, production inputs, and managerial factors. OBERS adjustment factors are based on recent yield trends and give consideration to possible trends in technology, resource availability, and input-product price relationships. The general technique used in estimating future yields is a curvilinear Spillman regression model that projects yields to increase at a decreasing rate over time. A linear extrapolation of the base period, 1950-1974, to the year 2020, serves as a maximum constraint.

OBERS projections tend to show exports, yields, and domestic consumption increasing at a decreasing rate over time. Long term projections are less reliable than short run. National production projections are more reliable than individual state projections. The broader the economic activity, and the shorter the time horizon, the more reliable the projections.

State Production Projections

The underlying assumption for state production estimates is that agricultural production has historically and increasingly moved to areas of comparative economic advantage. Factors such as precipitation, growing season, and soil and water resources are considered in state estimates. The projection techniques provide an extension of historical trends from 1950-1975, but at a decreasing rate of change.

Regional Production Projections

Reduction of the State of Oklahoma projections to the Oklahoma Panhandle's projections involves a simple average of the percentage of state crop production that took place in the Panhandle for the agricultural census years 1954, 1959, 1964, and 1974. These average percentages were held constant in determining the Panhandle's share of projected state production (Table 5).

OBERS projections require state production of a crop to be greater than one percent of national output if projections are to be made on a state level. For Oklahoma, projections are made for wheat, grain sorghum, barley, and hay. For these crops a simple average (5 census years) was taken of the Panhandle's percentage of state production. However, OBERS did not project state production of alfalfa hay, corn, or soybeans. For these crops, alternative methods were developed to project production for the Oklahoma Panhandle.

TABLE 5

AVERAGE PERCENTAGE DISTRIBUTIONS USED TO DERIVE PANHANDLE PRODUCTION GOALS FROM OBERS E' STATE AND NATIONAL PROJECTIONS

Crop	Method	5 Census Year Average
Wheat	Panhandle wheat production as a percentage of Oklahoma wheat production	.0949
Grain Sorghum	Panhandle grain sorghum production as a percentage of Oklahoma grain sorghum production	.4421
Barley	Panhandle barley production as a percentage of Oklahoma barley production	.0243
Hay	Panhandle hay production as a percentage of Oklahoma hay production	.0158
Alfalfa Hay	Panhandle alfalfa hay production as a percentage of panhandle hay production	.5951
	Panhandle alfalfa hay production as a percengate of Oklahoma hay production	.0094
Corn	Oklahoma corn production as a percentage of U.S. corn production	.0013
	Panhandle corn production as a percentage of Oklahoma corn production	.9
	Panhandle corn production as a percentage of U.S. corn production	.0011

Crop	Method	2 Census Year Average
Soybeans	Panhandle soybean production as a percentage of U.S. soybean production	.0000033532

OBERS provide a projection of total hay production for the state, but does not break out alfalfa hay production as a separate category. To derive alfalfa hay production for the Oklahoma Panhandle, a five census year average of Panhandle hay as a percent of state hay (1.58%) was multiplied by a five census year average of Panhandle alfalfa hay as a percentage of projected Oklahoma hay.

For corn, a simple average of Oklahoma's percentage of national production of corn was determined. This average was held constant and used to estimate Oklahoma's future production of corn as a function of national projections. It was assumed that the Panhandle would produce 90 percent of state projections of corn. For soybeans, a simple two year average of the Panhandle's percentage of national soybean output was used to estimate future regional production of soybeans as a function of national projections. The average percentage distributions of crop production are presented in Table 5, and country, state, and Panhandle crop projections are presented in Table 6.

The Distribution of Production

Unless the LP model is controlled in some way, all production would be allocated to the most profitable soil and water resource situations. Because surface irrigation is more profitable than sprinkler, production would be concentrated on clay soils with the lowest depths to water. To guarantee a distribution of production across all resource situations, irrigated crop production was distributed among the 26 soils and water resource situations according to the weight each one carries with respect to the total number of irrigable acres (Table 4). These weights were calculated in the following manner:

$$g^{ijk} = \frac{a^{ijk}}{A} \qquad (3)$$

TABLE 6

PROJECTED QUANTITY OF CROPS PRODUCED FOR THE COUNTRY, STATE, AND PANHANDLE (1980-2020)

	Production Period						
Crop	1980-84	1985-89	1990-94	1995-99	2000-09	2010-19	2020-29
Wheat (1,000 bu.)							
US	1,701,665	1,763,986	1,844,662	1,925,338	2,006,014	2,108,817	2,211,620
OK	140,236	148,655	159,142	169,629	180,116	197,819	215,522
Pan	13,310	14,109	15,104	16,099	17,095	18,775	20,455
Grain Sorghum (1,000 Cwt.)							
US	572,332	633,639	714,176	794,713	875,250	932,094	988,938
OK	13,788	14,897	16,904	18,911	20,918	22,277	23,635
Pan	6,096	6,586	7,473	8,361	9,248	9,849	10,449
Barley (1,000 bu.)							
US	509,014	549,684	284,494	619,304	654,113	698,877	743,641
OK	21,261	24,136	27,046	29,954	32,863	37,424	41,986
Pan	517	586	658	730	801	911	1,021
Hay (1,000 bu.)							
US	131,986	139,617	147,065	154,513	161,961	172,790	183,618
OK	3,157	3,426	3,990	3,990	4,272	4,980	5,688
Pan	49	54	63	63	67	78	90

TABLE 6 (Continued)

	Production Period						
Crop	1980-84	1985-89	1990-94	1995-99	2000-09	2010-19	2020-29
Alfalfa (1,000 bu.)							
US	63,748	67,434	71,320	74,629	78,226	83,456	88,686
OK	1,524	1,654	1,791	1,927	2,063	2,405	2,747
Pan	29	32	34	37	40	46	53
Corn (1,000 bu.)							
US	6,078,769	6,610,181	7,317,351	8,024,521	8,731,691	9,270,959	9,810,226
OK	7,709	8,383	9,280	10,177	11,074	11,758	12,422
Pan	6,938	7,545	8,352	9,159	9,966	10,582	11,197
Soybeans (1,000 bu.)							
US	1,738,010	2,061,304	2,344,010	2,626,717	2,909,423	3,071,054	3,232,684
OK	4,733	5,614	6,384	7,154	7,924	8,364	8,805
Pan	5	6	7	8	9	10	10

where:

i = 75, 150, 225, represents the three depths to water

j = 50, 100, ..., 550, represents the k^{th} saturated thickness class

k = c, s, represents either clay or sandy soils

g^{ijk} = the weight for soil and water resource situation (i. j. k)

a^{ijk} = the number of irrigable acres in soil and water resource situation (i, j, k), and

A = 2,317,187 (the total number of irrigable acres).

Since the number of irrigable acres in the 26 soil and water resource situations sum to A, the weights sum to 1.0. Hence we have:

$$\Sigma\, g^{ijk} = \sum_{i=j}^{3} \sum_{j=1}^{6} \sum_{k=1}^{2} \frac{a^{ijk}}{A} = 1 \tag{4}$$

The production of any one crop is distributed among the 26 soil and water resource situations by multiplying these weights by the appropriate a priori projected production for the specified period given in Table 6. For any period t, let p_t^x, X = 1, 2, . . ., 6. represent the a priori projection of total production for the six irrigated crops in model. The distribution of production among each soil and water resource situation is given by:

$$p_t^{xijk} = g^{ijk} \cdot p_t^x \tag{5}$$

where p_t^{xijk} is the upper limit for production of the X^{th} crop in soil and water resource situation (i, j, k), in period t. These 26 upper limits for each crop are entered in the B_t vector as right hand side restrictions.

Capital and Labor

There are no restrictions on the amount of capital and labor available. It was assumed that all the capital needed for agricultural borrowing could be borrowed at a 10 percent simple interest rate and that the labor necessary for all operations can be hired at a wage rate of $3.50 per hour. The LP model contains activities to total the amount of capital and labor required for all production activities in the 26 soil and water resource situations.

Crop Enterprise Activities

Only the crops currently being irrigated in significant quantities were considered as enterprise activities in the model. Crops included were wheat, grain sorghum, barley, alfalfa, corn for grain, and soybeans. Wheat activities include dryland production and eight, twelve, and eighteen acre inches of irrigation water per acre. Grain sorghum activities include dryland production and six, eighteen, and twenty four acre inches of irrigation water. Barley is produced either dryland and under eighteen inches of irrigation water; corn and soybeans are produced only with twenty-four acre inches of water and alfalfa is produced only with thirty-three inches of water.

The input levels, yields, costs and net returns were calculated for each of the 25 enterprise activities. Irrigation pumping and distribution costs were estimated for center pivot and surface distribution systems for the water resource situations. Irrigated crops were charged the full fixed and variable costs of irrigation water, except for wheat. Because wheat typically receives supplemental water from a system purchased to irrigate summer crops, only the variable costs of irrigation were charged to the wheat activities.

Prices

In an analysis of this type, relative prices of inputs and outputs are of greater importance than absolute price levels. The OBERS projections include historical deflated prices for each crop as well as projections of deflated prices into the future. In this analysis, deflated prices were adjusted to reflect current input/output price relationships and then relative prices, except for the price of natural gas, were held constant throughout the analysis. The deflated wheat price ($1.39 per bushel) was adjusted up to $3.00 to represent current input/output price relationships. Then, other crop prices were adjusted to current levels maintaining the same relationships to wheat price as reflected in the deflated price series. The historical deflated prices, conversion factors, and adjusted prices are presented in Table 7.

Irrigation Costs

Irrigation costs per acre inch and per acre vary depending upon the water resource situation, distribution system, and fuel type. Surface and center pivot sprinkler irrigation systems were designed for each water resource situation specified in the analysis. Well yields varied from 350 gallons per minute for 50 feet of saturated thickness to 1,500 GPM for a saturated thickness of 550 feet (Table 8). Irrigation cost analyses were conducted to determine the engine and pump size required to generate the specified well yield for each water resource situation. In addition, fixed and variable costs per acre inch and per acre were estimated for each irrigation system and water resource situation. These irrigation costs, presented in Table 9, were accounted for in calculating net returns per acre for use in the LP model.

TABLE 7

CROP PRICES

Crop	Units	Deflated Price	Conversion Factor	Adjusted Price
Wheat	bu.	1.39	1.00	3.00
Grain Sorghum	cwt.	1.77	1.27	3.82
Barley	bu.	1.00	.72	2.16
Alfalfa Hay	ton	-	18.00	54.00
Corn	bu.	1.06	.76	2.29
Soybeans	bu.	2.50	1.80	5.40

TABLE 8

INITIAL WATER RESOURCE SITUATIONS AND IRRIGATION PARAMETERS

Soil and Water Resource Situation	Depth to Water (ft.)	Saturated Thickness (ft.)	Well Depth (ft.)	GPM	Drawdown (ft.)	Acres Irrigated
Surface System						
75-50-C	75	50	125	350	35	60
75-150-C	75	150	225	500	90	80
75-250-C	75	250	325	750	140	125
75-350-C	75	350	425	1000	175	165
150-150-C	150	150	300	500	90	80
150-250-C	150	250	400	750	140	125
150-350-C	150	350	500	1000	175	165
150-450-C	150	450	575	1250	200	210
150-550-C	150	550	650	1500	220	250
225-150-C	225	150	375	500	90	80
225-250-C	225	250	475	750	140	125
225-350-C	225	350	550	1000	175	165
225-450-C	225	450	625	1250	200	210
Center Pivot						
75-150-S	75	150	225	500	90	130
75-250-S	75	250	325	750	140	130
75-350-S	75	350	425	1000	175	130
150-150-S	150	150	300	500	90	130
150-250-S	150	250	400	750	140	130

TABLE 8 **(Continued)**

Soil and Water Resource Situation	Depth to Water (ft.)	Saturated Thickness (ft.)	Well Depth (ft.)	GPM	Drawdown (ft.)	Acres Irrigated
150-350-S	150	350	500	1000	175	130
150-450-S	150	450	575	1000	155	130
150-550-S	150	550	650	1000	135	130
225-150-S	225	150	375	500	90	130
225-250-S	225	250	475	750	140	130
225-350-S	225	350	550	1000	175	130
225-450-S	225	450	625	1000	155	130

TABLE 9

INITIAL ENGINE SIZES AND ACRE INCH COSTS

Soil and Water Resource Situation	Depth to Water (ft)	Saturated Thickness (ft)	Engine Size (HP)	Fixed Cost per Acre Inch ($)	Variable Cost per Acre Inch ($)	Total Cost per Acre Inch ($)
Surface Systems - Clay Soils						
75-50-C	75	50	50	1.20	1.48	2.68
75-150-C	75	150	50	1.19	1.51	2.70
75-250-C	75	250	110	1.04	1.62	2.66
75-350-C	75	350	150	.98	1.71	2.69
150-150-C	150	150	70	1.47	1.79	3.26
150-250-C	150	250	130	1.20	1.87	3.07
150-350-C	150	350	190	1.14	1.98	3.12
150-450-C	150	450	280	1.06	2.11	3.18
150-550-C	150	550	370	1.09	2.24	3.33
225-150-C	225	150	90	1.72	2.06	3.78
225-250-C	225	250	170	1.43	2.16	3.59
225-350-C	225	350	250	1.29	2.25	3.54
225-450-C	225	450	330	1.23	2.38	3.61
Center Pivot Systems						
75-150-S	75	150	90	1.92	1.91	3.83
75-250-S	75	250	150	2.15	2.01	4.16
75-350-S	75	350	220	2.41	2.11	4.52
150-150-S	150	150	110	2.11	2.19	4.29
150-250-S	150	250	190	2.36	2.29	4.64

TABLE 9 **(Continued)**

Soil and Water Resource Situation	Depth to Water (ft)	Saturated Thickness (ft)	Engine Size (HP)	Fixed Cost per Acre Inch ($)	Variable Cost per Acre Inch ($)	Total Cost per Acre Inch ($)
150-350-S	150	350	270	2.62	2.39	5.01
150-450-S	150	450	270	2.73	2.34	5.07
150-550-S	150	550	250	2.83	2.28	5.10
225-150-S	225	150	130	2.27	2.46	4.73
225-250-S	225	250	220	2.65	2.56	5.10
225-350-S	225	350	300	2.75	2.61	5.35
225-450-S	225	450	300	2.87	2.59	5.46

Water Level - Pumping Cost Relationships

The decline in the static water level from period to period is directly proportional to the net volume of water removed from the aquifer. This decline may be estimated using the relationship

$$d_t^{ijk} = \frac{W_t^{ijk} \cdot (1-R)}{CS \cdot a^{ijk}} \tag{6}$$

where:

d_t^{ijk} = the decline in the static water level in feet in soil water resource situation (i, j, k)

W_t^{ijk} = the acre feet of water withdrawn from soil and water resource situation (i, j, k)

R = the proportion of water applied which percolates into the aquifer, .20

CS = coefficient of storage, 0.1

a^{ijk} = the appropriate surface (land) area for soil and water resource situation (i, j, k)

Such an approach does not yield an average decline in the water table throughout the study area. It is assumed that water does not move from areas of high pressure to areas of low pressure in sufficient velocity to insure a uniform decline.

The effects of a declining water table are two-fold. First, pump lift (total dynamic head) is increased by the amount of the decline. Second, a decline in the water table decreases the saturated thickness which reduces well yield. As the saturated thickness decreases the new well capacity is computed in the relation:

(7) $$GPM_{t+1} = \left[\frac{ST_{t+1}}{ST_t} \right]^2 \cdot GPM_t$$

where:

GPM_t = the original well capacity in period t

GPM_{t+1} = the new well capacity in period t+1

ST_t = the original saturated thickness in period t

ST_{t+1} = the remaining staurated thickness in period t+1

Curvilinear relationships were developed to estimate irrigation pumping costs as the water levels, saturated thicknesses, and well capacities decreased over time. Engine and pump sized were respecified each time well yield decreased by 250 GPM. The relationships for surface and center pivot irrigation systems are specified in equations (8) and (9), respectively.

(8) Surface: $$WC_{t+1} = \sqrt[2]{\frac{ST_t}{ST_{t+1}}} \cdot WC_t$$

(9) Center Pivot: $$WC_{t+1} = \sqrt[3]{\frac{ST_t}{ST_{t+1}}} \cdot WC_t$$

where:

ST_t = the saturated thickness in period t

ST_{t+1} = the saturated thickness period t+1

WC_t = the water cost in period t

WC_{t+1} = the water cost in period t+1

Equations (8) and (9) are used to revise the water buying activities in vector C_t for period t+1 based on the amount of water pumped and the decline in saturated thickness resulting from the solution for period t.

The multitude of factors which interact to determine the future economic life of the Ogallala aquifer make analysis for the future extremely difficult. Rather than attempting to predict the future, this study attempts to set upper and lower boundaries on possible future outcomes. This task is accomplished by analyzing two separate future scenarios. The first scenario was designed to trace the impact of the decline in the water table through time if current input and output prices maintain their relative positions and the water table declines gradually. Essentially, rising pumping costs are hypothesized to lead to a shift from high to lower intensity irrigation levels and eventually to dryland production. The second scenario is designed to evalute the potential effect on profitability and irrigated production patterns of a gradual increase in the price of natural gas, all other prices maintaining current relative positions. It is hypothesized that the economic life will be shortened somewhat by the rise in the price of natural gas relative to other input and output prices.

The RLP production model was run under each scenario, with Scenario I representing a gradual decline in the water table and Scenario II representing a continuous increase in the price of natural gas. The price of natural gas is allowed to rise by 2 percent per year relative to all other input and output prices. In Scenario II, natural gas cost \$1.40 per thousand cubic feet (MCF) for the 1980-84 period, \$1.54/MCF for 1985-1989, \$1.69/MCF for 1990-94, \$1.86/MCF for 1995-1999, \$2.25/MCF for 2000-2009, \$2.73/MCF for 2010-19, and \$3.30/MCF for 2020-29. These prices are quite similar to predictions made by Holloway. These figures are used to update the cost of the water buying activities in P_t from period to period by revising the appropriate elements of vector C_t in Scenario II.

The following section of this report presents the results of the analysis conducted under Scenario I and II.

RESULTS OF THE ANALYSIS

The changes projected for the study area under Scenarios I and II are presented in this section of the report. Scenario I traces the impact of the decline in the water table through time if relative input and output prices maintain unchanged and the water table declines gradually. Scenario II evaluates the effect on profitability and irrigated production patterns of a gradual increase in the price of natural gas relative to other input and output prices. Results derived from the regional linear programming model include estimates of the number of acres irrigated, the rate of depletion of the aquifer, the quantity of crops produced under alternative irrigation levels, the pattern of irrigated crop production among the 26 soil and water resource situations, and the aggregate annual income for the region.

Benchmark Conditions

Elements of the input-output matrix and the right hand side restrictions were described in the previous chapters. The solution for 1980 was obtained by using the Mathematical Programming System - Extended (MPSX) simple algorithm on the IBM-370 computer. The key solution variables were compared with the reported values of those variables for the year 1977 to establish benchmark conditions and test the validity of the model. Criterion variables of the test included irrigated acreages under surface and center pivot systems, the acreages of the primary irrigated crops in the study area, and the proportions of total crop production resulting from dryland versus irrigated acres.

In 1977, approximately 85,000 acres were irrigated by center pivot irrigation and 300,000 acres were irrigated by surface irrigation in the study area. The regional linear programming model solution contained 68,000 acres under center pivot irrigation and 193,000 acres under surface irrigation. The model further depicted dryland production of 255,000 acres on sandy soils, 3.6 times the acreage irrigated, and 373,000 acres of dryland production on clay soils, almost twice the acreage irrigated on clay soils (193,000). The model's irrigated acreage of individual crops appeared very similar to those reported in 1977. For example, irrigated wheat was reported to total 129,000 acres and irrigated grain sorghum 89,000 acres in 1977. The model's initial solution contained 130,000 acres of irrigated wheat and 80,000 acres of irrigated grain sorghum.

Exact reproduction of the actual events of 1977 was not the goal in verifying benchmark conditions. There are a number of factors which suggest that the model's initial solution may be quite reasonable. First, the enterprise budgets used in fulfilling production requirements within the model represent good management practices with yields considerably above county or study area averages. It is doubtful that all producers in the study area could obtain these yields, particularly on all the acres they have in production. When using the higher budget yields, fewer acres were required to fulfill the production requirements than under actual conditions. Second, all irrigators may not apply as much irrigation water as suggested by the budgets. Some may irrigate alternate rows, others may only apply a pre-plant application, and still others may irrigate five or six times after planting, Thus, irrigated yields exhibit more variability than reflected in the activities included in the model. Third, irrigator's using a center pivot system may report a whole quarter section (160 acres) as being irrigated when only 130 acres are actually irrigated. Thus, more irrigated acres may be reported than actually occur. Farmers may also over-report irrigated acres to establish a water use pattern in case of future control of water use. Finally, a linear programming (LP) model is a normative tool which determines the production pattern required to maximize net returns to the region, subject to resource constraints. This production pattern may be quite different from the actual pattern in the area. When these factors are taken into account, the model was judged to perform satisfactorily in the initial period.

Results of Scenario I: Projected Changes in Irrigated and Dryland Acreage and the Rate of Decline in the Water Table

Clay Soils

The empirical results under Scenario I (Table 10) indicate that as the study area produces its regional share of the six irrigated crops over time, the number of acres under surface irrigation remains fairly constant from the initial 1980-84 period until the 1995-99 period. There are 193,000 acres irrigated in the initial period and 200,000 acres irrigated in 1995-99, followed by a decline to 161,000 acres in the 2000-09 period. There are 75,000 acres under surface irrigation in the period 2010-19, and this number declines to 68,000 acres by the conclusion of the planning horizon. Increases in irrigated acreage are due to the increasing production levels during each

TABLE 10

SCENARIO I - ESTIMATES OF TOTAL IRRIGATED AND DRYLAND ACREAGES (1980-2029)

	Period						
Crop	1980-84	1985-89	1990-94	1995-99	2000-09	2010-19	2020-29
Clay Soils (Acres)							
Wheat Dryland	212,294	225,038	240,914	312,626	369,487	625,408	694,472
Wheat Irrigated	94,657	100,342	111,032	106,292	93,081	9,041	5,574
Grain Sorghum Dryland	147,137	229,667	282,389	349,910	485,964	564,056	611,425
Grain Sorghum Irrigated	61,053	36,810	36,562	43,970	14,172	6,992	3,412
Total Dryland*	372,918	470,016	540,480	681,580	876,342	1,213,236	1,332,532
Total Irrigated**	193,604	178,368	193,132	200,141	161,433	74,697	67,646
Sandy Soils (Acres)							
Wheat Dryland	147,728	156,596	217,778	232,129	275,333	379,863	429,876
Wheat Irrigated	36,505	42,244	24,715	26,343	30,495	7,148	-
Grain Sorghum Dryland	100,737	108,086	135,737	162,562	230,049	311,489	330,485
Grain Sorghum Irrigated	18,429	19,912	20,682	20,829	13,468	-	-

TABLE 10 **(Continued)**

	Period						
Crop	1980–84	1985–89	1990–94	1995–99	2000–09	2010–19	2020–29
Total Dryland*	255,660	272,812	362,581	404,752	516,438	703,908	774,272
Total Irrigated**	67,763	75,365	59,983	62,600	60,751	23,587	14,044

*Includes barley.

**Includes alfalfa, corn, and soybeans.

successive period and to the shift to less intensive levels of water application as the cost of pumping water increases. Producers have an economic incentive to cut back on water application as water costs rise, but decreased yields due to decreased water application result in more irrigated acreage being required to fulfill the projected production levels for future time periods. Dryland production increases steadily on clay soils, from 373,000 acres to 1,300,000 acres by 2020. The largest increase in dryland production occurs after the 2000-09 period, and a large decrease in irrigated production occurs during the same period. The rising water costs in some of the water resource situations tend to divert production from high intensity levels of water application to less intensive levels and finally to dryland production.

Declines in the static water level by soil and water resource situation are presented in Table 11. Water resource situations with small depths to water and large saturated thickness (75-250-C, 75-350-C) experience rapid declines in their water levels over time as a result of increased pumping to irrigate increased production. In these situations the water table declines 12 feet (2.4 feet per year) in the initial period, 33.5 feet (3.3 fpy) in the period 2000-09, and 26 feet (2.5 fpy) during the final period. Other water resource situations with larger depths to water (150-150-C) and smaller saturated thicknesses (75-50-C) show reductions in the decline in the water level as production is switched to less intensive water applications and as irrigated production is replaced by dryland production.

TABLE 11

SCENARIO I - ESTIMATED DECLINES IN THE STATIC WATER LEVEL BY SOIL AND WATER RESOURCE SITUATIONS (1980-2029)

Soil and Water Resource Situation (WRS)	Static Water Level Decline (ft.)						
	1980-84	1985-89	1990-94	1995-99	2000-09	2010-19	2020-29
75-50-C	12.11	12.54	6.91	2.70	5.88	6.30	.02
75-150-C	12.11	12.97	14.22	14.94	21.90	6.30	6.72
75-150-S	11.86	12.70	13.91	15.12	28.79	6.50	.78
75-250-C	12.10	12.97	14.22	15.48	33.46	28.84	6.72
75-250-S	11.86	12.70	13.55	14.71	31.76	6.52	6.96
75-350-C	12.10	12.97	14.22	15.48	33.46	31.37	26.13
75-350-S	11.57	12.39	13.55	10.49	22.42	18.14	6.96
150-150-C	10.31	8.85	9.55	8.72	15.92	6.62	6.72
150-150-S	11.57	11.16	6.34	7.03	6.08	6.52	6.94
150-250-C	11.71	12.55	13.73	8.72	14.87	6.30	6.72
150-250-S	5.21	5.65	2.56	2.80	6.08	6.52	6.94
150-350-C	10.45	11.20	12.30	10.20	5.87	6.30	6.72
150-350-S	2.12	2.31	2.55	2.79	6.07	.68	.78
150-450-C	5.47	5.93	6.70	7.39	16.24	6.53	6.96
150-450-S	2.12	.24	.25	.27	.58	.68	.78
150-550-C	2.06	2.24	2.47	2.70	5.87	6.30	6.72
150-550-S	.22	.23	.25	.27	.58	.68	.78
225-150-C	5.97	6.38	6.91	2.70	5.87	6.30	5.94
225-150-S	2.13	2.31	2.56	2.80	6.08	6.50	6.93
225-250-C	2.06	2.24	2.47	2.70	5.87	6.30	6.72

TABLE 11 **(Continued)**

Soil and Water Resource Situation (WRS)	**Static Water Level Decline (ft.)**						
	1980-84	1985-89	1990-94	1995-99	2000-09	2010-19	2020-29
225-250-S	.17	.18	.20	.22	.47	.55	.63
225-350-C	2.06	2.24	2.47	2.70	5.87	6.30	6.72
225-450-C	2.06	2.24	2.47	2.70	5.84	6.30	6.72

Sandy Soils

The number of acres irrigated by center pivot systems follows a pattern similar to the surface irrigated acres. Irrigated acreage is fairly stable, declining from 68,000 acres during the initial period to 61,000 acres during the 2000-09 period. A large decline in acres irrigated occurs in the 2010-19 period when only 23,500 acres are irrigated on sandy soils. Dryland production increases steadily from 256,000 acres in the initial period to 774,000 acres in the terminal period, with the biggest increase occurring after the 2000-09 period.

Declines in the static water level follow a pattern similar to the clay soils beginning with declines of 11.86 feet (2.4 feet per year) in WRS 75-250-S, increasing to 31.8 feet (3.2 fpy) in the 2000-09 period, before decreasing substantially at the conclusion of the study period. The total acres of dryland and irrigated production for clay and sandy soils are presented in Table 10. The declines in the static water level by soil and water resource situation are given in Table 11.

Projected Acreages in Irrigated and Dryland Crop Production

Clay Soils

As the static water level declines and the cost per acre inch of water increases, producers are provided an economic incentive to reduce water applications. For those crops with reduced levels of water application, irrigators are expected to switch to the less intense levels and then to dryland production. This applies to wheat, grain sorghum, and barley. Corn, alfalfa, and soybeans are assumed to be produced at an intensive irrigation level and are not assumed feasible under dryland conditions in the area. As water costs increase, these activities will drop out of the solution when their net returns decline to the point where dryland crops are more profitable. The net return of wheat is the most sensitive to water cost changes followed by grain sorghum, soybeans, corn, and alfalfa, respectively. Wheat is the first crop to shift to less intense application levels and finally to dryland production. There are 95,000 acres of irrigated wheat in the initial period, 110,000 acres in the 1990-94 period, and only 5,000 acres of irrigated wheat at the conclusion of the study period. There are 61,000 acres of irrigated grain sorghum in the initial period, 41,000 acres irrigated in the 1995-99 period and only 3,000 acres of irrigated production occurring in the terminal period. Irrigated barley fails to enter the solution. Alfalfa and soybeans show gradual increases in irrigated acreage over the study period. Irrigated corn acreage increases from an initial 35,000 acres to 54,000 acres in the terminal period. Dryland wheat increases steadily from 212,000 acres in the initial period to 700,000 acres in the terminal period. The largest increase comes after the period 2000-09 when dryland wheat acreage increases from 370,000 to 625,000 acres. Dryland grain sorghum increases from 147,000 acres up to 611,000 acres with the largest increase occurring after the 1995-99 period. These changes are presented in Table 12.

Sandy Soils

Irrigated wheat on sandy soils entered the solution at 37,000 acres in the initial period and increased to 42,000 in the subsequent,

TABLE 12

SCENARIO I - CLAY SOILS - ESTIMATES OF ANNUAL IRRIGATED AND DRYLAND ACREAGES OF THE VARIOUS CROPS (1980-2029)

		Period						
Crop		1980-84	1985-89	1990-94	1995-99	2000-09	2010-19	2020-29
Wheat	Dry (Acres)	212,294	225,038	240,914	312,626	369,487	625,408	694,472
"	8"	10,368	10,990	24,178	28,856	71,355	-	5,574
"	12"	20,226	21,440	22,952	56,975	-	9,041	-
"	18"	64,066	67,912	63,902	20,461	21,726	-	-
Grain Sorghum	Dry (Acres)	147,137	229,667	282,389	349,910	485,864	564,056	611,425
"	6"	27,681	-	-	22,479	-	5,174	3,412
"	18"	22,075	28,440	27,065	18,124	10,448	1,818	-
"	24"	11,297	8,370	9,497	3,367	3,724	-	-
Barley	Dry (Acres)	13,487	15,311	17,177	19,044	20,891	23,772	26,635
"	18"	-	-	-	-	-	-	-
Alfalfa	33" (Acres)	2,981	3,236	3,495	3,769	4,003	4,831	5,648
Corn	24" (Acres)	34,805	37,848	41,897	45,947	49,996	53,642	53,411
Soybeans	24" (Acres)	108	132	146	163	181	191	201

1985-89 period. There were 30,000 acres irrigated in the 2000-09 period, 7,000 acres irrigated in the 2010-19 period, and no irrigated wheat at the conclusion of the study period. Irrigated grain sorghum acreage on sandy soils increased steadily from 18,000 acres in the initial period to 21,000 acres in the 1995-99 period. There were only 13,000 acres irrigated from 2000-09, but no irrigated grain sorghum in the final period. All barley was produced under dryland conditions. Irrigated alfalfa showed steady increases throughout the study period while corn and soybean acreages peaked in the period 2000-09. Dryland acreage for wheat showed a large increase after 1985-89, and another large increase after 2000-09. Dryland grain sorghum showed a large increase after 1995-99, and a larger increase after 2000-09. In summary, the most dramatic shifts from irrigated to dryland production on sandy soils occurred after the period 2000-09. These shifts are presented in Table 13.

Changes in Production Patterns Among Water Resource Situations

Clay Soils

For the first two time periods, production patterns were stable except for water resource situations with shallow saturated thicknesses. As the water supply in water resource situation (WRS) 150-150-C was being depleted during the initial period, grain sorghum production shifted from irrigated to dryland. This resulted in early declines in the number of acres of clay soils irrigated and the number of acres of irrigated grain sorghum.

TABLE 13

SCENARIO I - SANDY SOILS - ESTIMATES OF ANNUAL IRRIGATED AND DRYLAND ACREAGE OF THE VARIOUS CROPS (1980-2029)

					Period			
Crop		1980-84	1985-89	1990-94	1995-99	2000-09	2010-19	2020-29
Wheat	Dry (Acres)	147,728	156,596	217,778	232,124	275,333	379,863	429,867
"	8"	-	-	-	-	-	7,148	-
"	12"	-	19,158	-	-	15,247	-	-
"	18"	36,505	23,068	24,715	26,343	15,548	-	-
Grain Sorghum	Dry (Acres)	100,037	108,086	135,737	162,562	230,049	311,489	330,485
"	18"	11,127	12,022	15,952	15,537	13,468	-	-
"	24"	7,302	7,890	4,730	5,292	-	-	-
Barley	Dry (Acres)	7,195	8,130	9,066	10,061	11,056	12,556	13,911
"	18"	-	-	-	-	-	-	-
Alfalfa	33" (Acres)	1,355	1,471	1,592	1,713	1,834	2,138	2,442
Corn	24" (Acres)	10,763	11,705	12,957	13,673	14,878	14,268	11,583
Soybeans	24" (Acres)	28	33	37	42	46	33	19

Major shifts in production patterns occurred after the 1995-99 period, the 2000-09 period, and after the 2010-19 period. Two factors contribute to the shifts in production patterns. First, water resource situations with shallow saturated thicknesses experience rapid declines in well yields and increases in pumping costs as the water table declines. Second, water resource situations with relatively large depths to water have high initial costs and, as the water level declines, water costs need only increase slightly in some cases to cause shifts in production patterns. Thus, irrigation of wheat and grain sorghum ceases in some water resource situations early in the planning horizon while in intermediate water resource situations with adequate water and reasonable pumping costs, irrigation of wheat and grain sorghum continues in the terminal period.

In water resource situations with higher initial water costs, and in the water resource situations when irrigated wheat and grain sorghum are discontinued, less water is pumped to irrigate the more profitable crops of alfalfa, corn, and soybeans. As a result, changes in water costs are substantially smaller, and it is not until after the 2010-19 period that these crops are affected by increased water costs.

Net Returns

Net returns to producers in the study area increase from 19.5 million dollars per year in the initial period to 28.4 million dollars per year at the conclusion of the study. Since dryland production is profitable, and the production requirements increase throughout the study, net income increases as crop production shifts from high levels of irrigation to less intensive levels and finally to dryland, The change in net income reflects a reduced rate of growth in the area. Income increases at an increasing rate until 1995. During the period 1995-2000, the first annual decline in the rate of growth occurs as production on clay soils shifts from irrigated to dryland. During the following period, 2000-2010, a sharper decline in the rate of growth is experienced as larger numbers of acres shift from irrigated to dryland production.

Results of Scenario II: Projected Changes in Irrigated and Dryland Acreage and the Rate of Decline in the Water Table

Clay Soils

Scenario II reflects a gradual increase in the price of natural gas relative to the prices of other inputs and outputs. Under this scenario, there is a steady decline in irrigated acres to 56,000 acres in the 2000-09 period. There is a small increase of irrigated acreage in the final period of analysis (Table 14). There are shifts to less intense applications of water as costs increase accompanied by some increases in irrigated acres. However declines in the water table and rising natural gas price eventually lead to shifts from irrigated to dryland production.

Declines in the static water level in the alternative water resource situation are presented in Table 15. Water resource situations with small depths to water and deep saturated thicknesses exhibit the largest declines over the period of analysis. WRS 75-150-C, 75-250-C, and 75-350-C have declines of 12.1 feet (2.4 fpy) in the initial period and the declines increase to 14.94 feet (2.9 fpy) in the 1995-99 period. After the 1995-99

TABLE 14 (Continued)

	Period						
Crop	1980-84	1985-89	1990-04	1995-99	2000-09	2010-19	2020-29
Total Dryland*	245,960	-	450,059	582,991	629,802	718,603	774,264
Total Irrigated**	67,088	52,863	47,557	17,379	18,864	3,931	323

*Includes barley.
**Includes alfalfa, corn, and soybeans.

TABLE 15

SCENARIO II - ESTIMATED DECLINES IN THE STATIC WATER LEVEL BY SOIL AND WATER RESOURCE SITUATIONS (1980-2029)

Soil and Water Resource Situation (WRS)	Static Water Level Decline (ft.)						
	1980-84	1985-89	1990-94	1995-99	2000-09	2010-19	2020-29
75-50-C	12.11	12.54	2.47	2.70	5.88	-	-
75-150-C	12.11	12.97	13.74	14.94	5.87	6.30	6.72
75-150-S	11.86	12.70	12.60	7.03	15.44	.68	.78
75-250-C	12.10	12.97	14.22	14.94	11.99	6.30	6.72
75-250-S	11.86	12.38	12.24	2.80	6.09	6.50	-
75-350-C	12.10	12.97	14.22	12.12	16.24	6.30	6.72
75-350-S	11.57	6.69	2.55	2.79	.58	.68	-
150-150-C	10.31	8.85	8.11	2.70	5.90	6.62	-
150-150-S	11.57	5.64	2.56	2.80	6.01	.68	.78
150-250-C	11.71	11.20	2.46	2.70	5.87	6.29	6.72
150-250-S	5.21	2.32	2.55	.27	.58	-	-
150-350-C	10.45	10.07	2.47	2.70	5.87	6.29	6.72
150-350-S	2.12	.23	-	-	-	-	-
150-450-C	5.47	4.41	2.47	2.70	5.87	6.29	6.72
150-450-S	2.12	.23	-	-	-	-	-
150-550-C	2.06	2.24	2.47	2.70	5.87	6.29	6.72
150-550-S	.22	.23	-	-	-	-	-
225-150-C	5.97	2.24	2.47	2.70	5.87	6.29	6.72
225-150-S	2.13	2.31	2.55	2.79	.58	-	-
225-250-C	2.06	2.24	2.47	2.70	5.87	6.29	.78

TABLE 15 **(Continued)**

Soil and Water Resource Situation (WRS)	Static Water Level Decline (ft.)						
	1980-84	1985-89	1990-94	1995-99	2000-09	2010-19	2020-29
225-250-S	.17	.19	-	-	-	-	-
225-350-C	2.06	2.24	2.47	2.70	5.87	6.29	6.72
225-450-C	2.06	2.24	2.47	2.70	5.84	6.29	6.72

period, the rate of decline slows as irrigated production becomes less economical and less water is pumped.

Sandy Soils

Acreage irrigated by center pivot systems declined from 67,000 acres at the outset, to 48,000 acres in the 1990-95 period. In the following periods, acres irrigated fall to 17,000 acres in the 1995-99 period, increase to 19,000 acres in the 2000-09 period, and decline further to 323 acres in the terminal period. This phenomena of irrigated acreage decreasing, increasing and then decreasing through time is due to increasing pumping costs and projection of increasing production in the region during the period of analysis. As the water table decreases, GPM decreases and the cost of pumping water increases. The profitability of irrigated activities decreases and approaches the profitability of dryland production. Intensively irrigated activities become unprofitable, while lower intensity activities still remain more profitable than dryland. With production projected to increase, more acres of lower intensity activities are required to meet production projections.

Projected Acreages in Irrigated and Dryland Crop Production

Clay Soils

In the initial period of the analysis, 94,600 acres of wheat are irrigated with the acreage increasing to 95,400 acres in the subsequent 1985-89 period. With rising natural gas prices, there is a substantial decrease to 57,000 acres irrigated in 1990-94 period, followed by another decrease to 21,000 acres in the subsequent period. No wheat is irrigated after the 1995-99 period. Irrigated grain sorghum follows a similar pattern, but does not go out of irrigation until 2000-09. Dryland wheat acreage increases steadily with the largest increase occurring after the 1990-94 period. Dryland grain sorghum showed steady increases with the biggest increase occurring after the 1990-94 period. Alfalfa showed a steady increase in irrigated production throughout the study, while corn and soybeans peaked in the 2010-19 period (Table 16).

Sandy Soils

There are 36,500 acres of wheat being irrigated by center pivot systems in the 1980-84 period, 24,700 acres in the subsequent period and 25,500 acres in the 1990-94 period. There is no irrigated wheat beyond 1990-94 due to rising gas prices and declines in the water table. Irrigated grain sorghum shows a steady decline but there are 7,000 acres still being irrigated in the 2000-09 period. Dryland production shows a steady increase for both crops as shown in Table 17. Irrigated production of alfalfa, corn, and soybeans was relatively constant over time indicating a somewhat higher level of profitability for these crops than for wheat and grain sorghum. However, only irrigated alfalfa remains in production in the 2020-29 period.

Changes in Production Patterns Among Water Resource Situations

Clay Soils

With the increase in the price of natural gas, the model depicts changes in irrigated acres in six water resource situations after the first five-year period. Crops being produced under high levels of irrigation switch to less intense applications and some crops being produced

TABLE 16

SCENARIO II - CLAY SOILS - ESTIMATES OF ANNUAL IRRIGATED AND DRYLAND ACREAGES OF THE VARIOUS CROPS (1980-2029)

		Period						
Crop		1980-84	1985-89	1990-94	1995-99	2000-09	2010-19	2020-29
Wheat	Dry (Acres)	212,294	225,038	363,987	493,577	590,477	648,513	706,549
"	8"	10,368	25,288	-	3,505	-	-	-
"	12"	20,225	13,716	38,769	-	-	-	-
"	18"	64,066	56,440	19,196	17,975	-	-	-
Grain Sorghum	Dry (Acres)	147,137	229,667	395,572	442,541	529,656	583,889	619,492
"	6"	27,681	13,164	-	-	4,857	-	-
"	18"	22,075	20,999	7,756	12,705	1,707	-	-
"	24"	11,297	8,370	3,010	-	-	-	-
Barley	Dry (Acres)	13,487	15,311	17,177	19,044	20,891	23,773	26,635
"	18"	-	-	-	-	-	-	-
Alfalfa	33" (Acres)	2,981	3,236	3,495	3,768	4,003	4,680	5,298
Corn	24" (Acres)	34,805	37,848	41,896	45,946	49,996	51,034	50,794
Soybeans	24" (Acres)	109	131	146	163	181	182	182

TABLE 17

SCENARIO II - SANDY SOILS - ESTIMATES OF ANNUAL IRRIGATED AND DRYLAND ACREAGES OF THE VARIOUS CROPS (1980-2029)

		Period						
Crop		1980-84	1985-89	1990-94	1995-99	2000-09	2010-19	2020-29
Wheat	Dry (Acres)	147,728	227,241	255,093	338,332	359,248	394,558	429,867
"	8"	-	5,372	-	-	-	-	-
"	12"	-	-	25,495	-	-	-	-
"	18"	36,505	19,405	-	-	-	-	-
Grain Sorghum	Dry (Acres)	100,037	128,055	185,901	234,598	259,498	311,489	330,485
"	18"	11,127	12,239	5,132	6,433	7,116	-	-
"	24"	7,307	4,168	4,736	-	-	-	-
Barley	Dry (Acres)	7,195	8,130	9,065	10,061	11,056	12,556	13,912
"	18"	-	-	-	-	-	-	-
Alfalfa	33" (Acres)	1,358	1,473	905	974	1,042	966	323
Corn	24" (Acres)	10,763	10,173	11,262	10,939	10,686	2,965	-
Soybeans	24" (Acres)	28	33	33	33	20	-	-

at less intense applications levels shift to dryland production. As the water table declines, increases in the price of natural gas accelerate the movement towards dryland production in the shallower saturated thickness and larger depth-to-water resource situations. These movements result in wheat and grain sorghum being produced under dryland conditions in WRS 75-150-C, 150-250-C, and 150-350-C, after the 1985-89 period. Alfalfa, corn, and soybeans are forced out of production in the later time periods as the shallow saturated thicknesses run out of water.

Sandy Soils

The increase in the price of natural gas has a more pronounced effect on center pivot systems than on surface irrigation systems. Consumption of natural gas is a function of brakehorsepower and center pivot systems require higher brakehorsepowers to sustain the pressure necessary to operate. After the first period 1980-84, there are shifts to less intensive water applications is WRS 75-250-S and 75-350-S. There are shifts to dryland production in WRS 75-350-S, 150-150-S, and 150-250-S. Corn drops out of production in WRS 150-350-S and 150-450-S, and soybeans drop out of WRS 225-150-S. After fullfilling production requirements in the period 1985-89, returns from dryland production were higher than those under irrigation in four water resource situations with large saturated thickness. The rise in the price of natural gas curtailed irrigation in water resource situations with large depths to water.

Net Returns

Net returns on an annual basis were 19.5 million dollars in 1980 and increase up to 27.5 million dollars in the year 2020. Net returns increase at an increasing rate from 1980 until the year 2000. Thereafter, net returns increase at a decreasing rate. Reduced profitability accompanying the increase in natural gas price and the conversion of substantial acres to dryland production after the year 2000 account for the slowing of the rate of increase of income.

SUMMARY AND CONCLUSIONS

This study analyzes the economic life of the underground water supply in the Oklahoma Panhandle under two basic sets of assumptions or scenarios. In scenario I relative prices of inputs and outputs are assumed constant over the period of the analysis. This scenario evaluates the effects of the declining water supply on irrigation well yields and pumping costs and on the pattern of irrigated and dryland crop production in the study area. Irrigation technology is assumed constant over the period and public institutions, such as the Oklahoma Water Resources Board, are assumed to take no regulatory actions to reduce water use. The Oklahoma Panhandle region is assumed to maintain its relative share of state production of the prinicipal crops in the area. State projections of future production levels are based on OBERS E' population and production estimates. Because state production of the principal crops in the Oklahoma Panhandle is projected to increase, production of the crops in the Panhandle is also projected to increase. The regional linear programming model developed for this analysis selects the combination of dryland and irrigated crop activities which maximizes net returns to producers in the region subject to a set of constraints, including the projected production levels for the region.

Under Scenario I, solutions of the model depict a gradual conversion from irrigated to dryland production (Table 18). Production of irrigated wheat is projected to increase during the 1985-89 period and thereafter to decline gradually. Part of this increase in wheat acreage during the initial period relfects shifts to less intensive levels of irrigation. Because wheat is a winter crop and most irrigation systems are purchased to irrigate the summer crops corn and grain sorghum, only variable costs of production are charged against the wheat enterprise. Fixed and variable costs are charged against all other crop activities. Beginning with the 1990-94 period, production of irrigated wheat is projected to decline for the remainder of the period of analysis. However, by the 2020-29 period, only about 5,600 acres of wheat are projected to remain in irrigated production. Dryland wheat acres expand throughout the period of the analysis. With irrigated acreage of wheat decreasing due to the declining water table and rising pumping costs, the higher production levels projected for the region are satisfied by substantial expansion in dryland wheat acres.

The pattern of production changes projected for grain sorghum is similar to that of wheat. Irrigated acres of grain sorghum are projected to decline during the 1985-89 period. However, during the next two periods, irrigated acres expand by about 14 percent as shifts from high intensity to lower levels of water application are projected to occur. Following a peak in the 1995-99 period, irrigated grain sorghum acres are projected to decline to about 3,400 acres during the 2020-29 period. Production of dryland grain sorghum is projected to increase throughout the entire period to satisfy the projections of increased grain sorghum production in the region.

Scenario II is designed to determine the potential impact of the

Table 18. Summary of Irrigated and Dryland Wheat and Grain Sorghum Acreages, Scenarios I and II.

Crop	1980-84	1985-89	1990-94	1995-99	2000-09	2010-19	2020-29
			(SCENARIO I - CONSTANT RELATIVE PRICES)				
Wheat	491,184	524,220	594,439	677,390	768,396	1,021,460	1,129,922
Dryland	360,022	381,634	458,692	544,755	644,820	1,005,271	1,124,876
Irrigated	131,162	142,586	135,747	132,635	123,576	16,189	5,574
Grain Sorghum	327,356	394,475	475,370	577,271	743,653	882,537	945,322
Dryland	247,874	337,753	418,126	512,472	716,013	875,545	941,910
Irrigated	79,482	56,722	57,244	64,799	27,640	6,992	3,412
			(SCENARIO II - RISING RELATIVE PRICE OF NATURAL GAS)				
Wheat	491,184	572,500	701,771	853,389	949,725	1,043,071	1,136,416
Dryland	360,022	452,279	619,080	831,909	949,725	1,043,071	1,136,416
Irrigated	131,162	120,221	82,691	21,480	0	0	0
Grain Sorghum	327,356	416,662	602,101	695,277	802,834	895,378	949,977
Dryland	247,874	357,722	581,473	677,139	789,498	895,378	949,977
Irrigated	79,482	58,940	20,628	18,138	13,680	0	0

Crop	1980-84	1985-89	1990-94	1995-99	2000-09	2010-19	2020-29
			(SCENARIO I - CONSTANT RELATIVE PRICES)				
Wheat	491,184	524,220	594,439	677,390	768,396	1,021,460	1,129,922
Dryland	360,022	381,634	458,692	544,755	644,820	1,005,271	1,124,876
Irrigated	131,162	142,586	135,747	132,635	123,576	16,189	5,574
Grain Sorghum	327,356	394,475	475,370	577,271	743,653	882,537	945,322
Dryland	247,874	337,753	418,126	512,472	716,013	875,545	941,910
Irrigated	79,482	56,722	57,244	64,799	27,640	6,992	3,412
			(SCENARIO II - RISING RELATIVE PRICE OF NATURAL GAS)				
Wheat	491,184	572,500	701,771	853,389	949,725	1,043,071	1,136,416
Dryland	360,022	452,279	619,080	831,909	949,725	1,043,071	1,136,416
Irrigated	131,162	120,221	82,691	21,480	0	0	0
Grain Sorghum	327,356	416,662	602,101	695,277	802,834	895,378	949,977
Dryland	247,874	357,722	581,473	677,139	789,498	895,378	949,977
Irrigated	79,482	58,940	20,628	18,138	13,680	0	0

rising real price of natural gas over the coming years. While the assumption of the rate of growth in natural gas price relative to other inputs and outputs is arbitrary, most observers agree that real price increases will occur. In this analysis, the price of natural gas was assumed to increase by two percent per year relative to the prices of other inputs and output. Resources did not permit separate projections of input and output prices for this study. Separate analyses and projections of relative price changes into the future should be of high priority for additional analyses in this area.

The rising price of natural gas relative to other prices reduces substantially the economic life of the irrigation water supply in the study area.

The production of irrigated wheat is projected to decline steadily until, during the 2000-09 period, no wheat is produced under irrigated condition. Production of dryland wheat expands throughout the period of analysis. The production of irrigated grain sorghum also declines throughout the study period. About 13,700 acres remain under irrigation during 2000-09, but all grain sorghum is produced dryland by the 2010-19 period.

While these estimates of the economic life of the water supply in the Oklahoma Panhandle must be considered tentative and preliminary in nature pending the outcome of more comprehensive analysis such as the $6 million Six States High Plains Ogallala Aquifer Area Study, these results seem reasonable from an intuitive standpoint. The decline in the underground water supply and conversion from irrigated to dryland-production will be a part of the future of the Oklahoma Panhandle. One may question exactly when this conversion will occur and which crops

Schwartz, Harold J. "An Economic Analysis of Energy Use and Agricultural Output for Representative Farms in the Oklahoma Panhandle." M.S. thesis, Oklahoma State University, Stillwater, 1975.

Sharples, Jerry A. "The Representative Farm Approach to Estimating Supply Response." American Journal of Agricultural Economics, 51(1969):353-34.

Thompson, Mark. Soils and Groundwater Resource Situation in the Oklahoma Panhandle, Beaver, Cimarron, and Texas Counties, U.S.D.A. Unpublished paper, Ag. Econ. Dept., Oklahoma State University, Stillwater, 1978.

Water Resource Council. Guidelines 3 OBERS E' Baseline Projections Agencies and Individuals. 1975.

Universal Oil Products Co. Groundwater and Wells. St. Paul: Johnson Division, 1972.