AN ECONOMIC ANALYSIS OF WATER-RELATED TECHNOLOGY IN THE OKLAHOMA HIGH PLAINS

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AN ECONOMIC ANALYSIS OF WATER-RELATED
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INTRODUCTION

Statement of the Problem

Irrigated agriculture is important to the economic well-being of the Oklahoma Panhandle. The Oklahoma Panhandle consists of Beaver, Texas, and Cimarron counties of Oklahoma. During the growing season, crop growth is affected by high evaporation of water from the soil and transpiration by the plant. The climatic conditions that cause this are characterized by sparse precipitation, high temperatures, and often strong winds. The mean annual rainfall in the Oklahoma Panhandle ranges from 16 inches in Cimarron county to 22 inches in Beaver county. Low yields in this semi-arid area have led to increased development of irrigation in the past 40 years.

The primary source of irrigation water for the Oklahoma Panhandle is the High Plains-Ogallala Aquifer. As depicted in Figure 1, the Ogallala Aquifer encompasses an area of about 225,000 square miles in Colorado, Nebraska, Kansas, New Mexico, Texas, and Oklahoma. The Ogallala Formation is the most productive groundwater formation of the High Plains and one of the most intensively developed aquifers in the United States.

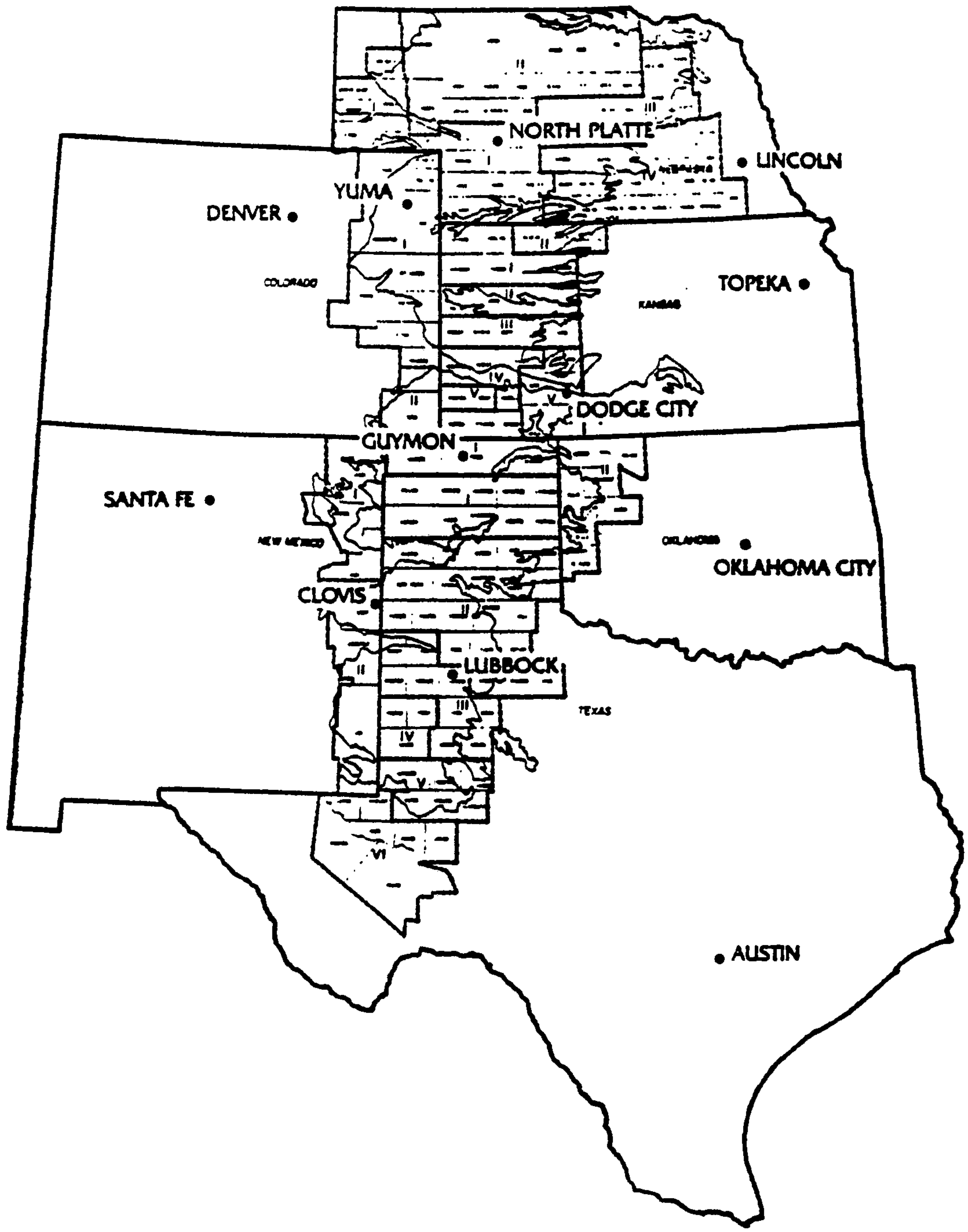

Figure 1. Map of the Ogallala Aquifer in the Central Great Plains

The Ogallala Aquifer underlies about 6,300 square miles or 9 percent of the land in Oklahoma (Figure 2). Counties that benefit from the Ogallala are Beaver, Texas, Cimarron, Harper, Woods, Ellis, Woodward, Roger Mills, Beckham, and Dewey. The overlying land contributes a significant proportion of the state's irrigated crops. Approximately 75 percent of the irrigated wheat, 85 percent of the irrigated sorghum, and 76 percent of Oklahoma's total feed corn crop are irrigated using groundwater from the Ogallala (Sparks, 1983). The Oklahoma Panhandle lies within the Central Basin of the Ogallala Aquifer, an area bounded on the north by the Arkansas River in Kansas and the south by the Canadian River in Texas.

Most of the well development for mining the Ogallala has occurred in the three Panhandle counties (Beaver, Texas, and Cimarron). In 1960, there were approximately 400 wells in the three county area. As a result of irrigation development occurring over the next two decades, this number increased to 2,227 wells by 1980. The number of acres under irrigation grew from 11,500 acres in 1950 to more than 400,000 acres in 1981 (Schuab, 1981). As a result of depressed agricultural conditions in the current decade, irrigation acreage has declined to a little over 330,000 acres by 1985 (Schuab, 1985). Municipal and industrial requirements also account for a portion of the water pumped from the Ogallala.

Much of the area's and state's industrial economy has

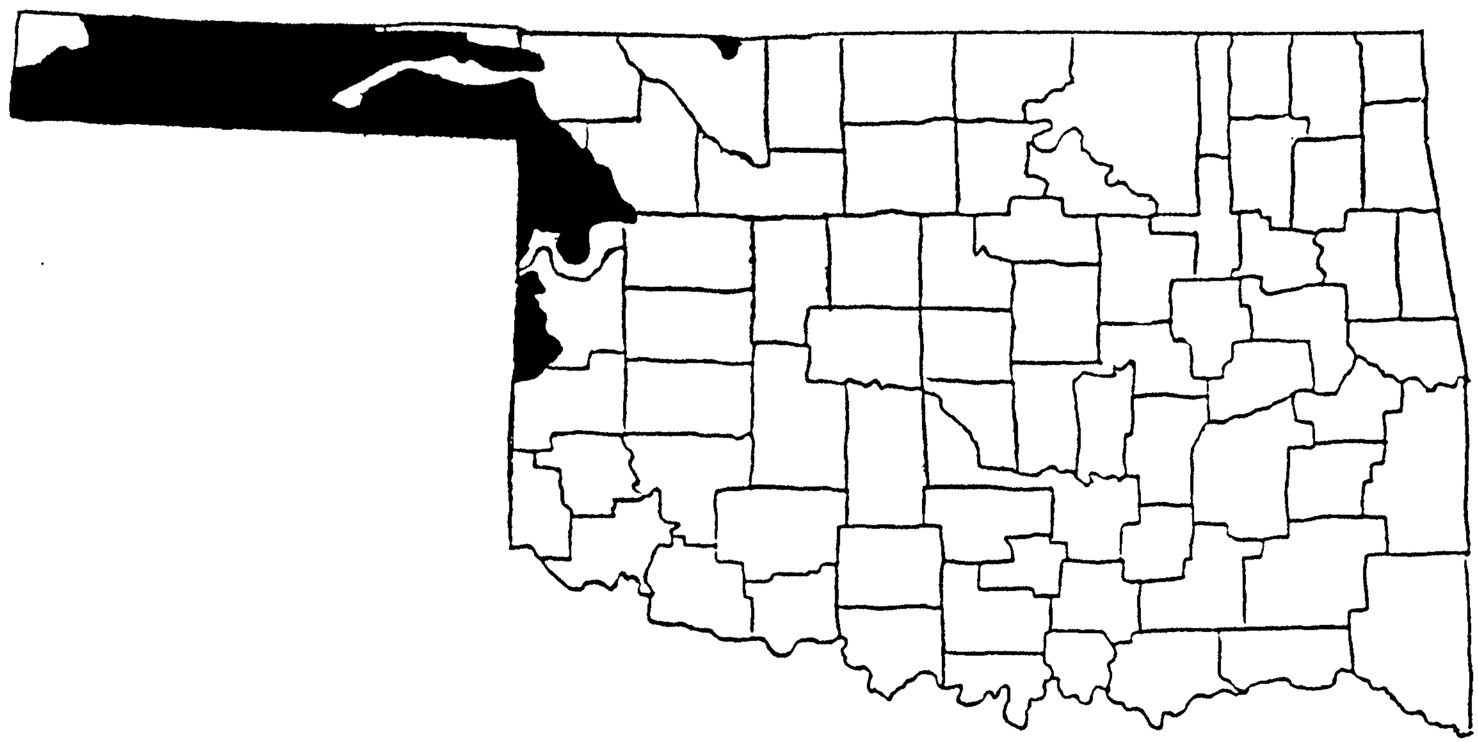

Figure 2. Ogallala Aquifer Area Underlying Oklahoma

grown in response to such agricultural development and is largely dependent upon its continuation. The Ogallala was once considered an inexhaustible water source on which the wealth of the region could feed forever. However, as acres under irrigation increased during the 1950-1980 period, withdrawals of water from the Ogallala aquifer greatly exceeded natural recharge. The water table began to decline, pumping lifts increased, well yields were reduced and irrigation pumping costs rose. Continued overdraft of the aquifer results in a declining water table and will lead to eventual economic exhaustion of the water resource. Economic exhaustion occurs when it is no longer profitable to continue pumping the ground water. Increases in the price of natural gas and other fossil fuels further reduce the economic life of the aquifer (Sparks, 1983).

As indicated in Table I, natural gas is the primary fuel used for pumping ground water in the Oklahoma Panhandle. In 1983, 91 percent of the irrigated acres in the Oklahoma Panhandle were irrigated by natural gas fueled engines. This increased to 93 percent in 1985.

With the mining of the Ogallala taking place at a faster rate than the aquifer can be recharged compounded with increased pumping costs, doubts are being cast as to how long it will remain economically feasible to continue pumping from the aquifer. The growth of irrigation slowed during the 1970's due to declining water supplies, combined with rising energy costs and depressed commodity prices.

TABLE I

ENERGY SOURCE FOR PUMPING GROUNDWATER IN THE OKLAHOMA PANHANDLE, 1983 AND 1985

County	Natural Gas	Diesel	Propane	Electric
	------------Acres------------			
1983:				
Beaver	16,806	5,041	2,689	8,402
Texas	165,780	---	---	6,000
Cimarron	122,600	500	5,500	1,500
Total	305,186	5,541	8,189	15,902
State Total	393,737	32,714	63,811	127,574
1985:				
Beaver	16,806	5,041	2,689	8,402
Texas	170,780	---	---	5,815
Cimarron	117,600	500	500	400
Total	305,186	5,541	3,189	14,617
State Total	383,851	31,073	48,333	127,574

Source: Irrigation Survey Oklahoma 1983 and 1985

Low profitability has resulted in a partial return to dryland production since 1980.

Producers in the Oklahoma Panhandle are experiencing similar problems as farmers throughout the United States. These problems center around high production costs and low commodity prices. This problem is compounded for irrigated producers because the price of natural gas (the primary energy source used for pumping irrigation water in the Oklahoma Panhandle) is rising faster than inflation. The large capital costs required by irrigation also places an additional economic burden on area producers. Commodity prices are lowered by high transportation costs due to the remote location of the three panhandle counties from major terminal markets. A recent analysis suggests that agricultural commodity prices have an even larger impact than energy prices on the economic life of the irrigation water supply in the Oklahoma Panhandle (Camp Dresser et al., 1982).

Irrigated acreage under the different irrigation systems for 1985 in the Oklahoma Panhandle counties, along with state totals, are shown in Table II. In 1985, 68 percent of the state's gravity systems and 43 percent of the state's center pivot systems were located in the three Panhandle counties. Ninety-eight percent of the irrigated acreage in the Oklahoma Panhandle in 1985 consisted of either gravity or center pivot systems. This finding indicates the importance of considering these two systems

TABLE II

1985 IRRIGATION SYSTEM ACREAGE

System	Beaver	Texas	Cimarron	Total	State Total
	Acres				
Gravity	8,304	133,875	100,000	242,179	354,426
Handmove	0	30	0	30	30,855
Side-roll	5,250	500	0	5,750	103,341
Traveling Gun	0	150	0	150	19,346
Center Pivot	20,046	42,640	19,970	82,656	194,256
Lateral Move	0	120	0	120	2,456
Total	33,600	177,315	119,970	330,885	704,680

Source: 1985 Irrigation Survey Oklahoma

for studies with applications for the future. Therefore, this study analyzes irrigation adoption based on these systems.

The adoption of new irrigation technologies and practices is one means that farmers throughout irrigated regions may respond to the current situation. Many irrigators have converted to various energy and water efficient low-pressure center pivot or gated-pipe systems. Other recently developed technologies, such as the Low Energy Precision Application (LEPA) sprinkler system, may result in significant irrigation cost savings. Variable pumping costs are reduced by these systems because they reduce operating pressure and improve water application efficiency. Surge valves and tailwater reuse systems are important adjustments to conventional gated-pipe systems to increase application efficiency and reduce variable costs.

Investment decisions in irrigation are among the most important decisions undertaken by irrigation producers. These decisions typically involve the commitment of large sums of money and will affect the farm operation over a number of years. The cost of the investment is incurred immediately, whereas the income or benefits occur over time. Because the benefits are based on future events, producers have to evaluate investment alternatives as thoroughly as possible. This evaluation may include alternative scenarios with respect to prices, productivity, water availability, and government policies. When making investment decisions producers should also take into consideration their financial conditions, labor availability, and attitudes toward risk.

Irrigation farmers are also becoming more concerned with irrigation scheduling and improved management techniques. Adoption of new irrigation technology can allow producers more flexibility in the irrigation schedules and practices they choose to implement in order to increase yields or lower costs through fewer applications.

Research Focus

This study focuses on outlining the optimal path of adoption of new irrigation technology through the use of a multiperiod mathematical programming model. The analysis centers on converting basic center pivot and flood irrigation systems to more efficient and cost effective irrigation systems over a period of time.

The model developed in this analysis was applied to representative production settings in the Oklahoma Panhandle. Irrigated agriculture in this area is extremely important to the region. Several crops are grown using a variety of farm sizes, irrigation technologies, and managerial practices. In addition, producers are experiencing increases in irrigation costs, generating a need for information on more efficient irrigation system alternatives.

Specific recommendations from this research are unique to the study area, but general prescriptions can be derived from the results. Information from this study should be useful to irrigators seeking to develop optimal strategies for converting existing systems to more efficient ones.

Objectives

The overall objective of this study was to develop a farm-level multiperiod mathematical programming model which maximized net returns to irrigated producers in the Oklahoma Panhandle through an optimal path of adoption of available irrigation technology. More specific objectives were:

1. Identify alternative irrigation technologies, irrigation practices, and cultural practices potentially available to High Plains irrigators and evaluate their applicability to various production settings.

2. Estimate the costs and returns derived from applying the technologies and practices identified in (1).

3. Determine the optimal paths of adoption of available irrigation technology alternatives for High Plains producers characterized by alternative financial resources, production settings, and existing irrigation systems.

Procedures for Analysis

A firm-level, multiperiod mathematical programming model of Oklahoma Panhandle agriculture was used to estimate efficient irrigation technology adoption strategies over a 21-year time horizon (seven, three year time periods). This model reflected irrigated agriculture production at the firm level.

Modeling of irrigated agriculture in the Oklahoma Panhandle requires accurate representation of the responses of area crops to alternative irrigation strategies. Using experimental findings from water response studies and computer plant growth models, crop-water response relationships were developed for major crops grown in the region (wheat, corn, and sorghum). These relationships were used to develop a set of crop production activities for the model. Basic hydrologic relationships were employed to determine the effects of previous withdrawals on pumping depths. The revised parameters were used to estimate pumping costs for the current production period.

A survey of professional literature provided information used to develop a set of irrigation technologies and practices available to the Panhandle producers that could improve pumping and application efficiency. Based upon irrigation system design, a determination was made as to which technologies and practices could be practically applied to the current production conditions. A combination of published data available from Agricultural Experiment Stations, interviews with irrigation and farm management specialists, a survey of producers, and Oklahoma State University enterprise budgets was used to develop data on the costs, input levels, and crop yields associated with each technology. An economic engineering approach in the form of an irrigation cost generator (Kletke et al.,1978) was employed to estimate pumping and distribution costs per acre inch for each irrigation system operating in the region. These costs were based upon specified system characteristics as well as soil type and water supply conditions. Capital costs were estimated for both installation of a complete system as well as retrofiting existing systems.

The multiperiod mathematical programming model consists of a constrained optimization model for seven time periods of three years each. The objective of the model was to maximize the sum of discounted net returns to land and management over the 21-year time horizon of the analysis by selecting the efficient set of irrigation technologies and practices available. Maximization of this objective was subject to several constraints including limits on the availability of various land classes, water supply, and limits on other production resources (e.g., labor, capital, etc.). Time periods within the model were linked by:

(1) Irrigation costs (based upon revised estimate of depth to water).

(2) Current acreage of each irrigation technology.

(3) Commodity and factor prices.

The solution of the model provided estimates of: 1) rates of adoption of available irrigation technologies, 2) annual returns from crop production, 3) annual crop mix, and 4) annual energy and water use. Differences in the rate of decline in the Ogallala Aquifer, irrigated acreage, and net returns provide a basis for establishing the potential impacts from adopting various technologies.

Organization of the Research

Relevant literature addressing the issue of adopting water-related technologies in irrigated agriculture will be discussed in Chapter 2. The review addresses two specific areas: 1) economic irrigation studies in the region, and 2) multiperiod optimization models designed to analyze irrigation decision making in the region.

The firm-level multiperiod mathematical programming model used in this analysis is presented in Chapter 3. A detailed description of the development and workings of the model is given.

In Chapter 4 the appropriate data needed for the model is identified, and a brief overview of the alternative irrigation technologies available to irrigators in the Oklahoma Panhandle is presented.

The results from applying the multiperiod model to selected production settings in the Oklahoma Panhandle are reported in Chapter 5. Also the effects of a number of different economic conditions, resource limitations, and technical constraints on optimal irrigation adoption strategies are discussed.

Chapter 6 includes a review of the principal findings and major conclusions of the analysis. A discussion of the study's limitations and recommendations for future research follows.

CHAPTER II

REVIEW OF RELEVANT LITERATURE

The purpose of this chapter is to selectively review relevant studies addressing the issue of adopting water-related technologies in irrigated agriculture. This review of literature is intended to provide background and direction to this research effort and similar future efforts. There have been numerous studies conducted on the agricultural sector of the High Plains. These studies cover a broad array of issues which impact irrigated agriculture in the area. The issues addressed include ground water availability and cost, energy inputs, cropping systems, irrigation strategies, and the influence of new technology on production. Only those works most relevant to this study will by cited.

This review addresses two areas pertinent to the analysis of adoption of water-related technologies in irrigated agriculture. First, a review of recent economic irrigation studies conducted in the study region is given. Particular emphasis is placed on research directed at evaluating irrigation strategies which reduce water and energy use. Intertemporal optimization models which have been developed to analyze irrigation in the region are discussed in the next section.

Economic Irrigation Studies

This section's main emphasis is on irrigation scheduling and irrigation technology. Irrigation scheduling is an important aspect in developing a method to allocate a finite volume of water over an irrigation season. The type of irrigation technology can dictate which irrigation management alternatives and schedules can be implemented to allocate irrigation water throughout the season.

Irrigation scheduling is the process of determining when to irrigate and how much water to apply per irrigation. Proper scheduling is essential for the efficient use of water, energy, and other production inputs, such as fertilizer. It allows irrigations to be coordinated with other farming activities including cultivation and chemical applications. Among the benefits of proper irrigation scheduling are improved crop yield and/or quality, water and energy conservation, and lower production costs.

Mapp, Eidman, Stone, and Davidson (1975), developed a model capable of simulating soil water-crop yield relationships for the major irrigated and dryland crops produced in the Oklahoma Panhandle. Within the model is a production subroutine which computes daily soil water levels on the basis of rainfall, irrigation, and evapotranspiration. Critical stages of plant development were identified for wheat, grain sorghum, and corn. Crop yields were determined based on the length and severity of soil water and atmospheric stress in relation to the stages of plant growth. The production subroutine was combined with a farm firm simulator designed to represent a typical irrigated farm operation in the Oklahoma Panhandle. A general irrigation strategy typical of that followed by progressive irrigators in the study area was simulated over a 20-year period and replicated 20 times.

The results of the model consist of a series of crop yields for dryland and irrigated wheat, dryland and irrigated grain sorghum, and irrigated corn for grain and silage. Yields for each of the 20 replications during the 20-year period are given. The mean yield, standard deviation, maximum and minimum yield, range, and coefficient of variation for each year are also reported.

In a related study Harris, Mapp, and Stone (1983) evaluated alternative irrigation strategies developed with the objective of reducing water and energy use in the production of grain sorghum in the Oklahoma Panhandle. They used a firm-level decision model to evaluate the effects of alternative irrigation strategies on yields, water use, and net returns. A major component of their model consisted of the dynamic grain sorghum plant growth model developed by Arkin, Vanderlip, and Ritchie (1976). Different irrigation schedules were simulated in the firm level model and the results were compared to the contemporary practice of applying 24 acre inches per acre (one 6-inch preplant irrigation and five 3.6-inch postplant irrigations). Alternative irrigation schedules investigated were: 1) a "no stress" irrigation schedule which initiated irrigations when the critical extractable soil moisture ratio reached 45 percent and 2) a set of irrigation schedules which used the 45 percent critical soil moisture level to initiate irrigations, but also allows the producers the option of not irrigating if the plant is in a specific stage of growth where water stress is not critical.

The evaluation of irrigation schedules was performed using stochastic efficiency procedures. The analysis revealed that most of the irrigation schedules which include irrigation in stage 4 of plant growth are stochastically dominant over contemporary practices.

Harris, Mapp, and Stone (1983) also employed the Modified Box-Complex algorithm to derive optimal irrigation schedule solutions from the simulation model. With the optimal control scenario, water is applied whenever the daily extractable soil moisture ratio is 45 percent or below. The criteria employed was that the producer would irrigate from 1 to 3 inches per application while maximizing net returns. Under the optimal control scenario the average quantity of water applied was 9.87 inches, compared to contemporary practices of applying 24 acre inches per acre.

Additional research focusing on irrigation scheduling in the Oklahoma Panhandle was conducted by Hornbaker (1985). Hornbaker developed an irrigation simulation model which can be used to obtain irrigation schedules which maximize net returns for irrigated sorghum in the Oklahoma Panhandle. A grain sorghum plant growth model was modified for use on a microcomputer to schedule irrigations on a day-to-day basis. The model can be updated daily and can use feedback of soil, climatic, irrigation and planting conditions. A dynamic programming recursion algorithm within the model maximizes net revenue of irrigated grain sorghum. The results from the dynamic programming model were tested against scheduling irrigations by a critical soil moisture ratio based on the SORGF Irrigation Scheduling Model. Optimal irrigation schedules were derived under varying fuel prices, irrigation efficiencies and market prices.

The dynamic programming model outperformed the SORGF model under five different critical soil moisture scenarios in 14 of 23 years. The dynamic programming model derived a near optimal irrigation scheduling policy; net revenue was not maximized in every year, it averaged only $1.89 per acre per year below the maximum. The next best scheduling model analyzed averaged $7.46 per acre per year below the maximum. The dynamic programming model also achieved substantial water savings. The results indicate incorporation of irrigation scheduling technology in the Oklahoma Panhandle could reduce total ground water pumping and reduce the rate of decline in the static water table.

Stoecker (1985) analyzed some of the effects of federal tax rates on returns from irrigation systems in the Texas High Plains. Stoecker compared the discounted after tax returns (DATR) from selected irrigation systems for producers with different federal income tax brackets. He determined the impact of interest rates and the effects of changes in the rate of investment credit on discounted after tax returns from the selected irrigation systems.

Five possible irrigation systems considered were: (1) conventional furrow with underground pipe and water use efficiency of 50 percent, (2) a furrow irrigation system with an overall efficiency of 65 percent, (3) a furrow system with 65 percent application efficiency and every other row diked, (4) a moveable low pressure center pivot (LPCP) system with dikes, and (5) a low energy precision application (LEPA) system with dikes.

The analysis employed a combination of recursive linear programming and capital budgeting techniques. Stoecker used recursive linear programming to determine the maximum returns over variable costs over a 15-year period for each irrigation system. The net returns from the recursive linear programming model were then incorporated into a capital budgeting program. The capital budgeting program aggregated the income, depreciation, and investment credits of the producer and then calculated total taxable income.

The results indicated that returns to the furrow irrigation systems with 50 percent application efficiency were less than returns obtained by non-irrigated production with furrow dikes. The furrow system with the largest discounted after tax return (DATR) was the system with 65 percent efficiency used with furrow dikes. When comparing all five irrigation systems Stoecker, found that the LPCP and LEPA systems were not profitable when interest rates were 10 percent or more. He also determined it was more profitable to operate one instead of two quarter section pivot systems while it was more profitable to operate two of the furrow distribution systems. Investment tax credit affected producers with higher levels of taxable income the most, and increasing investment tax credit from 10 to 20 percent favored the producer in the higher tax bracket. Discounted after tax return (DATR) in all total income levels was highest for the furrow system with 65 percent efficiency.

Bernardo (1988) studied the effects of irrigation system uniformity on the selection of risk-efficient irrigation strategies using crop simulation and stochastic dominance procedures. He evaluated alternative strategies under assumptions of both uniform and non-uniform application.

The grain sorghum crop growth model, SORGF, was employed to determine the influence of alternative irrigation strategies and uniformity conditions on crop yield (Arkin et al., 1976; Maas and Arkin, 1978). This model simulates the daily growth and development of a single sorghum plant based upon the prevailing climatic and soil moisture conditions. Using specified population data, (plant population of 100,000 per acre) the growth data from the single sorghum plant was extrapolated to the field level. Bernardo represented the spatial distribution of irrigation applications in a field setting to investigate the effect of non-uniform application depths on irrigation decision making. An empirically derived application pattern reported by Ring and Heerman was employed to represent the areal distribution of a representative center pivot irrigation system. A uniformity curve relating the dimensionless irrigation depth to the fraction of the field area receiving at least that depth was derived based upon the application pattern. These curves were programmed into the growth model so that when an irrigation was applied the appropriate curve was selected and applied to the desired irrigation depth.

The results of the analysis indicate that the variability of net returns resulting from using a specified schedule increases when irrigation uniformity is represented. The results also indicate that when using economic efficiency and stochastic dominance criteria the uniformity with which irrigations are applied contributes to the application of water-intensive irrigation schedules.

Further studies looking at irrigation technology are numerous and include a wide range of systems. LEPA irrigation systems have been evaluated in several studies (Lyle and Bordovsky, 1981a, 1981b, 1983; Lyle, 1986; New and Holloway, 1984). Wistrand (1984) looked at furrow diking and irrigation water savings with the use of furrow dikes. Another form of LEPA irrigation is the Multi-Function

Irrigation System (MFIS). MFIS can provide accurate application of water-conserving chemicals as well as traditional types of agricultural chemicals. These systems have been studied by Lyle and Bordovsky (1986). Studies conducted on surge-flow irrigation include (Schneider, 1984; Bishop and Walker, 1981; Soil Conservation Service, 1986a; Walker, 1984).

These studies assisted in identifying feasible irrigation strategies available to Oklahoma Panhandle producers which reduce water and energy use. In recent years, efficient irrigation technologies and practices have become important due to increased irrigation costs relative to returns. Studies on the influence different production settings have on irrigation investment decisions are becoming more important. While investment and operating costs have been reported for several irrigation systems and practices additional research is needed to update these costs. In addition, economic information concerning several progressive technologies is not available and must be estimated. Most of the studies discussed above dealt with a single crop and irrigation system; research is needed to determine how these systems and practices may be incorporated into farm plans involving several crops and irrigation systems.

Multiperiod Optimization Models

Multiperiod models can overcome many of the limitations of the stationary equilibrium approach to modeling. As their name implies, multiperiod models include two or more periods in which decisions must be made. Periods are usually defined as years, but can also be based on longer intervals or intervals of unequal length. Activities and constraints, for all the relevant decisions, are included in each period. The periods are linked together by investment decisions or other management decisions and the objective function (Hazell and Norton, 1986).

The work of Bekure (1971) serves as an example of economic analysis on the intertemporal allocation of ground water in the Central Ogallala Formation. This study provided estimates of the growth of irrigation in the study area, the rate of depletion of the aquifer over time, its effects on the pattern of irrigated crop production, and the gross and net receipts to irrigated crop production over time.

The study was composed of two separate but complementary analyses. One component projected the future growth of irrigation under two assumptions and estimated the rate of ground water withdrawal from the Central Ogallala Formation. The second component of the study took a long-run approach of maximizing the present value of the stream of net returns accruing to the entire study area over a planning horizon of 100 years. Results concerning rates of ground water use from the two approaches were compared.

The study was based on an inventory of the soil and water resources taken from county soil surveys and various hydrologic studies of the Central Ogallala Formation. Based on saturated thickness and depth-to-water classes, the study area was stratified into 48 discrete water resource situations. Irrigatable soils of each water resource situation were grouped into four types. The pattern of irrigated crop production over the period 1965-2070 was estimated by the use of two recursive linear programming models. One of these models estimated the minimum and the other the maximum rate of irrigation development expected in the area.

The first model used the study area's historic share of the projected U.S. supply of the eight irrigated crops (grain sorghum, wheat, silage, corn, alfalfa, sugar beets, cotton and soybeans) as a production goal. The model's solution was forced to produce the study area's projected supply of the eight irrigated crops as long as the land and water resources permitted. The second model used an exponential growth equation to project the maximum number of acres that could possibly be irrigated at different points in time, taking into account potentially irrigatable land and past trends in the growth of irrigation in the study area. The model allowed irrigation to grow to a maximum of this projection.

The second component of the study consisted of a multi-stage sequential decision model which used a dynamic programming technique to determine the optimal allocation of ground water over a planning horizon of 100 years. Parametric (or variable resource) programming was employed to generate the net returns that accrue to various alternative rates of ground water withdrawal at different storage levels of the aquifer. Two sets of parametric programming models were designed to incorporate the assumptions and results of the two recursive linear programming models. The multi-stage sequential decision model was designed and run using the two sets of data.

The results of this study provide upper and lower estimates of the magnitude of the changes that will take place in the growth of irrigation, depletion of the ground water supply, and its repercussions on the pattern of crop production and income of the study area. The results also project growth of irrigation in the study area occurring from 1965 to 2000. After the year 2000 the extent of irrigation was projected to decline precipitously. If future returns are discounted at very low interest rates, the results indicate that it is advantageous to withdraw ground water at a low rate to provide an adequate supply of water for future years. When discount rates of four percent or higher were applied, higher rates of ground water withdrawal occured in order to maximize the present value of the net return streams over the planning horizon.

The Six-State High Plains Ogallala Aquifer Regional

Resources Study (1982) assessed the economic, environmental, and social impacts of alternative water resource management strategies designed to extend the useful life of the Ogallala Aquifer. This was a comprehensive study conducted with participation of governmental agencies at the federal, state, and local levels; universities; and firms in the private sector.

The study analyzed a baseline situation and five alternative water resource management strategies. The baseline scenario assumed conservation and technology practices to continue current trends, with no new public policy intervention. Management strategies ranged from voluntary action to reduce water demands to inter-state surface water transfers.

Under each water management strategy a state-level linear programming (LP) model was used to project crop production, irrigated and dryland crop acreages, value of agricultural production, returns to land and management, and groundwater use, for 1985, 1990, 2000 and 2020. The LP model identified a choice among a variety of crop production activities that maximized the objective function of returns to land and management. Projected changes in agricultural and irrigation technology were incorporated into the analysis through changes in objective function and technical coefficients specified over the study period. Energy prices were assumed to have a moderate annual increase in real prices with the exception of the early portion of the study period. Real prices of other farm inputs were projected by the researchers and specified using constant 1977 dollars. Future real prices for key crops were projected using the NIRAP model. The NIRAP model is an econometric/equilibrium model which reflects past price/production trends, future demand and production, and the interrelationship of price of different crops.

Within the LP model, major constraints included the amount of arable land and ground water availability. Saturated thickness was estimated for each production region. This data was used to determine how much water would by used for irrigation each year given current crop prices and pumping costs. Aquifer depletion resulting from annual water use was factored back into the hydrologic estimates to determine water remaining in storage and depth to water in the next year.

The projected results developed in the LP models for each area were aggregated for the entire High Plains Region. State and regional input/output (I/O) models were then used to project industry sector activities, sector employment, total value added, total household income, and state and local tax revenues. The I/O model divided outputs by northern (Nebraska, Kansas and Colorado) and southern (Oklahoma, New Mexico and Texas) to show probable geographical differences in conditions. Projections of energy production, economic effects and prices were incorporated into the LP and the I/O models. Overall national economic growth and changes in labor productivity were also incorporated. These projections were developed from the INFORUM national forecasting model. INFORUM projections were also used in projecting the domestic demand for food and fiber in the NIRAP corp pricing model.

The results of this study were comprehensive and reported the following information: (1) water use and water remaining in storage, (2) energy utilization, (3) the quantity and value of agricultural production, (4) regional economic effects, and (5) water importation cost estimates. Results were reported for three alternative water policy scenarios. In the baseline scenario, it was assumed that there would be no changes in laws within each respective state that would affect ground water use or technology adoption. The second scenario considered several alternative water conservation policies. A third scenario evaluated the case where sufficient quantities of water would be imported to maintain irrigated acreage in each respective state at the 1977 level.

Research on water-related technologies used in the High Plains has been extensive. Ellis, Lacewell and Reneau (1985) estimated the expected benefits from adoption of new water-related technologies for the Texas High Plains over a 40-year period. A recursive linear programming (LP) model was used as the major tool of analysis to study the adoption of three basic irrigation technologies: limited-tillage, LEPA, and improved furrow irrigation. Price, cost, and yield data for the numerous cropping activities were incorporated into a linear programming algorithm which identifies the mix of activities that maximizes the predetermined objective function of net returns. Solutions were subject to constraints including availability of irrigation water within specified time periods, maximum acreage using a given technology, and available soil types.

Four separate scenarios, each permitting additional levels of irrigation technology adoption, were examined. The base scenario consisted of the use of center pivot sprinkler systems, conventional furrow irrigation, and conventional tillage practices. Adoption of limited tillage practices in combination with the base irrigation systems comprised the second scenario. Conversion from conventional to improved furrow acreage with limited tillage adoption was permitted in the third scenario. In addition to allowing the previously described conversions, the final scenario permitted the conversion of sprinkler and a limited amount of furrow acreage to use of LEPA systems.

The model allowed the use of one to all four irrigation distribution systems (conventional furrow, improved furrow, center pivot sprinkler, and LEPA). Tillage practices, limited and/or conventional could be selected. Possible irrigation schemes depended upon the crop and ranged from one preplant to a preplant and five postplant irrigations. Furrow and improved furrow activities could only be used on hardland soils, and center pivot activities were restricted to mixed and sandy soils. LEPA use was unrestricted on mixed and sandy lands, but was limited on hardlands, subject to assumed rates of conversion from furrow to LEPA irrigation systems. Selected nonoptimal schemes were also included as production activities available to producers. Postplant irrigation(s) occurring at non-optimal times were sometimes adopted as a result of competition among crops for water during the heavy demand summer months.

The recursive nature of the model accommodated the depletion of the aquifer after each year's solution. Saturated thickness, pumplift, and the resulting pumping costs were calculated for each year, based upon the previous year's water use.

The Texas High Plains was divided into two subregions, one with cotton production and the other without. These subregions were further classified into ten groups based on their soil texture, slope, and crop yields. Crop prices were based upon a 20-year average valued in 1982 dollars. Crop production activities were based upon a one-acre unit of land and inputs were defined per acre regardless of crop yield. County-level studies relating saturated thickness to surface acreage, as well as pumping lift to surface acreage, were used to define the groundwater situation (Wyatt, Bell and Morrison).

Feasible rates of adoption for sprinklers were estimated by the use of a regression analysis of historical acreage in the study region at 66,000 acres per year for the first 10 years. Conversion rates to LEPA were estimated to be 5 percent of sprinkler acreage the first year and 10 percent the next 9 years. Adoption rates for limited tillage were estimated using a function relating year and estimated percentages of U.S. cropland adopting this practice (Office of Technology Assessment 1982). The resulting assumption was that 25 percent of current cropland used limited tillage practices in 1980, and will increase to a maximum of 75 percent by 2010.

The results indicate that it is unlikely that the adoption of new technology could greatly extend the life of the aquifer for agricultural producers. In general, use of these technologies lowers the per unit cost of obtaining and distributing groundwater. Distribution efficiency is increased which increases the available water supply within a given time period, thus allowing more effective and timely application of irrigation water. Both effects encourage greater use of the limited water supply. However, lower pressure distribution systems could extend the economic life of the aquifer for areas with large pumping lifts due to lower energy costs. Improved efficiency distribution systems and limited tillage practices do not appear to reduce yearly water use, but they were found to be energy saving. This energy savings contributes to much of the estimated increase in net returns to farmers and supports the adoption of the technologies considered. Using improved technologies was shown to aid in sustaining irrigated acreage in the region, thus maintaining production, and input demand for the region.

A study to determine the temporal pattern of investment in irrigation systems (furrow and low-pressure center pivot) and the resulting use of groundwater reserves which will maximize expected net present value of future returns was conducted by Stoecker, Seidmann, and Lloyd (1985). They utilized linear dynamic programming (LDP) and parametric linear programming to measure the economic benefits of irrigation system development over a depleting aquifer on a typical farm situation in the Texas High Plains.

Their procedure consisted of two computational phases. Phase one used several parametric linear programming models to generate detailed optimal one-year farm plans, intratemporal allocations of water and net returns for specified irrigation decisions and aquifer states. It was assumed that at the beginning of every year, management could change the operational mode of the irrigation system by drilling additional wells, restaging existing wells, changing the size of the distribution system or changing time and/or amount of water applied to each acre. Constraints in the one-year intratemporal model were in four groups: (1) resource class, (2) well supply, (3) annual water pumpage, and (4) distribution capacity.

The second phase deduced the optimal allocation of water and irrigation resources over time and computed the resulting overall multiperiod benefits of the plan through the use of dynamic programming. During this phase decisions were made at the beginning of each stage, and it was assumed that the resulting benefits, as well as the appropriate changes in the states, are known with certainty.

The results of this study indicate that under the assumptions of the study, the producer using the low-pressure center pivot system with the higher application efficiency, would use the "saved" water to increase the number of irrigations in the near term rather than to increase the number of years in which irrigation is possible. This implies that benefits from more water-energy efficient irrigation systems may come from the expansion of current irrigation instead of extending the period of irrigation when water is initially scarce relative to land.

Lacewell (1988) conducted a study to identify adjustments in cropping systems selection and irrigation intensity at the whole-farm level in the Texas High Plains under three farm program assumptions. A multi-year/multi-crop biophysical growth simulation model provided input on stochastic crop yields by cropping system and irrigation scheme. Crop prices, cost of production estimates, and commodity program provisions were combined with the stochastic crop yields to estimate net present value distributions associated with each cropping system. The net present value distributions provided the principal input to a firm-level, multiperiod, recursive quadratic programming model developed to assess adjustments in cropping system selection and rate of ground water extraction over a 48-year time period. The firm-level optimization models were run in six-year intervals to derive optimal cropping systems, irrigation technologies, and production practices. Objective function values, technical coefficients, and key financial variables were updated over time, reflecting water quantities pumped in the previous time periods, irrigation investments, and previous production practices. Producer risk preferences and their impacts on crop rotation selection, irrigation practices and acres planted were also assessed.

Stochastic crop yields employed in the optimization models were estimated using the Erosion, Productivity Impact Calculator (EPIC) a daily time step crop growth simulation model. EPIC was used to estimate crop yields under 10 randomly generated 48-year weather patterns. A mulitvariate empirical probability distribution for prices in the region was used to generate the price series used in developing the net return distribution.

The three farm program scenarios evaluated were: (1) participation in the farm program given provisions in the 1985 farm bill, (2) non-participation in the program, and (3) participation in a flexible-base farm program similar to the 1985 farm bill. The Microcomputer Budget Management System (MBMS) was used to generate per acre budgets for each crop within each rotation by irrigation level and timing (McGrann, et al., 1986).

Major constraints used in the analysis were: (1) a limitation on total cropland acreage, (2) annual base acreage limitations for each crop, (3) limits of water requirements for critical water periods based on the pumping capacity in that period, and (4) financial constraints which maintain pretransition income levels by adding acreage when converting from irrigated to dryland production.

A set of recursive equations were developed to extend the multi-year firm level model through eight recursive cycles. The recursive specification allowed revision of the objective function, coefficient matrix, resource constraint, or any combination in period t+1 based on the optimal solution in time period t. The first series of recursive equations adjusted the irrigation operating parameters as a function of irrigation activity occurring over the previous six-year period. The current saturated thickness was estimated as a function of the previous saturated thickness, the quantity of water pumped over the previous period, as well as contributing aquifer acres and the coefficient of storage. Updating of the pump life was done by taking the previous lift minus the change in saturated thickness. Average well yield (in gallons per minute) was estimated by an equation from Hughes and Harmon (1969) which relates GPM to saturated thickness. Well yields were then converted to pump capacity (PRH) expressed in terms of acre inches pumped per 10 day time period. An equation from Kletke, et al.

(1978) comprised the second recursive equation which re-estimated per acre inch pumping cost for irrigation water. The final recursive equation evaluated creditworthiness. Maximum amount of loanable funds available to each farm in a given year was estimated as a function of the current leverage ratio and farm equity.

The results of this study dealt with a representative farm firm in the two production regions and addressed two general issues. One issue relates the likely path of transition from irrigated to dryland crop production under alternative farm program assumptions. The other issue focuses on how producer risk preferences affect the transition process.

Reduction or elimination of farm program benefits would substantially reduce farm income and erode already declining farm equity. The productive value of land would also decline as acreage reverted to dryland. It will be difficult for many producers to expand dryland crop acreage to maintain pre-transition income levels especially without farm program benefits.

Compliance with crop base acreage restrictions was found to limit the adoption of multi-year/multi-crop production systems. The results also indicated that projected ground water extraction was greater under flexible base as compared to the current program or nonparticipation option. Irrigation as input to crop production in the region was found to be a risk reducing input at the whole-farm level, and risk benefits of irrigation were further enhanced by farm program participation.

These studies along with several others have demonstrated the potential that multiperiod optimization models have as a tool for evaluating ling-run irrigation decision making. In the past twenty years much progress has been made in taking the work from a theoretical framework to a level that realistically portrays the production and investment alternatives facing irrigated producers. This study supplements this work by assessing irrigation technology adoption strategies for the typical Oklahoma Panhandle irrigation producer.

CHAPTER III

METHOD OF ANALYSIS

A multiperiod mathematical programming model was used in this analysis to derive optimal irrigation investment strategies for Oklahoma High Plains producers. The model consists of a set of annual submodels linked together by a series of transformation relationships that define the change in state variables through time. This method of modeling was chosen because it solves for optimal solutions in all periods of the planning horizon simultaneously. Thus, the influence of irrigation investments on the current period as well as all future periods is factored into investment decision making.

Linear Programming

This study was concerned with determining optimal paths of adoption of available irrigation technologies on irrigated farms, given initial farm situations. The farm situations consisted of specified sets of irrigation technologies, amount of land, capital, and other assumptions concerning available farm resources and productivity levels. In theory, a farm manager allocates resources until the marginal income received from using an additional unit of input is equal to the addition to total input cost caused by using an additional unit of input (Kay, 1981). This means the fixed resources (eg., land, operator labor, management, etc.) are allocated to the most profitable activities to the point that a change in resource allocation among the activities cannot increase returns. Variable inputs (eg., irrigation water, fertilizer, hired labor, etc.) are allocated to production as long as additional returns cover additional costs.

Linear programming utilizes the same concepts as marginal analysis to determine the optimal allocation of resources to the activities producing the greatest return. The objective of the linear programming model is to maximize a specific outcome variable that is influenced by and dependent on decisions made by the decision maker, subject to a set of restrictions or constraints limiting the decisions that can be made. Linear programming selects the combination of activities that satisfies the specified objective within the specified constraints.

To accomplish the objective, the linear programming model requires specification of:

1) the alternative farm activities, their units of measurement, their resource requirements, and any specific constraints on their production,
2) the fixed resource constraints of the farm, and
3) the forecasted net returns of the alternative activities.

The general formulation of the linear programming model can be written as follows:

$$\text{Max } Z = \sum_{j=1}^{n} c_j X_j$$

subject to:

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \qquad (i=1,2,...m)$$

$$X_j \geq 0 \qquad (j=1,2,...n)$$

where,

X_j = the level of the jth farm activity

c_j = the forecasted gross margin of a unit of the jth activity

a_{ij} = the quantity of the ith resource required to produce one unit of the jth activity

b_i = the amount of the ith resource available

m = the total number of resources available

A description of assumptions implicit in the linear programming model aids in understanding the advantages and limitations of the method. These assumptions are:

1. Optimization: an appropriate objective function is either maximized or minimized.
2. Fixedness: at least one constraint has a nonzero right hand side coefficient.

3. Finiteness of the activities and resources: there exists only a finite number of activities and constraints to be considered.
4. Single-value expectations: resources availability, input-output coefficients, prices, and other variables are known with certainty.
5. Divisibility of activities and resources: resources can be used and activities produced in quantities that are fractional units.
6. Homogeneity: all units of the same resource or activity are identical.
7. Additivity of resources and activities: the activities are assumed to be additive in the sense that when two of more are used, their total product is the sum of their individual products. Thus, no interaction effects between activities are permitted.
8. Proportionality of activity level to resources: the resource requirements and gross margin per unit of activity are assumed constant regardless of the level of activity used.

For a detailed discussion of mathematical programming, the reader is referred to Hazell and Norton (1986) or Hadley (1963).

Multiperiod Mathematical Programming

Investment decisions for farms are more difficult to model than annual cropping decisions. This is because the life of investments extends beyond a single agricultural year, and the investments' costs and returns are not uniformly distributed over their life. Two basic approaches to modeling investment decisions with linear programming models are the stationary equilibrium and multiperiod mathematical programming (Hazell and Norton, 1986). The multiperiod mathematical programming approach was selected for this study because it takes the initial level of investments as given, and provides an optimal growth strategy which gives both the longer-term investment levels and the optimal path of adoption that should be pursued.

The multiperiod model includes two or more periods in which decisions must be made. Time periods for the model are usually defined in years, but can also be based on longer intervals. Activities and constraints are included in each period for all relevant decisions. Investment decisions, the objective function, and the discounted sum of net returns generated over the entire planning horizon link the periods together. This linkage makes the multiperiod mathematical programming model more than a sequence of single period models. Rather, single period production decisions are made in concert with investment decisions that have ramifications over the entire planning horizon. Multiperiod models are better suited for investment analysis than recursive models because expectations about future events or situations are taken into consideration in all periods of the model at the same time, rather than one period at a time.

The margin is calculated each year or period through a series of counting activities and balance rows. Counting activities collect the annual margins into the objective function after they are discounted to period 1 values. The discounting is accomplished by multiplying all of the entries in the objective function by r^{t-1}, where r = 1/(1+i), i is the discount rate, and t is the year number of the relevant activity.

Hazell and Norton (1986) identified four key issues that need to be resolved when multiperiod models are built.

The first of these issues is the length of the planning horizon or number of periods to include in the model. Longer planning horizons increase the chance that activity levels in the later periods of an optimal solution will converge to a set of equilibrium values, but they add to the size of the model. The length of the planning horizon should be longer than the life of the longest gestation period of any of the investments.

A second issue concerns assigning terminal values to investments that extend beyond the planning horizon. This is done by calculating the discounted value of all returns to be realized beyond the planning horizon, and including these values directly in the objective function row under the activity columns.

The third issue is to select a discount rate. The use of bank interest rates or discount factors can often lead to unrealistic model solutions. This happens because the present-day value of investments with long gestations is smaller, the larger the discount rate. Investments made late in the planning horizon with smaller present-day values are less likely to be included in the optimal solution.

The fourth issue that needs to be resolved is that the model should be initialized to reflect the farmer's starting investment position. Initializing the multiperiod model allows the optimal solution to provide guidance to the farmer on how he should adjust his investments over future years.

Capital constraints can be incorporated into the model by adding capital balance rows to the rows section for each period, and entering activity requirements for capital. Transfer activities allow capital to be supplied in each period from credit or from family savings carried over from the previous period. Specification of the capital constraint allows the model to determine the optimal growth path for a farm given an initial stock of capital and investment levels.

Description of the Analytical Model

For this study, a constrained optimization model was specified in the form of maximizing the sum of discounted net returns to land and management by selecting the efficient set of irrigation technologies from those available. Maximization of this objective was subject to several constraints: limits on the availability of land that can be irrigated by each system, water supply and other resource limits, and financial constraints to limit the amount of capital that can be spent in any one time period.

The multiperiod mathematical programming model consisted of seven time periods of three years each, making the planning horizon twenty-one years in length. The series of three-year submodels was developed to allocate land and other production resources among the alternative production activities. These submodels were linked together by a series of transition relationships that defined changes in irrigation technology, pumping conditions, and financial resources through time.

The optimal solution of the multiperiod model provides estimates of: 1) the path of adoption of available irrigation technologies, 2) annual returns from crop production, 3) annual crop mix, and 4) annual energy and water use.

A schematic of the multiperiod mathematical programming model is presented in Figure 3. This figure shows a block diagram of how the seven periods were set up in the full model. Coefficients for each individual period are represented by the larger blocks labeled a_{ij}^{t} (t=1,...,7). The small blocks in Figure 3 represent linkages between

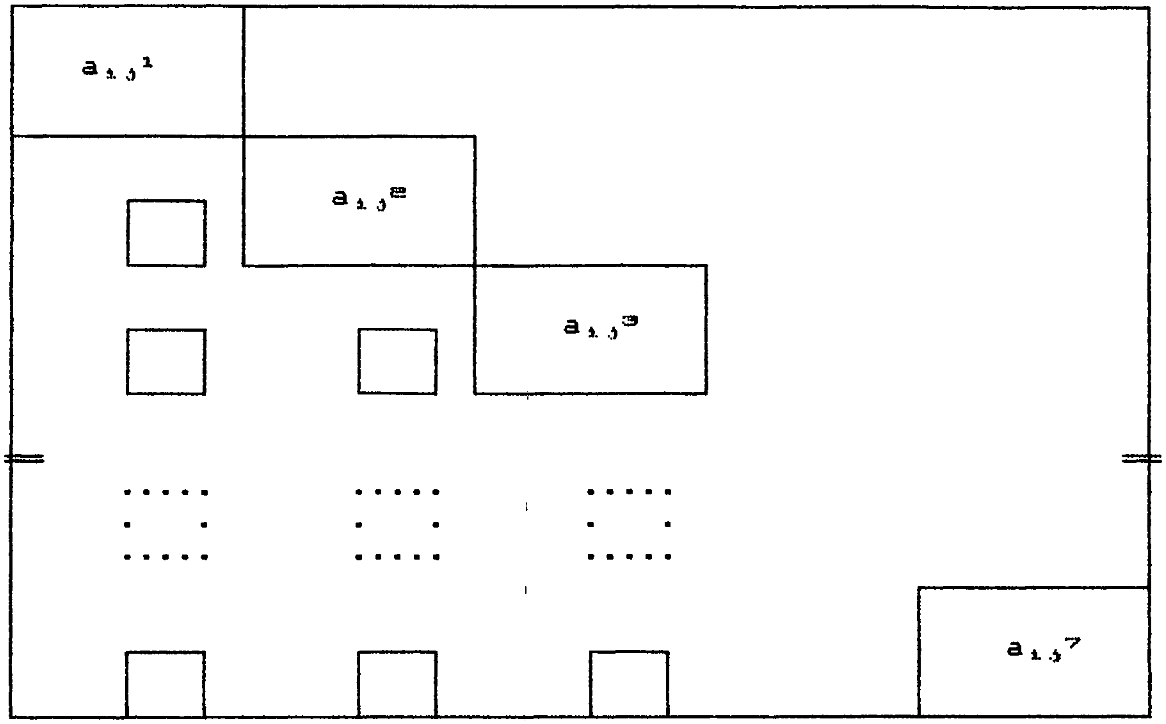

Figure 3. Block Diagram of Coefficient Matrix for Full Model

periods in the full model. Coefficients in the small blocks allowed the transfer of irrigation systems, acreages, and capital accounting from one period to the next. Coefficients in these blocks also controlled the irrigation system conversions that were possible between periods.

An abbreviated tableau of a single period submodel is presented in Table III. Table IV provides the nomenclature for Table III. For ease of illustration, the tableau includes only six production activities, one initial irrigation situation, and two irrigation system conversions, for the single period shown. Selected symbols are used in the tableau to represent the actual numerical values that were in the model. Subscripts were used to designate the period (t), crop activity (j), irrigation system (i), water period (p), irrigation schedules (k), and irrigation system conversion (c).

Single Period Model

Row 0 was the objective function of the multiperiod model and represented the sum of discounted annual net returns. D_t values appearing in the row were the discount factors associated with each respective period. No constraint was set on this row as it was the objective function row which would be maximized for a specific set of assumptions.

Annual net returns were estimated as the sum of gross receipts less production and investment costs in row 1.

TABLE III

ABBREVIATED TABLEAU OF THE MULTIPERIOD MODEL

		Production Activities						Sell Act.	Water Cost	Labor Cost	Initial System	Irr. System Conversions		Discount Activities		Accouting Activities				RHS		
Row		$X_{j\ldots}$	$X_{j\ldots}$	$X_{j\ldots}$	$X_{j\ldots}$	$X_{j\ldots}$	$X_{j\ldots}$	Crop j			Sys.1	Sys.2	Sys. 3	NRet.	PRet.	TA0	TL0	TAt	TLt			Row
0	Obj. Funct.													$-D_t$	D_t							0
1	Return t	$-R_{j\ldots}$	$-R_{j\ldots}$	$-R_{j\ldots}$	$-R_{j\ldots}$	$-R_{j\ldots}$	$-R_{j\ldots}$	$P_{j\ldots}$	$-V_{\ldots}$	$-F_{\ldots}$		$-U_{\ldots}$	$-U_{\ldots}$	.33	-.33					=	0	1
2a	Water 1t	$W_{j\ldots}$	$W_{j\ldots}$	$W_{j\ldots}$	$W_{j\ldots}$	$W_{j\ldots}$	$W_{j\ldots}$													≤	$b_{1\ldots}$	2a
2b	Water 2t	$W_{j\ldots}$	$W_{j\ldots}$	$W_{j\ldots}$	$W_{j\ldots}$	$W_{j\ldots}$	$W_{j\ldots}$													≤	$b_{\ldots}$	2b
2c	Water pt	$W_{j\ldots}$	$W_{j\ldots}$	$W_{j\ldots}$	$W_{j\ldots}$	$W_{j\ldots}$	$W_{j\ldots}$													≤	$b_{\ldots}$	2c
3	Water Total t	$T_{j\ldots}$	$T_{j\ldots}$	$T_{j\ldots}$	$T_{j\ldots}$	$T_{j\ldots}$	$T_{j\ldots}$		-1											≤	0	3
4	Labor t	$L_{j\ldots}$	$L_{j\ldots}$	$L_{j\ldots}$	$L_{j\ldots}$	$L_{j\ldots}$	$L_{j\ldots}$			-1										≤	0	4
5	Labor Const. t									1										≤	l_t	5
6	Acre Const. t	1	1	1	1	1	1													≤	a_t	6
7	Crop Const. jt	1	1	1	1	1	1													≤	$w_{j\ldots}$	7
8	Yield Tran. jt	$-Y_{j\ldots}$	$-Y_{j\ldots}$	$-Y_{j\ldots}$	$-Y_{j\ldots}$	$-Y_{j\ldots}$	$-Y_{j\ldots}$	1												≤	0	8
9a	Cont. Sys. 1t	1	1								$-A_{\ldots}$	$A_{\ldots}$								≤	0	9a
9b	Cont. Sys. 2t			1	1							$-A_{\ldots}$	$A_{\ldots}$							≤	0	9b
9c	Cont. Sys. 3t					1	1						$-A_{\ldots}$							≤	0	9c
10	Return 8											$S_{\ldots}$	$S_{\ldots}$		-1					=	0	10
11	Control i0										1									=	$g_{\ldots}$	11
12a	Transfer i0										-1	1	1							=	0	12a
12b	Transfer it										-1	-1	-1							≤	0	12b
13	Assets 0															1				=	e_t	13
14	Liab. 0																1			=	o_t	14
15	Assets t	$-Q_{j\ldots}$	$-Q_{j\ldots}$	$-Q_{j\ldots}$	$-Q_{j\ldots}$	$-Q_{j\ldots}$	$-Q_{j\ldots}$	$D_{j\ldots}$	$-G_{\ldots}$	$-E_{\ldots}$		$M_{\ldots}$	$M_{\ldots}$			1		-1		=	f_t	15
16	Liab. t											$N_{\ldots}$	$N_{\ldots}$				1		-1	≤	h_t	16
17	Net Worth t																	$-H_t$	1	≤	0	17

TABLE IV

NOMENCLATURE FOR MATHEMATICAL PROGRAMMING MODEL TABLEAU

Description	Symbol
SUBSCRIPTS	
Crop	j
Irrigation system	i
Irrigation Schedule	k
Time Period	t
Irrigation System Conversion	c
Irrigation water (acre inches) 2 week period	p
COEFFICIENTS	
Total irrigation water per 2 week period (acre inches)	W
Total irrigation water per year (acre inches)	T
Irrigation labor Hrs per acre	L
Crop yield (Bu, Cwt)	Y
Crop Price	P
Acres	A
Net return	R
Investment cost	U
Asset Change	M
Liabilities Change	N
Discount rate	D
Labor rate per hour	F
Debt to asset ratio	H
Production cost to assets	Q
Revenue addition to assets	O
Water cost to assets	G
Labor cost to assets	E
RHS COEFFICIENTS	
Total irrigation water available in 2 week period	b
Total irrigation labor available	l
Total acres available	a
Total acres available for each crop	w
Number of initial irrigation systems	g
Total beginning assets	e
Total beginning liabilities	o
Total assets	f
Total liabilities	h

Non-irrigation production costs, irrigation investment and variable costs as well as the returns from selling the commodities produced (i.e. wheat, corn, and sorghum) were included.

P_{jt} values were the prices of the crops minus variable harvesting costs. Irrigation system conversion costs that were incurred in the period were also included in row 1. For example, U_{ct} values were the investment costs for conversion c, to irrigation system i, in period t. The constraint on this row was that it must be equal to 0 so annual net returns could be transferred to the discount activities and enter the objective function. There were seven of these rows in the actual model, one for each period.

Rows 2a through 2c were used to estimate the acre inches of water applied in each subperiod. These subperiods were in two week intervals starting in April and ending in November. Therefore, in the actual multiperiod model there were fourteen subperiods in each of the seven periods. The subperiods were used to account for the timing of water applications by different irrigation schedules included in the model. The coefficient W_{jikpt} represented the acre inches applied in period p by production activity X_{jikpt}. Total acre inches of water applied was constrained so that total application of irrigation water could not exceed the total availability of irrigation water during that subperiod (b_{pt}). Subperiod water availability was limited by the farm-level irrigation pumping capacity.

Row 3 estimated the total acre inches of water applied during each of the seven periods. T_{jikt} values in Table III represented the total water applied by production activity X_{jikt}. This row also allowed a cost to be associated with applying the respective amount of water by being tied to the water cost activity. Row 3 was constrained so that total application of irrigation water could not exceed the total availability of irrigation water during the period.

Irrigation labor requirements for each of the production activities were given by the L_{jikt} values in Table III. The total irrigation labor requirement for the period was estimated in row 4. Row 5 constrained the hours of labor used for irrigation and required it to be less than or equal to the number of hours available during each of the seven periods (l_t).

Row 6 constrained the total number of acres that could be brought into production during each period (a_t). The total number of acres of each crop produced in period t (w_{jt}) was constrained in row 7.

Row 8 represented the yield transfer rows for wheat, corn, and sorghum. These rows allowed the model to transfer the end product of each respective production activity to be sold. Yield coefficients were specified for each crop (j), irrigation system (i), schedule (k), and time period (t) included in the model (Y_{jikt} values in Table III). A yield transfer row was specified for each crop included in the time period.

Multiperiod Linkages

Irrigation system and irrigation conversion control rows can be found in rows 9a, 9b and 9c. These rows controlled the number of acres that were irrigated under each irrigation system in the initial period and in each subsequent period. The rows also kept track of the acres available for conversion from one irrigation system to another in each period. In the actual model, for each period, there were separate control rows for each irrigation system included in the analysis as well as dryland production. The A_{it} values in Table III represented the number of acres comprising each of these systems. Negative A_{it} values were included in the control rows corresponding to the system over its entire useful life. The sum total of all acres under irrigation could not exceed the total number of acres available for irrigation. Terminal values for investments that extended beyond the planning horizon (S_{it} values in Table III) were in row 10.

The control row for the initial irrigation system in use was in row 11. This row indicated the initial irrigation system the farmer was using at the beginning of the planning horizon. Specification of this term (g_{it}) dictated what irrigation system conversions were allowed in the model during the first period in rows 9a through 9c.

Rows 12a and 12b transferred the existing irrigation system or conversion to the next period. For example, if the farmer initially had gated-pipe, this row allowed the model to transfer the gated-pipe to the next period or transfer the gated-pipe to a new irrigation system such as surge-flow. The full model had transfer rows for each system (gated-pipe, surge-flow, tailwater reuse, cablegation, high-pressure center pivot, low-pressure center pivot, low-pressure center pivot with corner system, low-pressure center pivot fitted with chemigation, LEPA, and dryland) in each period.

Capital accounting (rows 13 through 17 in all seven periods) was included in the model to determine the amount of investment capital needed in order to implement the irrigation investment plan and to regulate the expenditure on irrigation conversion in any one year. Borrowed money was charged at an interest cost based upon the time for which funds were held. Straight line depreciation, based upon the investment conversion cost and expected years of life, was also included. These rows allowed the model to track the change in assets, liabilities, and net worth over the planning horizon. Total assets (TA) and total liabilities (TL) were estimated as follows:

$$TA_{t+1} = TAt + I + \Delta TA_t - (FL + Pmt) \qquad (3.1)$$

$$TL_{t+1} = TL_t + \Delta TL_t - Prin \qquad (3.2)$$

where, I = income

FL = family living expenses

Pmt = total payments on existing debt

Prin = principal paid on existing debt

Income was calculated in row 15 by summing the Q_{jikt}, O_{jikt}, G_{jikt}, and the E_{jikt} coefficients. These coefficients were calculated by multiplying the respective coefficient in the return row (row 1) by 3 to account for the three years of income in each period. The changes in assets and liabilities were estimated in the M_{ct} and N_{ct} coefficients respectively rows (15 and 16). RHS coefficients e_t, o_t, f_t, and h_t accounted for family living expenses, total payments on existing debt, and principal paid on existing debt. The debt to asset ratio for the farm was the H_t coefficient in row 17.

The full model included production activities for wheat, corn, and sorghum grown under each of the irrigation systems for various irrigation schedules, and allowed dryland production of wheat and sorghum. Twenty-nine irrigation system conversions were also included in the full model for each period.

Pump Lift Transformations

Pumping costs were divided into two components to aid in estimating R_{jikt} and V_{it} coefficients. Pumping costs that were not affected by changes in pump lift were included in the first component, while costs that change as a function of pump lift made up the second component. Pumping costs were separated in this manner to aid in updating irrigation cost coefficients as pump lift changes through time. Pumping cost components were separated as follows:

$$FC = \frac{BHP * .011 * Hrs * Png}{ACIN} \quad (3.31)$$

$$= \frac{\frac{TDH * GPM}{3960}}{PE * DE} * .011 * \frac{452.5}{GPM} * Png \quad (3.32)$$

$$= \frac{(2.31 * psi + lift) * .0014 * Png}{PE * DE} \quad (3.33)$$

where, FC = fuel cost ($/year)

BHP = break horsepower

WHP = water horsepower

TDH = total dynamic head (ft)

psi = operating pressure (pounds per square inch)

Hrs = engine hours

P_{ng} = price of natural gas ($/mcf)

PE = pump efficiency (%)

DE = drive efficiency (%)

ACIN = acre inches of water applied annually

$$\text{let } K = \frac{.0014 * P_{ng}}{PE * DE} \quad (3.4)$$

Then, the portion of pumping costs not associated with pump lift (applicable to production activity X_{jikt} values) become,

$$O_{jikt} = 2.31 * psi * K * ACIN \qquad (3.5)$$

R_{jikt} values were net return coefficients for the respective production activities and were calculated as follows:

$$R_{jikt} = C_{jikt} + O_{jikt} \qquad (3.6)$$

where, C_{jikt} = non-irrigation costs of production for a specific crop, irrigation system, schedule, and time period

O_{jikt} = irrigation operating costs that are not dependent upon changes in pump lift, for a specific crop, irrigation system, schedule, and time period

The second component (water costs associated each irrigation system that were dependent upon changes in pump lift (V_{it} values)) were estimated as follows:

$$V_{it} = Lift * K \qquad (3.7)$$

Since this relationship is not system specific, only one relationship is needed per period to update irrigation pumping cost coefficients in response to changes in pump lift.

A set of recursive equations was specified to allow for revision of pumping conditions over the 21-year time horizon of the analysis. Objective function and technical coefficients defining saturated thickness, pump lift, pump capacity, and pumping costs in period t were updated based upon water use in the previous periods. Separable programming was used to represent the non-linear relationships defining the transition of these state variables over time.

Saturated thickness in year t (ST_t) was updated using a modified version of the following relationship proposed by Knowles (1981):

$$ST_t + ST_{t-1} - (W_{t-1}/(CA*CS)) \qquad (3.8)$$

where, W_{t-1} = acre feet pumped in year t-1

CA = contributing aquifer acres

CS = coefficient of storage

Pump lift was estimated in each period by subtracting the change in saturated thickness from the previous lift. Contributing acres and the coefficient of storage were adjusted to provide estimates of lift changes consistent with those observed in the study area at average water use levels.

Pump capacity (in gallons per minute) in period t was calculated based upon the updated estimate of saturated thickness using the following relationship from Hughes and Harman (1969):

$$GPM_t = 800*(ST_t/210)^2 \qquad (3.9)$$

The resulting pump capacity was expressed as an upper limit on subperiod water use (AI/subperiod).

CHAPTER IV

DATA REQUIREMENTS AND DESCRIPTION

This chapter specifies the data, irrigation production requirements, and assumptions used in the model. First, the procedures, assumptions, and operating parameters for computing estimated irrigation costs are detailed. This is followed by a description of the baseline irrigation systems, their investment costs, and a description of irrigation system conversions along with their conversion costs. Also included in this chapter are sections describing procedures used in estimating irrigation variable costs and constructing the production activities.

Information in the study was based on data from a survey of producers and irrigation equipment suppliers, state and regional irrigation specialists, professional literature, Oklahoma State University enterprise budgets, and the Oklahoma State University Irrigation Cost Generator. In those situations where the necessary data were missing, extrapolations were made from the available data. Explanations of the methods used are unique in each instance, and thus, are given as they occur.

Computational Procedures for Estimating Irrigation Costs

Fixed and variable costs for the various irrigation situations were calculated using a modified version of the Oklahoma State University Irrigation Cost Generator (Kletke et al., 1978). The generator provides a means of calculating fixed and variable costs under various assumptions regarding the well, fuel type, distribution system, and application rates. The program combines both technical (or irrigation engineering) computations with economic computations in estimating the cost of owning and operating irrigation systems.

The Irrigation Cost Generator was developed to calculate the investment and operating costs of new irrigation systems. Irrigation engineering relationships are used to size all components of the system (e.g., pump, engine, pipe sizes, etc.) to attain a specified level of performance. The modified version of the Irrigation Cost Generator was developed to evaluate irrigation investments involving modifications to an existing irrigation system. In this case, the user may hold constant the physical characteristics and performance parameters of portions of the irrigation system. For example, when modifications to the distribution system are evaluated, the program may not be permitted to size the pipeline, pump, engine, etc. to correspond to the application rates of the new system.

The second modification to the Irrigation Cost

Generator involves the computational procedures used to estimate the total dynamic head of the irrigation system. A three step procedure is used to determine total dynamic head. First, friction loss in the system's laterals and mainline is calculated. Next, the friction loss estimates are combined with the required discharge pressure to determine total pressure at the wellhead. Finally, estimates of the total pressure at the wellhead are used in conjunction with pump lift estimates to determine the total dynamic head.

The original Irrigation Cost Generator of Kletke et al. (1978) used Scobey's formula to calculate the coefficients for friction loss in pounds of pressure per 1,000 feet. In the modified version, Scobey's formula was replaced with the Hazen-Williams equation for estimation of head loss in pipes. The Hazen-Williams equation has replaced Scobey's formula as the most recognized procedure for estimating friction loss in irrigation mainlines and laterals. Friction loss coefficients were calculated as follows (Kizer, 1988):

$$H_f = 4.53 * L \, [Q/C * D^{2.63}]^{1.852} \qquad (4.1)$$

where, H^f = head loss, feet

L = pipe length, feet

Q = flow rate, gpm

D = pipe diameter, inches

C = roughness coefficient

The friction loss coefficients were used to estimate total friction loss in laterals and mainlines (FL) using the following relationship:

$$FL = [H^{f} * (L^{l}/1000) * F] + [H^{f} * (L^{m}/1000)] \qquad (4.2)$$

where, L^{l} = length of lateral

F = manifold flow factor, dimensionless

L^{m} = length of mainline

The first term represents total friction loss in the system's lateral, while mainline friction loss is determined in the second term. Manifold flow factors used in this analysis were .54 for center pivot systems and .4 for gated-pipe systems.

Total pressure at the well head was estimated as the sum of discharge pressure and friction loss estimates provided in equation 2. Total dynamic head (TDH) was then calculated as follows:

$$TDH = 2.31 * P^{w} + LIFT \qquad (4.3)$$

where, P^{w} = total pressure at the well head (psi)

LIFT = feet of lift at average drawdown level

The estimate of TDH was employed to estimate brake horsepower (through water horsepower), which was used along with hours of system use to estimate fuel use. Other operating parameters were calculated as follows:

Water Horsepower (WHP):

$$WHP = \frac{TDH * GPM}{3960} \qquad (4.4)$$

Brake Horsepower (BHP):

$$BHP = \frac{WHP}{PE * De} \qquad (4.5)$$

Hours of Annual System Use (HR):

$$HR = \frac{452.5}{GPM} * AI \qquad (4.6)$$

where, GPM = pump flow rate, gal/min.

PE = pump efficiency, percent.

DE = distribution efficiency, percent.

AI = total quantity of irrigation water applied annually, acre inches/year.

All other technical and economic relationships used to estimate irrigation investment and operating costs were identical to those employed in the Irrigation Cost Generator. The reader is referred to the Irrigation Cost Program User's Reference Manual for a more complete explanation and listing of these computational procedures.

Irrigation Cost Assumptions

Current costs for irrigation systems and various components were estimated from results of a survey of several Oklahoma and Texas Panhandle irrigation equipment dealers conducted in June, 1988. Cost estimates provided by the dealers were supplemented with information from professional publications and current manufacturer's price lists. Information concerning irrigation practices and operating costs were obtained from a series of interviews with Oklahoma irrigators during the same period.

Unless otherwise noted, all machinery and equipment was valued at its new purchase price. Evaluation of irrigation system modifications using used equipment would require the adjustment of expected repair and maintenance costs, as well as reduction of the useful lives of the system components. Salvage values reflected the current value of used equipment; thus, a stable market for irrigation equipment was assumed over the time horizon of the analysis. Only above-ground components of the pumping plant and distribution system were assumed to have a salvage value above zero.

Additional assumptions employed in deriving the irrigation costs estimates were:

1. Normally accepted years of life were used in deriving the irrigation cost estimates.

Item	Years of Life
Well	20
Bowls	8
Columns	16
Gear Head	15

Gated-Pipe	15
PVC Underground Mainline	20
Motors	15-20
Center Pivot	15

2. Labor was charged at $5.00 per hour.
3. Irrigation labor rates assumed for the gated-pipe and center pivot systems were .49 and .06 hours per acre per irrigation, respectively.
4. Natural gas fuel charges were assumed to be $1.00, $2.00, and $3.00 per mcf.
5. Well drilling cost was charged at $45.00 per foot.

Baseline Irrigation Systems

To estimate the investment costs of the various system conversions, baseline gated-pipe and center pivot irrigation systems were developed. These systems define the physical characteristics and performance parameters of the surface and sprinkler systems prior to system conversion. Performance characteristics of the baseline systems reflected the operation of a well-maintained, used system. Therefore, baseline assumptions regarding parameters such as pump efficiency and application efficiency were lower than those attainable from a well-designed, new system.

Investment costs estimated for the base gated-pipe and center pivot systems at 100, 200, and 300-foot pump lift scenarios are reported in Table V. Costs are divided into four categories: (1) well drilling and development costs,

TABLE V

INVESTMENT COSTS OF THE BASE GATED-PIPE AND CENTER PIVOT SYSTEMS

	Gated-Pipe	High-Pressure	Low-Pressure
(100-foot lift)	--------------dollars--------------		
Well	8,100	8,100	8,100
Pump	10,474	10,974	10,474
Engine	8,000	8,000	8,000
System	7,984	36,183	38,183
Total	34,558	63,257	64,757
(200-foot lift)			
Well	12,600	12,600	12,600
Pump	14,588	15,588	15,088
Engine	8,000	8,000	8,000
System	7,984	36,183	38,183
Total	43,172	72,371	73,871
(300-foot lift)			
Well	17,100	17,100	17,100
Pump	19,203	19,703	19,203
Engine	8,000	8,000	8,000
System	7,984	36,183	38,183
Total	52,287	80,986	82,486

(2) the cost of the pump, including columns, bowls, gear head, and pump base, (3) the cost of the internal combustion engine, and (4) distribution system costs. Total depth of the well was assumed to exceed the depth to water by 80 feet, while the depth setting of column pipe was assumed to be 20 feet less than the depth of the well. The total number of bowls comprising the pump was determined as a function of the total dynamic head and capacity (gpm) of the base system. Investment costs differ only in terms of the first two cost components; engine and distribution system costs were not affected by pump lift assumptions.

<u>Gated-Pipe System.</u> The base gated-pipe system was assumed to irrigate a 155-acre field (A_{it} values in Table III) and apply water at an average application efficiency of 60 percent. Furrow lengths of 2,640 feet and row spacing of 30 inches were assumed. The system operates at a discharge pressure of 10 pounds per square inch (psi), a system capacity of 900 gallons per minute (gpm), and average pump efficiency of 60 percent.

A diagram of the layout of the basic gated-pipe system is presented in Figure 4. The remaining useful life of these systems was assumed to be 15 years. Included in the investment cost of the distribution system were 1,300 feet of 10-inch PVC mainline, 2,640 feet of 10-inch aluminum gated-pipe, and the necessary valves. Total investment cost of the distribution system was $7,984. Investment costs for the complete gated-pipe system range from $34,558 for the

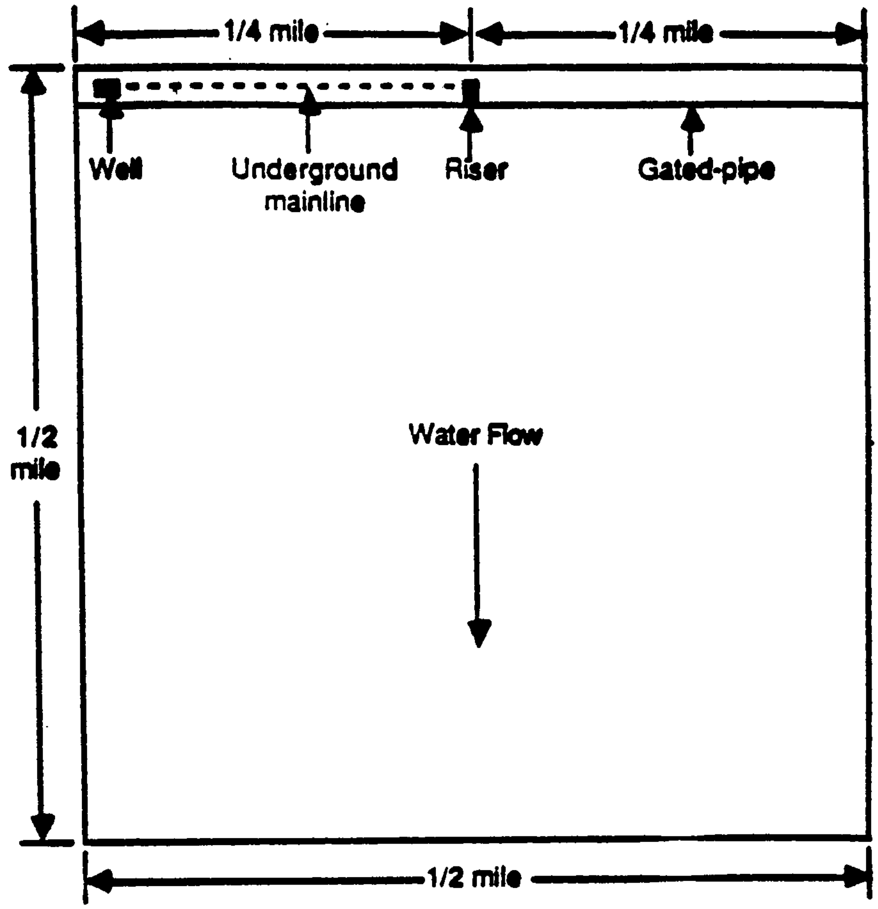

Figure 4. Basic Gated-Pipe System

100-foot lift scenario to $52,287 when a lift of 300 feet was assumed.

Center Pivot System. The base center pivot system was assumed to consist of either a one-quarter mile low-pressure or high-pressure system. Each system was assumed to irrigate a total of 125.6 acres (A_{i*} values in Table III) with an average application efficiency of 75 percent. Both systems were assumed to operate at a system capacity of 800 gpm and an average pumping efficiency of 60 percent. The high-pressure system operates at a discharge pressure of 55 psi, while the low-pressure systems operates at a pressure of 25 psi.

The layout of the basic center pivot system is presented diagrammatically in Figure 5. The remaining useful life of these systems was assumed to be 6 years. The low-pressure system consisted of a 1,320-foot lateral, pivot, riser valve, and employed goose necks and drops with low-pressure nozzles. The high-pressure system used impact sprinklers mounted on the top of the lateral. Also included in the base distribution system was 1,500 feet of 10-inch PVC underground mainline. Total costs of the base low-pressure and high-pressure center pivot distribution systems were $38,183 and $36,183, respectively. Total investment costs ranged from $64,757 to $82,486 for the low-pressure system, and between $63,257 and $80,986 for the high-pressure system.

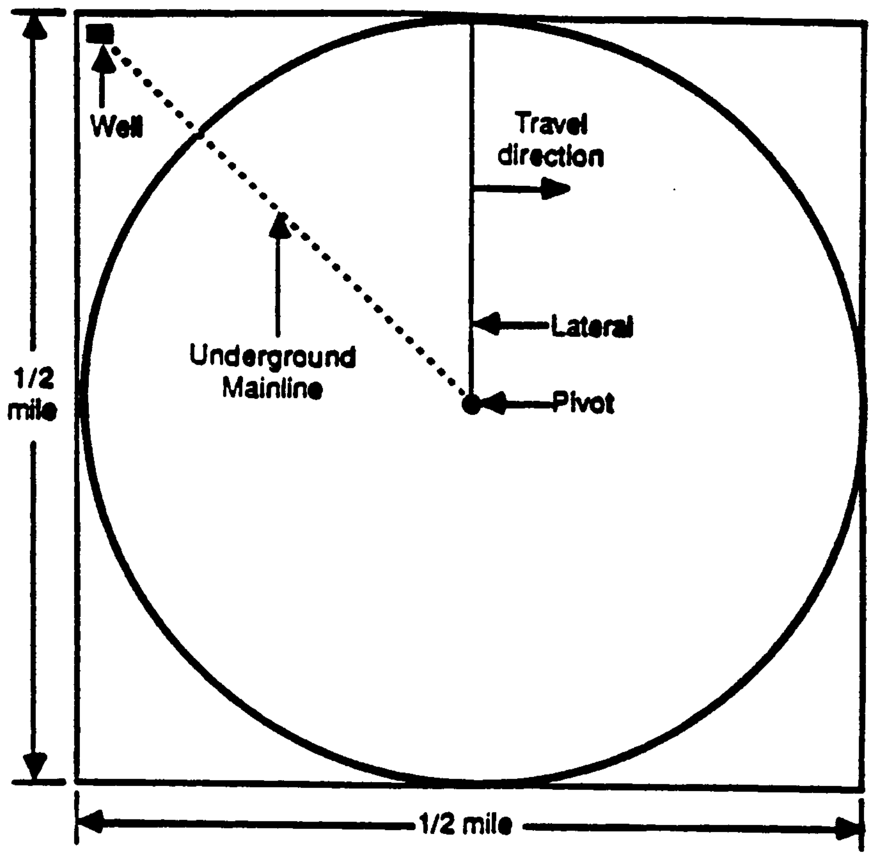

Figure 5. Basic Center Pivot System

Description of System Conversions

Table VI shows the investment costs for converting from one type of irrigation distribution system to another ($U_{c,t}$ values in Table III). Only conversions which could have a perceived increase in application efficiency, economic efficiency, or operating flexibility are shown.

Surge-Flow. Surge-flow irrigation involves intermittent application of irrigation water to furrows or borders through a series of on-off watering periods of constant or variable time spans. The primary benefit of surge-flow irrigation is a faster rate of advance down the furrows for a given size furrow stream, which reduces deep percolation losses and provides flexibility in the amount of water applied (Schneider, 1984).

With the exception of application efficiency, the operating parameters of the surge-flow system were identical to those of the base gated-pipe system. Increases in application efficiency resulting from conversion to surge-flow irrigation are dependent upon a number of managerial factors (e.g., flow rate, application rate, and cycle time) as well as the intake characteristics of the furrow (e.g. soil type, field slope, etc). An increase in application efficiency of 10 percent (from 60 to 70 percent) was assumed for this analysis. Adoption of surge-flow practices has resulted in larger increases in application efficiency in several field experiments (Harek and Ebeling, 1986; Soil

TABLE VI

INVESTMENT COSTS FOR IRRIGATION
SYSTEM CONVERSIONS

Change To	Change From Gated-pipe	Surge-flow	Tailwater	High-pressure	Low-pressure
	dollars				
Surge-flow	5,487	---	---	---	---
Tailwater	8,743	8,743	---	---	---
Cablegation	2,000	---	---	---	---
High-pressure	36,183	36,183	36,183	---	---
Low-pressure	38,183	38,183	38,183	2,200	---
Corner system	55,683	55,683	55,683	19,700	17,500
Chemigation	---	---	---	---	3,000
LEPA	45,183	45,183	45,183	8,255	7,000

Conservation Service, 1986b); however, these cases were typically characterized by low base efficiencies.

The surge-flow control system consisted of two components: an actuating valve and the valve controller or timer. Adaptation of the base gated-pipe system to a surge-flow system was assumed to require the installation of two surge-flow valves. The controller could be moved between the two valves as deemed necessary. Installation of the surge-flow system also required the addition of 660 feet of underground mainline and two riser valves (as shown in Figure 6). Total investment cost for the system conversion was $5,487. The useful life of the surge control system was unknown. Useful lives of all components were identical to those listed earlier, with the exception of the controller which was assumed to have a life of 10 years.

<u>Tailwater Reuse System.</u> When modifying the basic gated-pipe system to include a tailwater reuse system it was assumed that opportunities existed for applying the tailwater to another field in close proximity to the tailwater pit. The reuse system was assumed to operate at an efficiency of 70 percent; that is, 70 percent of total runoff was reapplied to the head of the tailwater field. Using the SCS Approach for Estimating Furrow Irrigation Performance to estimate runoff losses from the entire 155 acre field, it was estimated that 26 additional acres could be irrigated with the tailwater system. Assumptions employed were as follows:

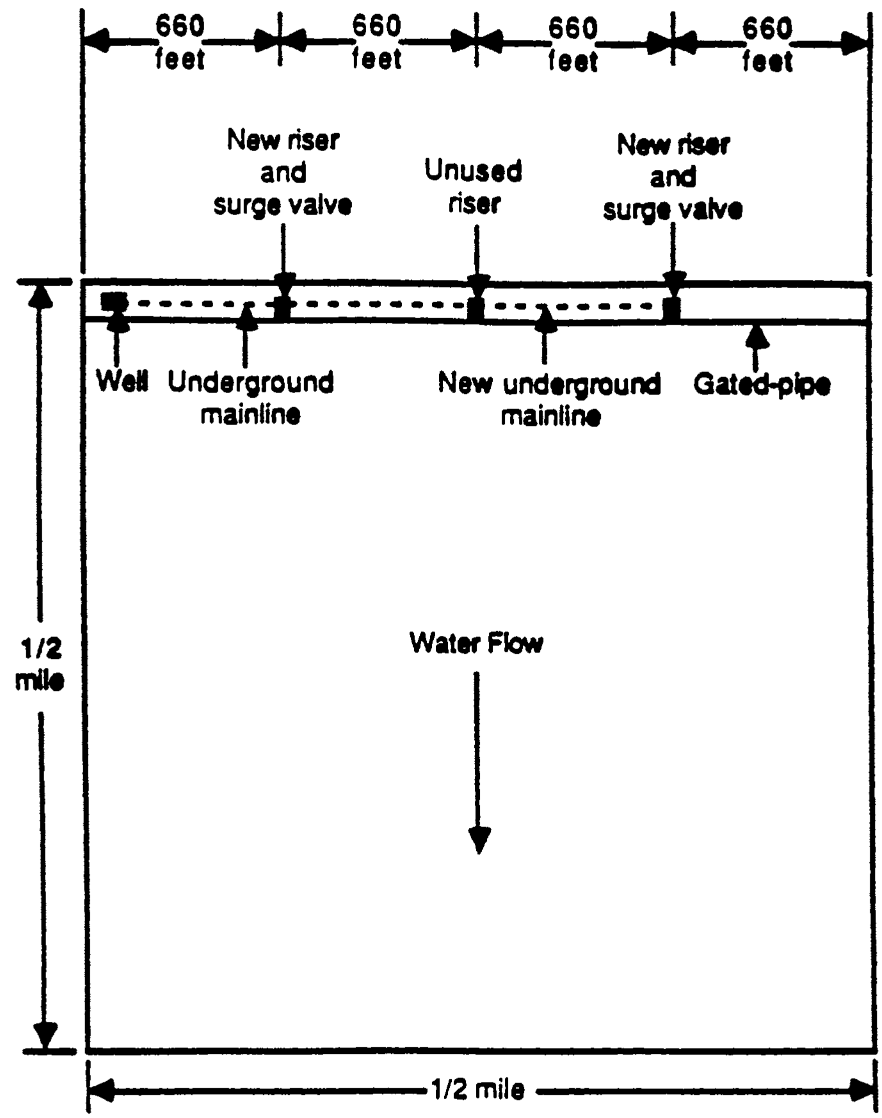

Figure 6. Surge-Flow System

1. 1 percent field slope.
2. 30 inch furrow spacing.
3. Gross average application depth of 4 inches.
4. 40 rows were watered per set.
5. Furrow length of 2,640 feet.
6. Well capacity of 900 gpm.

Water is applied to both the main field and the additional 26 acres at an average application efficiency of 60 percent. This makes a total of 181 acres irrigated with the tailwater reuse system for the $A_{i,t}$ value in Table III.

A diagram of this version of the tailwater reuse system is given in Figure 7. Investment required for the addition of the tailwater reuse system included 100 feet of 10-inch PVC underground mainline, the tailwater pit, an electric motor, the pumping unit, and the necessary valves. The pumping unit of the tailwater system was assumed to operate at a capacity of 400 gpm with a depth of 20 feet (one bowl). Total cost of the pumping unit and electric motor were $4,168. Construction costs of a tailwater pit with a volume of 56,250 cubic feet and a settling pit were estimated at $4,000. Costs of the additional underground mainline and valves was $575. Total investment costs were $8,743. It was assumed that the 26 additional acres represent a portion of an adjacent irrigated field; therefore, investment in additional gated-pipe was not required.

Conversion to the tailwater reuse system could also be

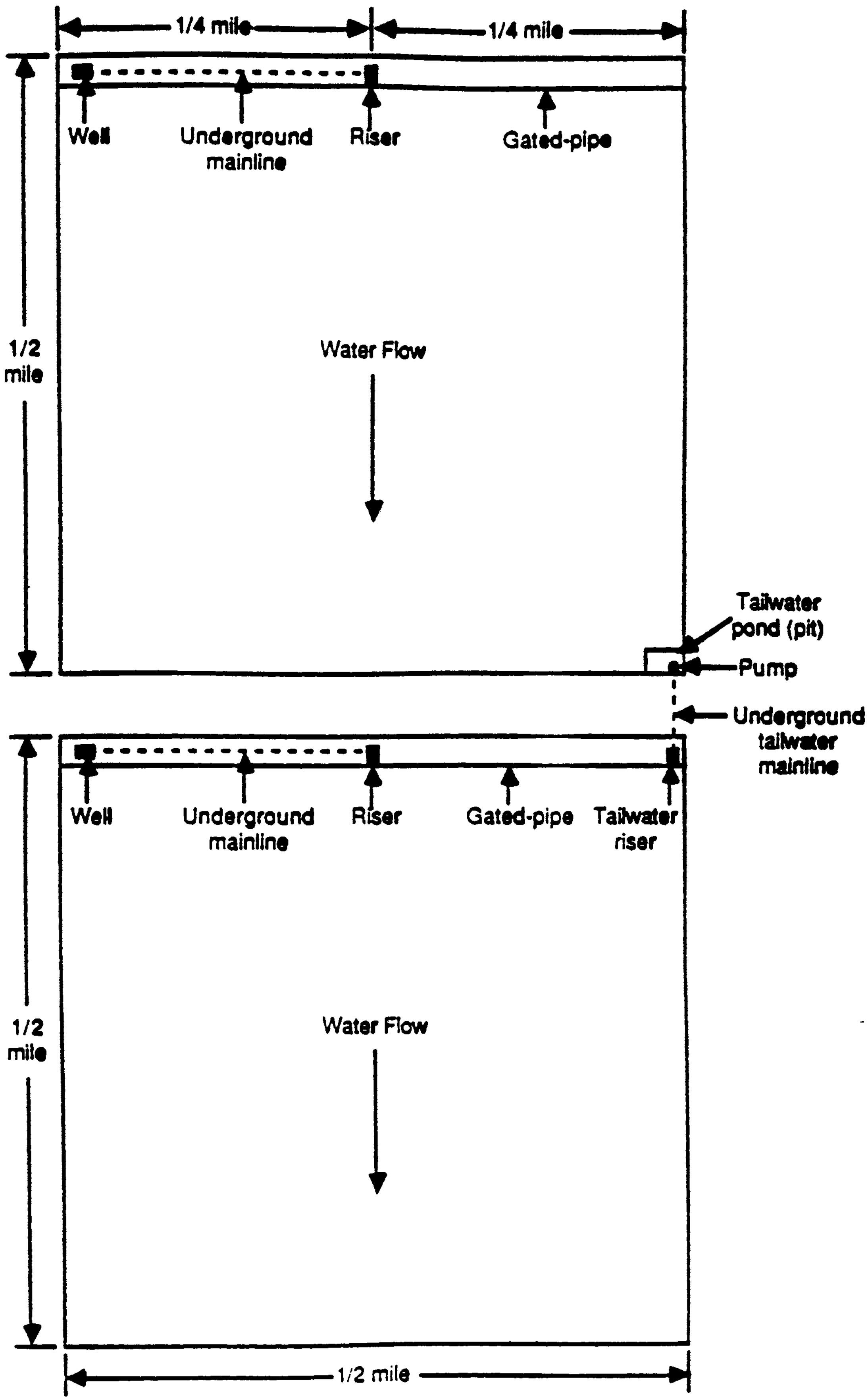

Figure 7. Tailwater Reuse System

achieved from the surge-flow system. All operating parameters and additional investments required were identical to the tailwater reuse system described above. Salvage value of the unused surge control system was $1000; therefore, the net investment for the conversion was $7,743.

Cablegation. Cablegation is a simple, automated method of surface irrigation. It is a form of gated-pipe irrigation with the open gates positioned near the top side of the pipe. Gated-pipe is laid on a precise grade, and a plug moves slowly through the outlets to the furrows in the field. The pipeline is sized so that the water flow, on the available slope, does not completely fill its cross section. Water flows through the pipe below the level of the gates until it approaches the plug. This plug causes the water to fill the pipe and flow from the gates near the plug. The plug is allowed to move downslope through the pipe at a controlled rate which automates the system. A cable is attached to the upstream end of the plug to control the rate the plug moves through the pipe. Irrigation is allowed to progress across the field as the cable is reeled out and the water pressure moves the plug. Total irrigation time and gross application for a given system are determined by the plug travel speed.

Investment costs for converting to this system were $2,000, excluding the gated-pipe. Included in the investment costs were the plug, cable, and the automation system to reel the cable in and out. Operating parameters for the cablegation system were the same as those for the base gated-pipe system. With the exception of irrigation labor, which was assumed to decrease by one-third.

<u>High-Pressure Center Pivot.</u> Converting to the high-pressure center pivot system from the gated-pipe system was assumed to result in an increase in application efficiency to 75 percent, discharge pressure to 55 psi, and reduce the irrigated acres to 125.6 (A_{hc} value in Table III). No adjustments to the pumping plant were included as part of the conversion process. The assumption was made that pump speed could be varied to attain the required operating pressure without pump modifications.

Investment requirements consisted of 1,500 feet of PVC underground mainline, the distribution system, and valves. The high-pressure center pivot system consisted of 1,320-foot lateral, pivot, riser valve, and impact sprinklers spaced at intervals of 120 inches mounted on the top of the lateral. Total investment costs for converting to the high-pressure center pivot system were $36,183. Salvage value of the unused gated-pipe was $2,640 ($1.00/ft. * 2640 feet of gated-pipe); therefore, the net investment for the conversion was $33,543.

When converting from the surge-flow or tailwater reuse system to the high-pressure system all operating parameters and additional investments were the same as described above. Salvage values of the unused surge-flow control system and the unused tailwater system were $3,640 and $3,140, respectively. Therefore, the net investment for the conversions were $32,543 and $33,043, respectively.

Low-Pressure Center Pivot. Converting to the low-pressure center pivot system from the gated-pipe, surge-flow, or tailwater reuse system was assumed to result in an increase in application efficiency to 75 percent, discharge pressure to 25 psi, and reduce the number of irrigated acres to 125.6 ($A_{1,6}$ value in Table III).

Investment requirements consisted of 1,500 feet of PVC underground mainline, the distribution system, and valves. The low-pressure center pivot system consisted of 1,320-foot lateral, pivot, riser valve, and goose necks and drops with low-pressure nozzles. Total investment costs for converting to the center pivot system were $38,183. Salvage value of the unused gated-pipe, surge-flow, and tailwater reuse systems were the same as the conversions to high-pressure center pivot. Net investment for the conversion from these systems were as follows: gated-pipe, $35,543; surge-flow, $34,543; and tailwater reuse, $35,043.

The high-pressure system utilizes impact sprinklers spaced at intervals of 120 inches mounted on the top of the lateral. Conversion to a low-pressure system involves replacement of the 132 high-pressure sprinklers with goose necks, drops, and nozzles. A total cost of $16.67 per sprinkler was used, resulting in a total investment cost of $2,200 for the conversion. It was assumed that pulling and redesigning the pumping plant when converting to the low-pressure system was not necessary. Internal combustion engines provide the opportunity to vary pump speed, which will give corresponding changes in pump discharge capacity and operating capacity. Discharge pressure was reduced from 55 psi to 25 psi as a result of the modification. Application efficiency was assumed to remain constant at 75 percent.

Installation of Corner System to Low-Pressure Center Pivot. Addition of a corner system to the low-pressure center pivot increases the total number of acres irrigated from 125.6 acres to 155 acres (A_{it} values in Table III). This conversion can be accomplished by adding a steerable corner arm to the existing low-pressure system. The steerable corner system follows the main system when not in use, then it automatically swings out to irrigate the corners as the system moves around the field.

Investment cost for this conversion were $17,500 and included the installation of a booster pump (mounted on the last tower), electrical wiring, and the corner lateral system with goose necks, drops and low pressure nozzles. Average discharge pressure and application efficiency were assumed to remain constant at 25 psi and 75 percent, respectively, following the installation.

Installation of Chemigation System to Low-Pressure Center Pivot. The addition of chemigation to a low-pressure system involves the purchase of a diaphragm pump, 200 gallon polyethylene tank, mechanical agitator, and the necessary valves and hoses. This unit is connected to the irrigation system at the pivot. The chemicals are applied through the lateral at the time of irrigation by mixing the chemicals with the irrigation water.

Total cost for adding the chemigation system to the low-pressure center pivot was $3,000. Operating parameters of the modified low-pressure system were identical to baseline levels. Production costs were assumed to decrease by one-half of the chemical and application costs for chemicals that were applied to the field after planting (Johnson, et al. 1987).

Low-Energy Precision Application System (LEPA). Converting to the LEPA system from the gated-pipe, surge-flow, or tailwater reuse system was assumed to result in an increase in application efficiency to 90 percent, maintain discharge pressure at 10 psi, and reduce the number of irrigated acres to 125.6 (A_{it} value in Table III). No adjustments to the pumping plant were included as part of the conversion process. The assumption was made that pump speed could be varied to attain the required operating pressure without pump modifications.

Investment requirements consisted of 1,500 feet of PVC underground mainline, the distribution system, and valves. The LEPA center pivot system consists of a 1,320-foot lateral, pivot, riser valve, and employs goose necks, drops, flexible drop tubes with low-pressure nozzles at 60-inch intervals. Total investment costs for converting to the LEPA center pivot system were $45,183. Salvage value of the unused gated-pipe, surge-flow, and tailwater reuse systems were the same as the conversions to high-pressure center pivot. Net investments for the conversion from these systems were as follows: gated-pipe, $42,543; surge-flow, $41,543; and tailwater reuse, $42,043.

Conversion from the high-pressure center pivot system to a LEPA system resulted in an increase in application efficiency from 75 to 90 percent. Discharge pressure changed from 55 to 10 psi as a result of the modification. Conversion requires the installation of flexible drop tubes spaced at 60-inch intervals along the center pivot lateral. High-pressure impact sprinklers located at the top of the lateral are replaced with goose necks, drop tubes, and low pressure nozzles. Total investment cost for the installation of the 264 flexible drop tubes, nozzles, and emitters was $8,255. Pressure regulators were not included in this application, but may be required in fields where there is considerable elevation change (National Food and Energy Council, 1986).

Conversion of the low-pressure system to LEPA is accomplished by fitting the flexible drop tubes to the goose necks already present on the center pivot lateral. Goose necks are also added to the lateral to obtain the required 60 inch sprinkler spacing. As above, 264 drop tubes, emitters, and nozzles are installed. Operating parameters for the LEPA system were identical to those described above. Total investment costs for the conversion were $7,000.

Dryland. Each of the irrigation systems had the possibility of being converted to dryland production. Conversion to dryland is accomplished by selling all of the above ground sections of the irrigation system including the engine. The salvage value for each of these conversions can be found in Table VII.

Description of Alternative Irrigation Practices

In addition to irrigation system conversions, producers can also adopt alternative irrigation practices to improve irrigation efficiency. Adopting an alternative irrigation practice changes operating parameters of the respective irrigation system (e.g. application efficiency). Several of these irrigation practices were included in the model.

Alternate-Furrow Irrigation. Alternate-furrow irrigation involves irrigation of one furrow for every two normally-spaced planted rows. This increases the distance between irrigated rows from 30 inches to 60 inches. All operating parameters were identical to the base gated-pipe system described above, with the exception of water applied. The use of alternate-furrow irrigation was assumed to decrease the amount of water applied by 33 percent and reduce sorghum yield by 12 percent (New, 1971). In this study, alternate-furrow irrigation was used only on grain

TABLE VII

IRRIGATION SYSTEM SALVAGE VALUES WHEN CONVERTING TO DRYLAND

System	Salvage value
Gated-pipe	$5,640
Surge-flow	$6,640
Tailwater reuse	$6,140
Cablegation	$750
High-pressure center pivot	$15,000
Low-pressure center pivot	$19,000
Low-pressure corner system	$10,000
Chemigation	$1,500
LEPA	$23,000

sorghum due to the fact that it is a stress tolerant crop and the availability of data. No additional investment was needed with alternate-furrow irrigation.

Limited Irrigation Dryland (LID). With LID, the upper half of the field is fully irrigated. The next 25 percent is a tailwater runoff section that receives limited irrigation, and the lower one-fourth is a dryland section which may receive runoff from the upstream sections. Alternate furrows are irrigated, and dikes are placed in all furrows on a 13-foot spacing. In irrigated furrows, the soil dams are lower and slightly cupped so that they are over topped and washed out with irrigation to the extent of water advance. Beyond the irrigated section, furrow dams remain until washed out by subsequent irrigations or rainfall, while the dryland portion of the furrow provides a "sink" for runoff from the upstream three quarters of the furrows. Operating parameters for the irrigated portion of LID were identical to alternate-furrow discussed above.

Total investment costs were identical to those of the base gated-pipe system, with the exception of the additional cost of the diking equipment. This equipment attaches to existing implement shanks or tool bars. The diking equipment was assumed to be used on four fields; thus, one quarter of the $1,979 total investment cost was allocated to each LID field.

Furrow Diking. Furrow diking was assumed to be used in conjunction with LEPA irrigation systems only. Dikes were placed in all furrows on a 13-foot spacing with furrow diking equipment. All operating parameters were identical to the LEPA system described above, with the exception of application efficiency. Dikes reduce the amount of runnoff from the field and were assumed to increase application efficiency an additional 5 percent; thus, average annual application efficiency for the LEPA system used in conjunction with furrow dikes was 95 percent.

Total investment costs were identical to those of the LEPA system, with the exception of the additional cost of the diking equipment. This equipment attaches to existing implement shanks or tool bars. The diking equipment was assumed to be used on four fields; thus, one quarter of the $1,979 total investment cost was allocated to each LEPA system ($496). Operating costs were assumed to increase $0.43 per acre (Witstrand 1984).

Deep Chiseling. Deep chiseling involves chiseling the field an additional time at a depth of 16 to 18 inches. This is done to loosen up the soil and allow water to reach the root zone more readily. Deep chiseling was assumed to be used in conjunction with low-pressure center pivots only. All operating parameters were identical to the base low-pressure system described above, with the exception of application efficiency. Application efficiency was assumed to increase 5 percent to 80 percent due to decreased runoff

(Wright et al., 1984).

No additional investment was needed with deep chiseling and variable production costs were assumed to increase $2.00 per acre.

Irrigation Operating Costs

Annual irrigation operating costs were estimated using the formulations presented by Kletke et al. (1978). Total annual fuel costs were estimated as the product of brake horsepower, hours of system operation, a fuel multiplier (.011 mcf/horsepower hour), and the fuel price.

Fuel Cost, $/AI (FC):

$$FC = \frac{.011 * BHP * HR * P_f}{AI} \qquad (4.7)$$

where, AI = total quantity of irrigation water applied annually, acre inches/year

P_f = price of natural gas, $/mcf

HR = hours of system operation

Annual lubrication costs were calculated as a function of hours of system operation and included both oil and grease. A lubricant multiplier of .001 gallons of oil used per water horsepower hour and a grease cost of 2 cents per hour was assumed.

Lubrication Cost, $/AI (LC):

$$LC = \frac{.001 * WHP * HR * Po}{AI} + (.02 * HR) \quad (4.8)$$

where, P_o = price of oil, $/gal

Annual repair costs were calculated as a function of hours of system operation with repair cost coefficients elicited from area irrigators. Annual repair costs were assumed constant over the life of the system and, thus, reflect the average annual repair charge. The expected life of the pump was assumed to be 30,000 hours. An engine repair multiplier (per hour per dollar of engine purchase price) of .00007 was also used.

Repair Cost, $/AI (RC):

$$\text{Pump:} \quad RC_p = \frac{[(P_c * F_t) + C_b] * HR}{(30{,}000 * AI)} \quad (4.9)$$

$$\text{Motor:} \quad RC_m = \frac{.00007 * HR * C_m}{AI} \quad (4.10)$$

$$\text{System:} \quad RC_s = \frac{R_d * C_d}{AI} \quad (4.11)$$

where, F_t = total feet of column pipe

P_c = price to pull the column pipe

C_b, C_m, C_d = total cost of bowls, motor, and distribution system, respectively

R_d = system repairs multiplier

Labor requirements were determined by the number of irrigations applied, as well as the hours of system operation.

Labor Cost, \$/AI (LB):

$$LB = \frac{(A * L_{m1} * S) + (L_{m2} * HR)}{AI} * P_L \qquad (4.12)$$

where, A = acres irrigated per year

L_{m1} = hours of labor per acre per set

S = total number of irrigation sets per year

L_{m2} = hours of engine labor required per hour of engine use

P_L = price of irrigation labor, \$/hour

Table VIII provides estimates of acre inch operating costs of the base gated-pipe, high-pressure center pivot, and low-pressure center pivot irrigation systems at pump lifts of 100, 200, and 300 feet. These costs represented initial operating costs of the system, but changed through time as a result of changes in the pump lift. A fuel cost of \$2.00/mcf of natural gas is assumed for this table. The operating costs are broken down into four parts: fuel, lubrication, repairs, and labor. The values were used in estimating R_{jikt} values in Table III.

The irrigation operating costs for those systems that originate from gated-pipe, surge-flow, or tailwater reuse are presented in Table IX and were used in estimating R_{jikt}

TABLE VIII

ACRE INCH OPERATING COSTS OF THE BASE SYSTEMS
AT THREE ALTERNATIVE PUMP LIFTS,
$2.00/mcf FUEL PRICE

	Pump Lift (feet)		
	100	200	300
Gated-pipe	dollars		
Fuel	.57	1.01	1.44
Lubrication	.09	.14	.20
Repairs	.32	.33	.35
Labor	.76	.76	.76
Total	1.74	2.24	2.75
High-pressure			
Fuel	1.11	1.54	1.98
Lubrication	.15	.21	.27
Repairs	.46	.49	.50
Labor	.37	.37	.37
Total	2.09	2.61	3.12
Low-pressure			
Fuel	.81	1.25	1.68
Lubrication	.11	.17	.23
Repairs	.45	.48	.49
Labor	.37	.37	.37
Total	1.74	2.27	2.77

TABLE IX

TOTAL ACRE INCH OPERATING COSTS OF THE CONVERSION SYSTEMS AT THREE ALTERNATIVE PUMP LIFTS, $2.00/mcf FUEL PRICE, 900 GPM

	Pump Lift (feet)		
	100	200	300
	------------------dollars------------------		
Surge-flow	1.74	2.24	2.75
Tailwater reuse	1.75	2.25	2.76
Cablegation	1.60	2.10	2.61
High-pressure	2.06	2.56	3.05
Low-pressure	1.72	2.22	2.72
Corner system	1.81	2.31	2.80
Cablegation	1.72	2.22	2.72
LEPA	1.59	2.02	2.46

coefficients in Table III. Again, operating costs for the three pump lift situations are presented for exposition purposes only; pump lifts, and hence, irrigation operating costs will change over the time horizon of the analysis. These systems can be grouped together because all of the assumptions that affect the acre inch operating costs are the same, including the assumption that each of the original systems had a 900 gpm capacity. A breakdown into fuel, lubrication, repair, and labor of these irrigation system conversion acre inch operating costs can be found in Appendix A Table XX.

Table X shows the acre inch operating costs for the conversions that originated from high-pressure or low-pressure irrigation systems. These systems started out with a capacity of 800 gpm. Appendix A Table XXI provides a breakdown of these irrigation system conversion acre inch operation costs into fuel, lubrication repairs, and labor.

Terminal Values

Terminal value estimates for the investments in irrigation systems (S_{it} values) are given in Appendix A Table XXII. This table shows terminal values for each irrigation conversion analyzed and the respective period. The S_{it} values were estimated as follows:

$$S_{it} = D * Y + SV \qquad (4.13)$$

where, D = yearly straight line depreciation for the respective investment

TABLE X

TOTAL ACRE INCH OPERATING COSTS OF THE CONVERSION SYSTEMS AT THREE ALTERNATIVE PUMP LIFTS, $2.00/mcf FUEL PRICE, 800 GPM

	Pump Lift (feet)		
	100	200	300
	dollars		
Low-pressure	1.74	2.27	2.77
Corner system	1.85	2.35	2.85
Cablegation	1.74	2.27	2.77
LEPA	1.63	2.07	2.50

Y = number of years the life of the investment extends beyond the planning horizon

SV = salvage value of the investment

Capital Accounting

Financing for investing in new irrigation systems was based upon the following assumptions:

1) interest was charged at 12 percent
2) 80 percent of the investment was financed
3) funds were borrowed for 6 years
4) only investments over $9,000 were financed

Changes in total assets due to an additional investment in irrigation (M_{ct} values) were estimated by the following equation:

$$M_{ct} = A - Dep - Pmt \qquad (4.14)$$

where, A = increase in assets due to purchasing an irrigation system

Dep = straight line depreciation during the period

Pmt = loan payments during the period

Changes in total liabilities due to an additional investment in irrigation (N_{ct} values) were estimated by the following equation:

$$N_{ct} = L - Prin \qquad (4.15)$$

where, L = increase in liabilities due to purchasing an irrigation system

Prin = amount of principal paid during the period

Development of Production Activities

The schematic in Figure 8 illustrates the data flow involved in the development of the production activities. Each one-acre production activity depended upon information from crop simulation models, farm budget data, and the irrigation cost generator. Production costs were estimated from farm budget data combined with information from the irrigation cost generator. The irrigation cost generator was also used to estimate irrigation labor. Yield estimates and water use coefficients were all derived directly from the crop simulation models.

Crop Simulation Models

To determine alternative irrigation schedules and crop yields, three crop growth models were employed. These growth models simulate the daily growth and development of a single plant based upon the prevailing climatic and soil moisture conditions.

The growth models begin each year of simulation by accepting initial values for various agronomic, edaphic, and climatic variables. Soil moisture is calculated on a daily basis. Each day of the growing season is simulated

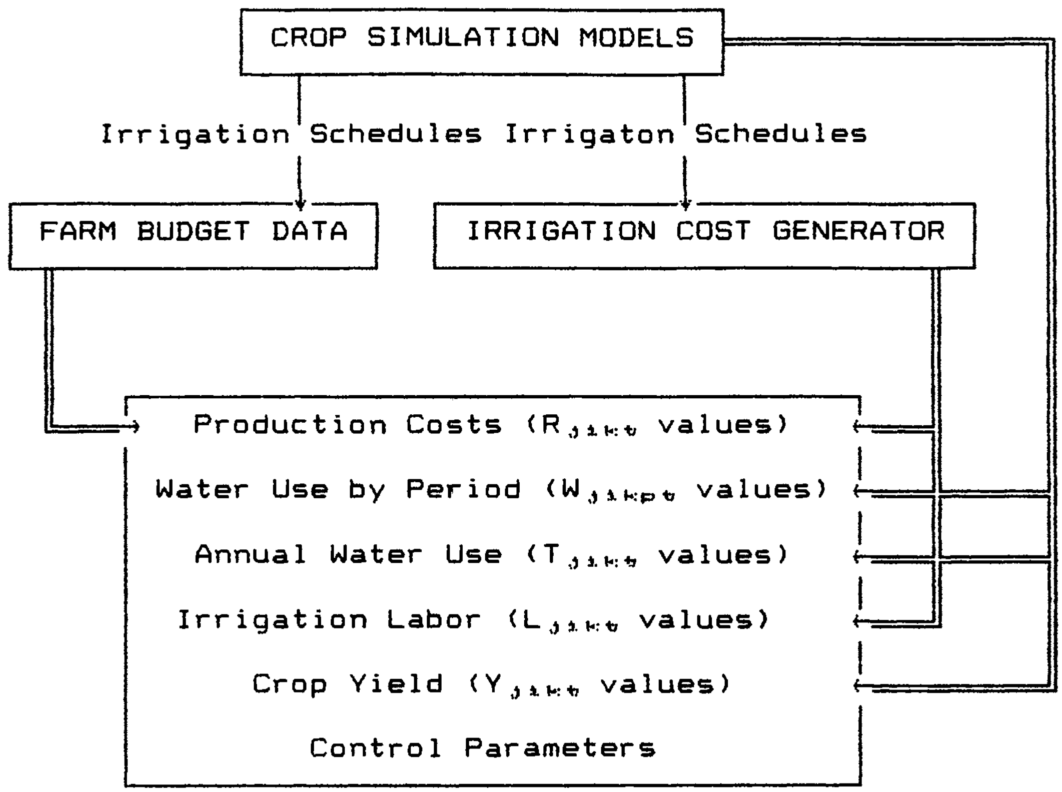

Figure 8. Schematic of the Development of a Representative Production Activity for the Multiperiod Mathematical Programming Model

sequentially, using the ending agronomic condition of the previous day as the starting point for the next day's calculations. Daily climatic data and estimated agronomic conditions are used to estimate daily potential evapotranspiration which is employed in a soil water balance equation to calculate the daily extractable soil water level. The estimate of the quantity of extractable soil water is employed in a relationship to estimate the reduction in net photosynthesis resulting from insufficient soil moisture. Net photosynthesis is converted to dry matter weight, which is then allocated to particular point of the plant according to the stage of plant development. Crop yield is estimated from dry weight during specific stages of plant development.

Wheat Simulation Model. The CERES-Wheat model, developed by Ritchie and Otter (1984) was used to simulate irrigated wheat schedules and yields. The main features of the model deal with the factors considered to be most influential in determining final yields. These include:

- Phasic development or duration of growth stages as related to plant genetics, weather, and other environmental factors
- Apical development as related to morphogeneses of vegetative and reproductive structures
- Extension growth of leaves and stems and senescence of leaves
- Biomass accumulation and partitioning

- Soil water deficit impact of growth and development
- Nitrogen deficit impact on growth and development

For a detailed description of the scientific principles and empirical relationships used in CERES-Wheat see the preliminary documentation (Ritchie and Otter, 1984).

Sorghum Simulation Model. The SORGF model, originally developed by Arkin et al. (1976) and later modified by Maas and Arkin (1978), has been successfully applied to irrigated conditions in western Oklahoma (Harris, Mapp and Stone, 1983; Hornbaker, 1985). Calculations of potential and net photosynthesis is used to estimate daily dry matter development of the grain sorghum plant. Sorghum crop yield is estimated from the portion of dry weight allocated to the grain head during the third and fourth stages of plant development.

Corn Simulation Model. The CORNF simulation model developed by Stapper and Arkin (1979) was used to simulate irrigated corn. CORNF is based on the same principles and has a structure similar to the previously developed sorghum model, SORGF (Arkin et al. 1976; Maas and Arkin, 1978). Location, climatic, plant, planting, and soil data were utilized in relationships which were developed for computing, stage by stage, corn phenological development.

Irrigation Schedules and Yields

The crop simulation models were run for a period of 10 years under various irrigation scheduling criteria. Irrigation schedules were based on soil moisture levels to initiate irrigations. Soil moisture levels were chosen so a broad range of irrigation schedules would be produced to include in the model. The results from each 10 year run were then averaged to give an average irrigation schedule and representative crop yield (Y_{jikt}) for the schedule.

The total acre inches applied per subperiod (W_{jikpt}) and year (T_{jikt}) for each irrigation system were estimated by holding the net irrigation water received by the crop constant and adjusting total acre inches applied, based upon application efficiency of the respective system.

Non-Irrigation Costs of Production

Operating costs for growing wheat, corn, and sorghum were estimated based upon 1988 budgets developed by the Oklahoma State University Cooperative Extension Service for the Northwest District. Budgets for wheat, corn, and sorghum that were produced under surface and center pivot irrigation systems were used. It was assumed that non-irrigation production costs for gated-pipe, surge-flow, tailwater reuse, and cablegation were identical to those of the surface irrigation systems. Non-irrigation production costs for high-pressure center pivot, low-pressure center pivot, low-pressure center pivot with a corner system, low-pressure center pivot fitted with chemigation, and LEPA were assumed to be identical to those of the center pivot irrigation system.

Costs associated with irrigation were taken out of the costs of production to estimate the non-irrigation costs of production. Harvesting costs that varied according to the yield of the respective crop were also removed from the costs of production. These variable harvesting costs were subtracted from the price per bushel or hundredweight of the crops (P_{jt} values in Table III).

Table XI provides estimates of non-irrigation costs of production per acre for wheat, corn, and sorghum grown under a surface irrigation system and a center pivot irrigation system. Dryland wheat and sorghum production costs are also included in Table XI. These values were used in estimating R_{jikt} values in Table III.

Crop Prices

Crop prices used in this analysis were based on five-year averages (1983-1987) of prices within Oklahoma. These prices were adjusted to account for the variable harvesting costs, found in Oklahoma State University enterprise budgets, in estimating the P_{jt} values. These estimates were calculated as follows:

	Wheat/bu.	Corn/bu.	Sorghum/bu.
Crop Price	\$2.78	\$2.67	\$3.78
Harvest Cost	\$0.14	\$0.38	\$0.33
P_{jt} value	\$2.74	\$2.29	\$3.45

TABLE XI

NON-IRRIGATION COSTS OF PRODUCTION $/ACRE

	Surface	Center pivot	Dryland
		dollars	
Wheat	88.69	72.36	73.57
Corn	151.76	134.79	---
Sorghum	84.86	74.18	29.28

Labor Requirements

Labor requirement coefficient (L_{jikt}) estimates for the production activities was estimated in the following manner:

$$L_{jikt} = (l \;/\; P_l) * AI \qquad (4.16)$$

where, l = labor cost per acre inch of water applied

P_l = price of labor per hour

AI = acre inches of water applied

The wage rate assumed in the analysis was $5.00/hour.

Variable Water Costs

The water costs associated each irrigation system that are dependent upon changes in pump lift (V_{it} values) were estimated as follows:

$$V_{it} = \text{Lift} * K \qquad (4.17)$$

where, $K = \dfrac{.0014 * P_{ng}}{PE * DE}$

P_{ng} = Price of natural gas ($1.00, $2.00, $3.00/mcf)

PE = Pump efficiency (.60)

DE = Drive efficiency (.97)

Alternative Irrigation Practices

Irrigation schedules, operating costs, labor, and yields were adjusted for the various alternative irrigation practices. These adjustments were based upon changes in application efficiency and additional farming operations needed to accomplish the alternative practice. The changes in application efficiency and farming operations for the respective systems are discussed in the section: "Description of Alternative Irrigation Practices", in this Chapter.

CHAPTER V

RESULTS AND ANALYSIS

This chapter reports results from applying the multiperiod model to selected production settings in the Oklahoma Panhandle. The effects of a number of different economic conditions, resource limitations, and technical constraints on optimal irrigation adoption strategies were analyzed.

An Overview of the Production Scenarios

A large number of institutional, economic and physical conditions can affect farm-level irrigation investment decisions. It was not practical to evaluate the influence of all possible combinations of physical and economic parameters. Therefore, several scenarios were developed by varying the parameters believed to exert the most influence on irrigation investment plans.

One base irrigated farm operation for the study area was used to analyze the various production scenarios. The representative farm was assumed to be comprised of 620 acres available for irrigated crop production and four irrigation wells. Net farm income was maximized through production of three crops - - wheat, corn, and sorghum.

The production scenarios analyzed, using the representative farm model, are dictated by varying three classes of parameters - - initial irrigation system, price of natural gas ($/mcf), and initial pumplift. In addition, the effect of downward trends in real crop prices was considered.

Table XII presents the various production scenarios chosen for analysis using gated-pipe, low-pressure center pivot, and high-pressure center pivot as initial irrigation systems. In this table the initial irrigation system, gated-pipe, low-pressure center pivot and high-pressure center pivot, are represented by GP, CP and HP, respectively. The following value (100, 200, or 300) represents the initial feet of pump lift. Numbers 1, 2, and 3 represent the natural gas fuel price in dollars per mcf. Acronyms ending with a "P" represent situations characterized by decreasing crop prices over the planning horizon. The baseline scenario at a 200-foot pump lift and a $2.00 fuel price will serve as a benchmark to which the remaining scenarios may be compared.

The assumed production costs, irrigation costs, investment costs and crop prices were described in Chapter IV. To represent crop rotation, risk management and commodity program considerations, limits on individual crop acreages were specified. These acreage limits were specified based upon survey results of crop mix for the study area reported by Kletke (1989). Individual crop acreage limits were set at 125.6 acres for corn and 155

TABLE XII

PRODUCTION SCENARIOS

GP100-1	GP100-2	GP100-3
GP200-1	GP200-2	GP200-3
GP300-1	GP300-2	GP300-3
GP100-1P	GP100-2P	GP100-3P
GP200-1P	GP200-2P	GP200-3P
GP300-1P	GP300-2P	GP300-3P
CP100-1	CP100-2	CP100-3
CP200-1	CP200-2	CP200-3
CP300-1	CP300-2	CP300-3
CP100-1P	CP100-2P	CP100-3P
CP200-1P	CP200-2P	CP200-3P
CP300-1P	CP300-2P	CP300-3P
HP100-1	HP100-2	HP100-3
HP200-1	HP200-2	HP200-3
HP300-1	HP300-2	HP300-3
HP100-1P	HP100-2P	HP100-3P
HP200-1P	HP200-2P	HP200-3P
HP300-1P	HP300-2P	HP300-3P

acres for sorghum. The acreage limit for wheat was set at 620 acres.

Gated-Pipe Initial System

The first set of solutions reports results when gated-pipe was the initial irrigation system on all 620 acres of irrigated land available for production. The underlying assumptions and physical properties of the four gated-pipe systems are given in Chapter IV.

Scenarios which started with gated-pipe as the initial irrigation system are discussed in this section. Results for each scenario, consisting of the irrigation system mix and irrigation practices employed in each of the seven time periods are presented in Table XIII. Irrigation systems and practices are shown only in those periods where a change occurred from the previous period.

Before describing the solutions for the various production scenarios, it is useful to thoroughly examine a single solution. This will indicate the level of detail available from the multiperiod model. Results of the GP200-2 scenario are given in Table XIV. This scenario was chosen because it represents the median initial pump lift and fuel price evaluated. Results for the scenarios GP100-1, GP200-2, and GP300-3 are contained in Appendix B, Tables XXIII, XXIV, and XXV, respectively.

Analysis of the solution shows that the model moved to more efficient irrigation systems through time as the pump

TABLE XIII

OPTIMAL IRRIGATION INVESTMENTS, GATED-PIPE INITIAL SYSTEM

Scenario	Period 1	2	3	4	5	6	7
GP100-1	3GP 1CPC					1GP 2SF 1CPC	
GP200-1	3GP 1CPC					1GP 2SF 1CPC	
GP300-1	3GP 1CPC					1GP 2SF 1CPC	
GP100-2	3GP 1CPC			1GP 2SF 1CPC			
GP200-2	1GP 2SF 1CPC					1SF 2LP,D 1CPC	
GP300-2	1GP 2LP,D 1CPC			1SF 2LP,D 1CPC			
GP100-3	1GP 2SF 1CPC					1SF 2LP,D 1CPC	
GP200-3	1GP 2LP,D 1CPC			1SF 2LP,D 1CPC			
GP300-3	1SF 2LP,D 1CPC						

TABLE XIV

OPTIMAL IRRIGATION PLAN, GP200-2 SCENARIO

	INITIAL SYSTEM Gated-pipe			INITIAL PUMP LIFT 200 Feet		FUEL PRICE $/mcf 2.00	
	PERIOD						
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	310.00	310.00	310.00	310.00	310.00	251.20	251.20
SYSTEM, PRACTICE	SF	SF	SF	SF	SF	LP,D	LP,D
WATER/ACRE (AI)	17.10	17.10	17.10	17.10	17.10	17.10	17.10
DRY WHEAT ACRES	29.40	29.40	29.40	29.40	29.40	88.20	88.20
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICE	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	155.00	155.00	155.00	155.00	155.00	155.00	155.00
SYSTEM, PRACTICE	GP	GP	GP	GP	GP	SF	SF
WATER/ACRE (AI)	12.72	12.72	12.72	12.72	12.72	10.90	10.90
WATER/YEAR (AI)	9282.20	9282.20	9282.20	9282.20	9282.20	6864.22	6864.22
INCOME $/YR	132564.14	132564.14	132564.14	132564.14	132564.14	127730.78	127730.78
PROD. COSTS $/YR	57730.18	57730.18	57730.18	57730.18	57730.18	52739.03	52739.03
IRR. COSTS $/YR	15435.98	15728.92	16021.86	16314.81	16607.75	13685.34	13845.53
LABOR COSTS $/YR	6229.11	6229.11	6229.11	6229.11	6229.11	2944.42	2944.42
TOTAL COSTS $/YR	79395.27	79688.22	79981.16	80274.10	80567.04	69368.79	69528.98
INVESTMENT $/PERIOD	52158.00	0.00	0.00	10563.00	0.00	131550.00	1290.00
DISC. NET RET. $/period	103226.00	135608.58	119885.41	98767.19	93697.74	23246.19	82263.71

OBJ. FUNCTION $ 690284.08

lift increases. Individual crop data for each period consisting of the number of acres, irrigation system used, and acre inches of water applied per acre are given in Table XIV. The total acre inches of irrigation water applied annually, as well as annual income and total variable costs are also reported. Total variable costs are broken down into non-irrigation production costs, irrigation variable costs, and irrigation labor costs. Investment costs and the discounted net return for each three year period are also provided. The objective function value of $690,284.08 is the discounted sum of the net returns and terminal values. This is a return over variable costs and irrigation system investments.

The solution indicates that in period 1 two surge-flow (SF) systems and one low-pressure center pivot fitted with a chemigation system (CPC) were installed. Adaptation of each of the gated-pipe systems to surge-flow requires the installation of two surge-flow valves, a valve controller, 660 feet of underground mainline and two riser valves. Converting to low-pressure center pivot with chemigation results in selling the unused gated-pipe distribution system. In period 4, the worn out surge-flow valve controllers were replaced along with the gated-pipe system used for sorghum irrigation. In period 6, the low-pressure center pivot chemigation system was replaced and two LEPA (LP) systems were installed. This purchase changed the final irrigation system mix to one surge-flow (SF), one low-pressure center pivot with chemigation (CPC), and 2 LEPA systems (LP).

In periods 1 through 5 the irrigation system and crop mix remained unchanged, which held the water applied (9,282 acre inches per year), income ($132,564/year), production costs ($57,730/year), and labor costs ($6,229/year) constant. The optimal set of production activities did not change over the five periods. Irrigation costs increased from $15,435.98 per year in period 1 to $16,607.75 per year in period 5. This increase was caused by the increase in pump lift over time. Irrigated wheat (310 acres), yielding 64.5 bu/acre, utilized two surge-flow systems (SF) in each of the first five periods. Dryland wheat (29.4 acres), yielding 34.5 bu/acre, was also grown. This acreage consisted of the corners on the 125.6 acre center pivot field. Corn was irrigated using a low-pressure center pivot fitted with a chemigation system (CPC) and yielded 150 bu/acre. The low-pressure center pivot chemigation system proves to be an efficient system to produce corn due to the fact that large amounts of insecticide, herbicide, and fertilizer can be applied through the system, reducing chemical and labor costs. Irrigated sorghum (155 acres) was grown using the initial gated-pipe system (GP), yielding 59.57 cwt/acre during the first five periods. A water deficit schedule (12.72 acre inches of water applied) was chosen because of the stress tolerance of sorghum as indicated by the SORGF simulation model. This deficit schedule permitted the sorghum to remain in the less efficient gated-pipe system with out additional investment. This result illustrates the substitution of irrigation practices (in this case, deficit irrigation scheduling) for irrigation technologies in meeting increases in pump lifts and associated increases in pumping costs.

The optimal solution shows a conversion to two LEPA systems (LP) used in conjunction with furrow dikes (D) in period 6, producing 251.2 acres of wheat. This conversion to a more efficient irrigation system reduced total variable costs by decreasing the amount of irrigation labor (1.84 hrs/acre), production costs ($16.33/acre), and irrigation costs ($8.00/acre) in period 6 and 7. Approximately 59 acres of irrigated wheat were moved to dryland production to account for the non-irrigated corners of the two additional LEPA systems. Irrigated corn remained in the low-pressure center pivot chemigation system (CPC) during the final two periods. One of the surge-flow systems (SF) used on wheat in the first five periods was sold in period 6, while the other surge-flow system provided water for 155 acres of sorghum in periods 6 and 7.

The optimal irrigation system mix for scenarios with a $1.00/mcf fuel price were identical (Table XIII). This result indicates that at a $1.00/mcf fuel price changes in initial pump lift did not affect irrigation costs to a point where changes in irrigation systems were merited.
The optimal solutions did require a conversion to one low-

pressure center pivot fitted with chemigation (CPC) in the first period. As stated earlier, investment in low-pressure center pivot chemigation systems results from the high use of chemicals in growing corn. The chemigation system decreases the application costs and amount of chemicals applied along with increasing the water application efficiency to 75 percent. Production costs for corn were $32.84/acre lower under chemigation than gated-pipe. Wheat and sorghum remained in gated-pipe (GP) systems through period 4. Lower irrigation and labor costs attainable from converting to a more efficient system would not cover the investment cost in these early periods. Conversion to two surge-flow (SF) systems occurred in period 5 in all three scenarios. Converting to the surge-flow systems increased application efficiency from 60 percent to 70 percent, which decreased irrigation water applied 899 acre inches per year. These surge-flow systems were used in the production of irrigated wheat (310 acres). Sorghum (155 acres) remained in gated-pipe (GP) all seven periods, indicating that large irrigation investments may not be required for crops with low water requirements, such as sorghum grown under deficit irrigation schedules. Irrigation costs can be kept down on crops that can be successfully grown under deficit irrigation schedules by reducing the quantity of water applied rather than the per acre individual irrigation costs.

Results for scenarios with a $2.00/mcf fuel price

(Table III) indicate that irrigation system investment was required earlier in the planning horizon than with a $1.00/mcf fuel price. The optimal solution for the GP100-2 scenario shows a conversion to two surge-flow systems (SF) producing wheat in period 4, one period earlier than any of the $1.00/mcf scenarios. Fuel prices at $2.00/mcf increased irrigation costs enough to dictate a move to a more efficient irrigation system. Results for the GP200-2 scenario, which was discussed earlier, show a conversion to two surge-flow systems (SF) and one low-pressure center pivot chemigation (CPC) in period 1. In period 6 the remaining gated-pipe system (GP) along with one of the surge flow systems (SF) were converted to LEPA (LP) systems used in conjunction with furrow dikes (D), producing wheat (251.2 acres). The remaining gated-pipe system was used in the production of sorghum (155 acres). Under the highest pump lift considered (300-foot) and a $2.00/mcf fuel price, irrigation during the first three periods involves the use of one low-pressure center pivot chemigation system (CPC) used on corn (125.6 acres), two LEPA systems (LP) with dikes (D) used on wheat (251.2 acres), and sorghum (155 acres) grown on the remaining gated-pipe system (GP). Investments in the LEPA irrigation systems were dictated by water costs associated with high pump lifts and high fuel prices. Investing in LEPA systems reduces irrigation costs by increasing the application efficiency to 95 percent when used in conjunction with furrow dikes. Irrigation labor was also reduced from 3.04 hrs/acre when using gated-pipe to .76 hrs/acre when using LEPA with furrow dikes. Conversion to LEPA with furrow dikes decreased variable costs by $38.42/acre, an amount sufficient to cover the $45,183 investment cost. In period 4, the gated-pipe system (GP) was converted to a surge-flow system (SF) to offset the increases in irrigation costs due to the increasing pump lift over time.

Results for $3.00/mcf fuel price scenarios indicate that conversion to more efficient irrigation systems occurs earlier in the planning horizon when pumping costs were increased. The optimal solution for the GP200-3 scenario (Table III) shows a conversion to one low-pressure center pivot chemigation system (CPC) for corn (125.6 acres) and two LEPA systems (LP) with dikes (D) for wheat (251.2 acres) in period 1. Converting to more efficient irrigation systems early in the planning horizon slows down the depletion of the aquifer and decreases future irrigation costs. Sorghum remained under gated-pipe irrigation (GP) until period 4, when it was converted to surge-flow irrigation (SF), which reduced irrigation water applied 282 acre inches per year.

The GP300-3 scenario had the highest water costs of any scenario evaluated. All four initial gated-pipe systems were converted to more efficient systems in period 1. Sorghum was produced on a surge-flow system (SF), wheat was produced on two LEPA systems (LP) with dikes (D), and corn used one low-pressure center pivot chemigation system (CPC). Irrigation water was applied at a rate of 6,864 acre inches per year in all seven periods. This irrigation system mix proved to be the most profitable in all seven periods.

One system common to all of these results was corn being grown on a low-pressure center pivot chemigation system. Without the possibility of chemigation as a possible irrigation system alternative, irrigation systems used to irrigate corn tend to follow the same trends as those used in wheat irrigation. However, conversions occur earlier in the planning horizon due to the larger irrigation water requirements of corn.

The optimal solutions for scenarios GP200-2 and GP100-3 (Table III) had the same irrigation system mix. This result illustrates the trade off that exists in irrigation costs between lower fuel prices with higher pump lifts and higher fuel prices with lower pump lifts. Results for GP300-2 and GP200-3 also illustrate this irrigation cost trade off; identical irrigation investment decisions were prescribed for a 300-foot initial pump lift with a $2.00/mcf fuel price and a 200-foot initial pump lift with a $3.00/mcf fuel price.

Decreased Crop Prices

In the first set of results it was assumed that crop prices did not change over the planning horizon. This assumption was made so that irrigation investment decisions could be analyzed with the expectation of constant real crop prices. The objective of the following set of scenarios was to determine the effect that decreasing real crop prices would have on irrigation investment decisions. Such an assumption may be appropriate given recent discussions concerning reductions in government commodity programs and their affect on producers' price expectations.

Results for each scenario consisting of the irrigation system mix and irrigation practices employed in each of the seven time periods are presented in Table XV. Irrigation systems and practices are shown only in those periods where a change occurred from the previous period. Detailed results for scenarios GP100-1P, GP200-2P, and GP300-3P are contained in Appendix B, Tables XXVI, XXVII, and XXVIII, respectively. All assumptions in these scenarios were identical to the first set of scenarios with the exception of real crop prices decreasing over time. Prices for wheat, corn, and sorghum were decreased by one third over the 21-year planning horizon of the model. Because these reductions would create a situation where variable costs of dryland wheat production would exceed receipts in periods 5 through 7, production costs for dryland wheat were decreased 20 percent from $73.57/acre to $58.86/acre in periods 5, 6, and 7. Without this adjustment, significant quantities of land would be idled in the optimal solutions. Reductions in production costs for dryland wheat would occur as producers reduced input use in response to declining marginal value

TABLE XV

OPTIMAL IRRIGATION INVESTMENTS,
GATED-PIPE INITIAL SYSTEM,
DECREASING CROP PRICES

	Period						
Scenario	1	2	3	4	5	6	7
GP100-1P	3GP 1CPC			1GP 2SF 1CPC			3DRY 1CPC
GP200-1P	3GP 1CPC		1GP 2SF 1CPC			2DRY 1GP 1CPC	3DRY 1CPC
GP300-1P	1GP 2SF 1CPC						3DRY 1CPC
GP100-2P	3GP 1CPC		1GP 2SF 1CPC			2DRY 1GP 1CPC	3DRY 1CPC
GP200-2P	1GP 2LP,D 1CPC					3DRY 1CPC	
GP300-2P	1GP 2LP,D 1CPC					3DRY 1CPC	
GP100-3P	1GP 2SF 1CPC						3DRY 1CPC
GP200-3P	1GP 2LP,D 1CPC					3DRY 1CPC	
GP300-3P	1GP 2LP,D 1CPC	1SF 2LP,D 1CPC			1DRY 2LP,D 1CPC	3DRY 1CPC	

products.

Unlike the first set of scenarios, results on irrigation system mix for scenarios with a $1.00/mcf fuel price were not identical (Table XV). Optimal solutions for GP100-1P and GP200-1P (Table XV) contain three gated-pipe systems (GP) and one low-pressure center pivot fitted with chemigation (CPC). Two of the gated-pipe systems were used in the production of wheat with the remaining system in sorghum. As in the constant price scenario, corn utilizes the low-pressure center pivot chemigation system. The two gated-pipe systems used in the production of wheat were converted to surge-flow (SF) in period 4 when the initial pump lift was 100 feet and in period 3 for the 200-foot lift. Larger pumping costs associated with the additional 100 feet of lift prompt an earlier conversion to surge-flow irrigation. In the optimal solution for GP100-1P, the irrigation system mix remained the same in periods 4, 5, and 6 (one gated-pipe, two surge-flow, and one low-pressure center pivot with chemigation).

The two surge-flow systems continued to produce wheat until their useful life ran out at the end of period 6; however, it was not profitable to reinvest in these systems. The difference between irrigated and non-irrigated returns was not sufficient to cover investment costs; thus, both fields were converted to dryland wheat production. The same situation occurred one period earlier in GP200-1P.

The optimal solution for GP300-1P (Table XV) in period

1 had one gated-pipe system (GP) for growing irrigated sorghum, two surge-flow systems (SF) for wheat, and one low-pressure center pivot chemigation system (CPC) for corn. Investment in surge-flow irrigation in the first period occurs in lieu of gated-pipe as in the constant price scenario. By converting to a more efficient irrigation system earlier in the time horizon, irrigation costs were reduced in two ways. First, decreases in the amount of irrigation water applied and reductions in irrigation labor costs are realized. Second, reducing the amount of water applied slows down the depletion of the aquifer and decreases future irrigation costs. This irrigation system mix remains constant until period 7 when the two surge-flow systems (SF) and the gated-pipe system (GP) converted to dryland for the production of wheat and sorghum. Decreasing crop prices dictates this move to dryland production because variable cost of irrigated wheat and sorghum exceed receipts.

Optimal irrigation investment decisions for scenarios GP200-2P and GP300-2P were identical (Table XV). This result indicates that, even with a decrease in crop prices, increases in the higher initial pump lifts do not increase irrigation costs to a point where changes in irrigation systems were required. The optimal solutions for both scenarios show investment in one low-pressure center pivot chemigation system (CPC) and two LEPA systems (LP) with furrow dikes (D). The remaining gated-pipe system (GP) was used to irrigate sorghum. By investing in these more efficient irrigation systems in the first period, the model increases net returns in the first five periods when crop prices were higher. Net cash flows derived from the conversion were sufficient to cover investment costs. As crop prices decline and irrigation for wheat and sorghum no longer remain profitable, the two LEPA systems and the gated-pipe system convert to dryland in period 6.

Results for GP200-3P and GP300-3P (Table XV) show a system mix of one gated-pipe system (GP) growing sorghum, one low-pressure center pivot chemigation system (CPC) for corn, and two LEPA systems (LP) with furrow dikes (D) for growing wheat. This system mix remained the same for GP200-3P until the end of the useful life of the LEPA system (period 6). As a result of decreasing crop prices and increasing irrigation costs, it was not profitable to replace the LEPA system or continue to produce irrigated sorghum with gated-pipe.

Decreasing crop prices and increased irrigation costs have an even larger impact on optimal irrigation investment under GP300-3P. In period 2 the 155-acre sorghum field was converted to a surge-flow system (SF), which reduced irrigation water applied per year 282 acre inches. In period 5 the surge-flow system (SF) that was previously used in sorghum production was converted to dryland wheat. The two LEPA systems (LP) with dikes (D) were split between wheat (125.6 acres) and sorghum (125.6 acres). Corn remains in low-pressure center pivot chemigation (CPC). Reinvestment in the two LEPA systems was not profitable in period 6; thus, both systems were converted to dryland.

When compared to the first set of results with constant crop prices (Table XIII), it can be seen that decreasing crop prices over time (Table XV) initiates irrigation investment decisions earlier in the planning horizon. Irrigation investments occur earlier so that increases in efficiency can be realized sooner and net cash flows derived from irrigation system conversions were sufficient to cover investment costs. With the exception of low-pressure center pivot chemigation used on corn, when the irrigation system's useful life was reached it was not profitable to reinvest in a new system. In both sets of results the low-pressure center pivot chemigation system saves enough money on chemicals, application costs, and irrigation costs to remain profitable in all seven periods.

Lower crop prices and dryland production in the last three periods caused the objective functions for scenarios with decreasing crop prices to be substantially lower than those with constant crop prices. For example the objective functions for the 200-foot lift $2.00/mcf fuel price scenario (GP200-2, and GP200-2P) under constant and decreasing crop prices, were $690,284.08 and $420,181.71, respectively. Discounted net returns range from 36 to 44 percent below those estimated under constant real output price assumptions.

Low-Pressure Center Pivot Initial System

The second set of solutions reports results when low-pressure center pivot was the initial irrigation system on all 620 acres of irrigated land available for production. The underlying assumptions and physical properties of the four low-pressure systems are given in Chapter IV. The initial low-pressure system was assumed to have six years of useful life remaining at the beginning of the time horizon.

Results for each scenario, consisting of the irrigation system mix and irrigation practices employed in each of the seven time periods, are presented in Table XVI. Detailed results for scenarios CP100-1, CP200-2, and CP300-3 are contained in Appendix B, Tables XXIX, XXX, and XXXI, respectively.

Optimal irrigation systems and practices were identical for scenarios CP100-1 through CP100-2 (Table XVI). In period 1 wheat remained in the two low-pressure systems (CP), while corn (125.6 acres) and sorghum (125.6 acres) production moved to low-pressure center pivot fitted with a chemigation system (CPC). This conversion simply involves the installation of a chemigation system to the existing low-pressure center pivot. Converting to low-pressure center pivot with chemigation reduced production costs $16.00/acre for corn and $2.58/acre for sorghum. During each of the six years, 7,262 acre inches of water was applied. Dryland wheat (88.2 acres) and dryland sorghum (29.4 acres) were produced in all seven periods. In period

TABLE XVI

OPTIMAL IRRIGATION INVESTMENTS,
LOW-PRESSURE CENTER PIVOT,
INITIAL SYSTEM

	Period						
Scenario	1	2	3	4	5	6	7
CP100-1	2CP 2CPC		2CPC 2LP,D				
CP200-1	2CP 2CPC		2CPC 2LP,D				
CP300-1	2CP 2CPC		2CPC 2LP,D				
CP100-2	2CP 2CPC		2CPC 2LP,D				
CP200-2	2CP,DC 2CPC		2CPC 2LP,D				
CP300-2	2CP,DC 2CPC		2CPC 2LP,D				
CP100-3	2CP,DC 2CPC		2CPC 2LP,D				
CP200-3	2CP,DC 2CPC		1CPC 3LP,D				
CP300-3	2CP,DC 2CPC		1CPC 3LP,D				

3, after the remaining life of the initial systems, the system mix changed to two low-pressure center pivot chemigation systems (CPC) and two LEPA systems (LP) with furrow dikes (D). Production of corn and sorghum remained in low-pressure center pivot with chemigation (CPC). Results for all four scenarios showed production of 251.2 acres of wheat on the two LEPA systems with dikes, in periods 3 through 7. The LEPA systems with furrow dikes increase application efficiency, reducing irrigation variable costs ($3.43/acre), and reduces the amount of irrigation water applied 854 acre inches per year. Total operating pressure decreased 15 psi which decreased fuel costs $1.52/acre at $1.00/mcf and $3.04/acre at $2.00/mcf fuel prices.

Optimal solutions for scenarios CP200-2 through CP100-3 contained the same system mix as above, with the exception that deep chiseling (DC) was used on the two low-pressure systems (CP) in wheat production during the first two periods. Deep chiseling reduces irrigation costs $0.20/acre more than the additional tillage costs at a 200-foot pump lift and $2.00/mcf fuel price. This differential increases as pump lift and/or fuel price increases.

Results for CP200-3 and CP300-3 (Table XVI) also contain two low-pressure systems (CP) used in conjunction with deep chiseling (DC) in periods 1 and 2. Following the useful life of the initial low-pressure center pivot systems, the irrigation system mix changed to one low-pressure center pivot chemigation system (CPC) and three LEPA systems (LP) with furrow dikes. Two of the LEPA systems produce wheat, and the other sorghum. The conversion to LEPA with furrow dikes on wheat and sorghum reduces irrigation water applied 603 acre inches per year. Annual water applied to sorghum decreased 260 acre inches per year compared to low-pressure center pivot with chemigation. At a 300-foot lift and $3.00/mcf fuel price, total variable costs of sorghum production under LEPA irrigation were $7.80/acre lower than low-pressure center pivot with chemigation. Pumping costs were not high enough in any of the nine scenarios to warrant the investment in water-conserving technology prior to the end of the existing system's useful life.

Decreased Crop Prices

Table XVII contains results for each scenario under conditions of decreasing crop prices. All assumptions in these scenarios were identical to the first set of low-pressure scenarios with the exception of crop prices decreasing over time and dryland wheat production costs in periods 5, 6, and 7. Crop prices and dryland wheat production cost assumptions were identical to those outlined in the "Decreasing Crop Price" portion of the "Gated-Pipe Initial System" section. Appendix B, Tables XXXII, XXXIII, and XXXIV contain detailed results for scenarios CP100-1P, CP200-2P, and CP300-3P, respectively.

TABLE XVII

OPTIMAL IRRIGATION INVESTMENTS, LOW-PRESSURE CENTER PIVOT INITIAL SYSTEM, DECREASING CROP PRICES

	Period						
Scenario	1	2	3	4	5	6	7
CP100-1P	2CP 2CPC		2CP 2CPC				
CP200-1P	2CP,DC 2CPC		2CPC 2LP,D				
CP300-1P	2CP,DC 2CPC		2CPC 2LP,D				
CP100-2P	2CP,DC 2CPC		2CPC 2LP,D				
CP200-2P	2CP,DC 2CPC		2CPC 2LP,D				
CP300-2P	2CP,DC 2CPC		2CPC 2LP,D				
CP100-3P	2CP,DC 2CPC		1CPC 3DRY				
CP200-3P	2CP,DC 2CPC		1CPC 3DRY				
CP300-3P	2CP,DC 2CPC		1CPC 3DRY				

Decreasing crop prices through time had no effect on irrigation system and practice mix in the first two periods for any of the solutions in Table XVII. Investment decisions were affected following the useful life of the initial low-pressure systems. Results for the CP100-1P scenario show that in period 3 wheat would be grown on two low-pressure center pivots (CP). Conversion to a more efficient system, such as LEPA, would not be profitable.

Optimal solutions for CP200-1P through CP300-2P scenarios were identical (Table XVII). Corn and sorghum utilize the low-pressure center pivot chemigation systems (CPC), while 251.2 acres of wheat was produced on the two LEPA systems (LP) with furrow dikes (D). At these combinations of pump lifts and fuel prices, savings in irrigation costs were sufficient to cover the additional investment costs of LEPA systems.

Wheat and sorghum fields were converted to dryland in period 3 in solutions for $3.00/mcf fuel prices, while corn remains in low-pressure center pivot chemigation (CPC). When the price of natural gas reaches $3.00/mcf, decreases in crop prices over time lower returns on wheat and sorghum to the point that receipts do not cover irrigation costs. This result contrasts with the reinvestment in all systems under constant output price expectations (Table XVI).

High-Pressure Center Pivot Initial System

The third set of solutions reports results when high-pressure center pivot was the initial irrigation system on all 620 acres of irrigated land available for production. The underlying assumptions and physical properties of the four high-pressure systems are given in Chapter IV. The initial high-pressure system was assumed to have six years of useful life remaining at the beginning of the time horizon.

Results for each scenario, consisting of the irrigation system mix and irrigation practices employed in each of the seven time periods are presented in Table XVIII. Detailed results for scenarios HP100-1, HP200-2, and HP300-3 are contained in Appendix B Tables XXXV, XXXVI, and XXXVII, respectively.

Optimal irrigation system investments were identical to those with low-pressure center pivot as the initial system. However, an additional $2,200/system investment was required to convert the high-pressure center pivots to low-pressure center pivots in the first period. Conversion to a low-pressure system involves replacement of the 132 high-pressure sprinklers with goose necks, drops, and nozzles. Discharge pressure was reduced from 55 psi to 25 psi as a result of the modification. At a $1.00/mcf fuel price, decreasing operating pressure to 25 psi reduces fuel costs by $2.66/acre for wheat and corn and by $3.27/acre for sorghum.

TABLE XVIII

OPTIMAL IRRIGATION INVESTMENTS,
HIGH-PRESSURE CENTER PIVOT,
INITIAL SYSTEM

	Period						
Scenario	1	2	3	4	5	6	7
HP100-1	1CP 2CPC		2CPC 2LP,D				
HP200-1	2CP 2CPC		2CPC 2LP,D				
HP300-1	2CP 2CPC		2CPC 2LP,D				
HP100-2	2CP 2CPC		2CPC 2LP,D				
HP200-2	2CP,DC 2CPC		2CPC 2LP,D				
HP300-2	2CP,DC 2CPC		2CPC 2LP,D				
HP100-3	2CP,DC 2CPC		2CPC 2LP,D				
HP200-3	2CP,DC 2CPC		1CPC 3LP,D				
HP300-3	2CP,DC 2CPC		1CPC 3LP,D				

Results for all scenarios indicated production of 251.2 acres of wheat on two LEPA systems in periods 3 through 7. LEPA systems with furrow dikes increased application efficiency to 95 percent, reducing the amount of irrigation water applied 854 acre inches per year. Operating pressure was decreased to 10 psi, which further decreases fuel costs ($4.18/acre at $1.00/mcf, $8.36/acre at $2.00/mcf and $12.54/acre at $3.00/mcf).

Decreased Crop Prices

The objective of the following set of scenarios was to determine the effect that decreasing real crop prices would have on irrigation investment decisions with high-pressure center pivots as the initial systems. Table XIX contains results for each scenario consisting of the irrigation system mix and irrigation practices employed in each of the seven time periods. All assumptions in these scenarios were identical to the first set of high-pressure scenarios with the exception of crop prices decreasing over time and dryland wheat production costs in periods 5, 6, and 7. Crop price and dryland wheat production costs assumptions were the same as those outlined in the "Decreased Crop Prices" portion of the "Gated-Pipe Initial System" section. Appendix B, Tables XXXVIII, XXXIX, and XL contain detailed results for scenarios HP100-1P, HP200-2P, and HP300-3P, respectively.

Decreasing crop prices changed irrigation system

TABLE XIX

OPTIMAL IRRIGATION INVESTMENTS, HIGH-PRESSURE CENTER PIVOT INITIAL SYSTEM, DECREASING CROP PRICES

	Period						
Scenario	1	2	3	4	5	6	7
HP100-1P	2CP 2CPC		2CP 2CPC				
HP200-1P	2CP,DC 2CPC		2CPC 2LP,D				
HP300-1P	2CP,DC 2CPC		2CPC 2LP,D				
HP100-2P	2CP,DC 2CPC		2CPC 2LP,D				
HP200-2P	2CP,DC 2CPC		2CPC 2LP,D				
HP300-2P	2CP,DC 2CPC		2CPC 2LP,D				
HP100-3P	2CP,DC 2CPC		1CPC 3DRY				
HP200-3P	2CP,DC 2CPC		1CPC 3DRY				
HP300-3P	2CP,DC 2CPC		1CPC 3DRY				

investments in the same way as with low-pressure center pivot as the initial system (Table XVII). However, conversion to low-pressure center pivot in the first period requires a $2,200 additional investment. The profitability of the LEPA system (LP) prescribed at the 100-foot pump lift and $1.00/mcf fuel price changed from the constant price scenario. Results for HP100-1P scenario (Table XVII) show that in period 3 two low-pressure center pivots (CP) were used in wheat production, instead of two LEPA systems with dikes. The decrease in crop prices, even with the $4.58/acre irrigation and labor cost savings, prevent LEPA from being used due to the $7000 higher investment cost.

Optimal irrigation systems and practices for scenarios HP200-1P through HP300-2P were identical (Table XIX). Corn and sorghum utilize the chemigation systems (CPC) to take advantage of the decrease in production costs. Wheat (251.2 acres) was produced on two LEPA systems (LP) with furrow dikes (D). Increases in irrigation costs, due to higher pump lifts and/or fuel prices, make LEPA systems more profitable the low-pressure systems by decreasing annual water application by 854 acre inches and reducing per-acre inch irrigation costs.

Solutions for HP100-3P, HP200-3P, and HP300-3P scenarios indicate that wheat and sorghum fields were converted to dryland in period 3, after the life of the initial systems. When increases in irrigation costs were combined with decreases in crop prices, investment in new irrigation systems was not profitable for the production of wheat or sorghum. However, low-pressure center pivot chemigation (CPC) remained profitable in corn production.

General Conclusions

Fuel price appears to have more affect on irrigation adoption rates and system mix than initial pump lift in all scenarios. This is particularly apparent when comparing results with high-pressure and low-pressure center pivots as the initial system.

Low application efficiencies associated with gated-pipe systems dictated the need for irrigation system investments in early portions of the planning horizon. High-pressure center pivots also required immediate conversion to low-pressure systems. In contrast, when initiated from low-pressure center pivot irrigation, significant irrigation system modifications were delayed. Low-pressure center pivot systems already operate at a relatively high application efficiency (75 percent) and low pressure (25 psi) and did not require additional investment until existing systems wore out.

When the assumption of decreasing real crop prices over time was made, dryland production of wheat and sorghum in later periods became optimal. After existing irrigation systems useful lives were completed it was not profitable to reinvest in new irrigation systems. Differences between irrigated and non-irrigated returns were not sufficient to cover investment costs. This is especially apparent in the gated-pipe scenarios. Dryland production was included in the optimal solution in all nine pump lift-fuel price combinations. Only when the fuel price reached $3.00/mcf did acreage move to dryland production in the high-pressure and low-pressure center pivot scenarios.

Tailwater reuse, corner systems on low-pressure center pivots, alternate-furrow irrigation, and limited irrigation dryland (LID) did not enter the optimal solutions for any of the scenarios. High investment costs and/or reduced yields prevented these systems and practices from entering the optimal irrigation plans. Several of these technologies may be profitable under the assumptions of this study; however, more efficient means of reducing irrigation costs may be available. When making irrigation investment decisions, producers need to take into consideration their personal preferences, management ability, and other aspects of their farming operation.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The importance of irrigated agriculture in Oklahoma is a well documented fact. A large portion of the state's irrigated land lies in the Oklahoma Panhandle, which utilizes the High Plains-Ogallala Aquifer as the primary source of irrigation water. Irrigation producers in the Oklahoma Panhandle use natural gas as the primary fuel for pumping groundwater.

Irrigated producers in the Oklahoma Panhandle are experiencing problems with increased costs for pumping irrigation water along with declining water supplies. One option available to irrigation farmers in responding to this problem is adopting new, more efficient, irrigation technologies and practices. However, investment decisions in irrigation typically involve large sums of money and affect a farm operation over a number of years. Investment costs must be paid out immediately, whereas the income or benefits occur over time. Due to relatively large investment costs and future events controlling benefits, evaluation of irrigation investment alternatives is needed. In addition, more detailed knowledge of production and/or economic conditions which can dictate a change in irrigation investments is needed.

The objective of this study was to develop a farm-level multiperiod mathematical programming model to maximize net returns to irrigated producers in the Oklahoma Panhandle through selected adoption of available irrigation technology. Specifically, the study was conducted to determine the optimal sets of irrigation technologies and practices over a multiple-year time horizon under alternative initial irrigation production situations.

Method of Analysis

The method of analysis employed in order to fulfill the study objectives was multiperiod mathematical programming. This method takes the initial irrigation technologies as given and determines an optimal temporal investment strategy. Seven time periods, of three years each, contained activities and constraints representing the relevant irrigation investment decisions. Investment decisions, the objective function, financial considerations, and pumping conditions linked the periods together.

Total acreage in the model was constrained so that the sum of all acres used in crop production could not exceed the total acreage available (620 acres). Limits on total acres of corn were set at 125.6 acres, sorghum was limited to 155 acres and wheat at 620 acres. Each production activity was calculated on a per acre basis and no double cropping of the land base was permitted. Production activities were developed through the use of wheat, corn, and sorghum simulation models and Oklahoma State University enterprise budgets. Crop prices used in the analysis were based on five year averages (1983-1987) of prices within Oklahoma.

Investment costs for irrigation systems and various components were estimated from results of a survey of several Oklahoma and Texas Panhandle irrigation equipment dealers conducted in June, 1988. Irrigation operating costs were estimated using a modified version of the Oklahoma State University Irrigation Cost Generator. Separable programming was used to represent changes in irrigation pumping conditions (e.g., pump lift and flow rate) over time, and the associated increases irrigation costs. This allowed for revision of pumping conditions over the 21-year time horizon of the analysis.

Irrigation technology alternatives analyzed included gated-pipe, surge-flow, tailwater reuse, cablegation, high-pressure center pivot, low-pressure center pivot, low-pressure with a corner system, low-pressure center pivot with chemigation, and low energy precision application systems (LEPA). Several alternative irrigation practices were also considered: alternate-furrow irrigation, limited irrigation dryland (LID), furrow diking, and deep chiseling.

Summary of Results

The model was developed for a representative Oklahoma Panhandle irrigated farm with 620 acres available for irrigated crop production. Net farm income was maximized through production of wheat, corn, and sorghum. Dryland production of wheat and sorghum was also allowed. Optimal irrigation technology and practice adoption strategies are given for several different initial production situations by varying the initial system, pump lift, fuel price, and crop price trends.

Gated-Pipe Initial System

In this set of scenarios, gated-pipe was the initial irrigation system used on all 620 acres. Initial pump lift, fuel prices, and crop price trends were varied to reflect a wide range of production situations.

Optimal solutions for scenarios with constant crop prices did not move to dryland production in any of the seven periods. Low-pressure center pivot fitted with chemigation proved to be the most profitable system in corn production because of the savings on insecticides, herbicides, and fertilizer. At a $1.00/mcf fuel price wheat remained in gated-pipe until period 5, when surge-flow systems entered the optimal solution. Sorghum remained in gated-pipe over the entire time horizon. Deficit irrigation may be used to produce crops with a high stress tolerance, such as sorghum. Large investments may sometimes be avoided by reducing the net irrigation requirement to reduce pumping costs.

Investment decisions were made in earlier periods as fuel price increased to $2.00/mcf and $3.00/mcf. As irrigation costs rose, the optimal system mix included more efficient irrigation systems. Wheat acreage moved to LEPA systems with furrow dikes and sorghum moved from gated-pipe systems to surge-flow. At a 300-foot initial pump lift and $3.00/mcf fuel price, irrigation pumping costs were high enough to merit the conversions in the first period of the analysis.

When crop prices were decreased over the 21-year planning horizon of the analysis, investment decisions were made in earlier periods. Investing in more efficient irrigation systems in earlier periods allowed the investment to be paid off while crop prices were higher. This strategy also increased net returns in later periods, when crop prices were lower. Dryland production of wheat and sorghum became profitable in later periods, following the useful lives of irrigation systems placed in service at the beginning of the planning horizon. Low-pressure center pivot fitted with chemigation producing corn remained profitable under the assumption of decreased prices, due to the savings on chemicals and application costs.

Low-Pressure Center Pivot Initial System

Low-pressure center pivots were the initial irrigation systems used on all 620 acres in this set of scenarios. The initial low-pressure systems were assumed to have six years of useful life remaining. A wide range of production situations were evaluated by varying initial pump lift, fuel prices, and crop price trends.

Irrigation system mixes in periods 1 and 2, for scenarios with constant crop prices were identical (two low-pressure center pivots used on wheat and two low-pressure center pivots with chemigation used on corn and sorghum). Deep chiseling on the two low-pressure systems became profitable for scenarios with 200-and 300-foot initial pump lifts at a $2.00/mcf fuel price and all $3.00/mcf fuel price scenarios. When the remaining life of the initial low-pressure systems was over (period 3), the irrigation system mix changed. Results for all $1.00/mcf and $2.00/mcf fuel price scenarios and 100-foot lift with $3.00/mcf fuel price scenarios were identical. Optimal solutions for these scenarios contained two LEPA systems with furrow dikes producing wheat and two low-pressure center pivot chemigation systems used for the production of corn and sorghum. At $3.00/mcf fuel prices, the irrigation system mix changes to one low-pressure center pivot chemigation system and three LEPA systems with furrow dikes. Increased irrigation costs made the LEPA system with furrow dikes more profitable than low-pressure center pivot with chemigation when producing sorghum.

Decreasing crop prices changes the profitability of the LEPA system on wheat at 100-foot pump lift and $1.00/mcf fuel price. Despite the $4.58/acre irrigation and labor cost savings, compared to low-pressure center pivot systems, the $7,000 higher investment cost prevented LEPA with furrow dikes from being used on wheat. Results for the remaining $1.00/mcf and $2.00/mcf fuel price scenarios are the same as with constant crop prices (two chemigation and two LEPA systems with dikes). With increases in irrigation costs, combined with decreases in crop prices, investment in new irrigation systems was not profitable for wheat and sorghum production at $3.00/mcf fuel prices. Thus, three fields were converted to dryland sorghum and wheat production following period 3. Production cost savings from using low-pressure center pivot fitted chemigation on corn, allowed the chemigation to system remain profitable.

<u>High-Pressure Center Pivot Initial System</u>

In this set of scenarios, high-pressure center pivots were the initial irrigation systems used on all 620 acres. The initial high-pressure systems were assumed to have six years of useful life remaining at the beginning of the time horizon. A wide range of production situations were evaluated by varying initial pump lift, fuel prices, and crop price trends.

In this scenario, all four irrigation systems were converted in period 1. All four of the high-pressure systems were converted to low-pressure center pivot; in addition two were fitted with chemigation. In period 3, after the remaining life of the initial systems, the irrigation system mix changed. At $1.00/mcf and $2.00/mcf fuel prices, for all three pump lifts (100 feet, 200 feet, and 300 feet), the irrigation system mix changed to two low-pressure center pivot chemigation systems (corn, and sorghum), and two LEPA systems with furrow dikes (wheat). Higher irrigation costs, due to increased pump lift through time, prompted this move to more efficient irrigation systems. At $3.00/mcf fuel prices, irrigation pumping costs increase to the point where a conversion to LEPA with furrow dikes on sorghum was warranted.

Decreasing crop prices changes the profitability of the LEPA system at 100-foot pump lift and $1.00/mcf fuel price. Despite the $4.58/acre irrigation and labor cost savings compared to low pressure systems, the $7,000 higher investment costs prevents LEPA from being used on wheat. Results on irrigation system mix in periods 3 through 7 for the remaining $1.00/mcf and $2.00/mcf fuel price scenarios are the same as with constant prices (two low-pressure center pivot chemigation systems and two LEPA with dikes). With increases in irrigation costs, combined with decreases in crop prices, investment in new irrigation systems was not profitable to produce wheat or sorghum at $3.00/mcf fuel prices. Higher returns above irrigation investment costs and variable cost could be earned in dryland production. However, low-pressure center pivot with chemigation remained profitable in corn production.

Conclusions

Multiperiod mathematical programming was employed as the analytical tool to simultaneously evaluate investment decisions over time under different initial farm production situations. The model developed for this study requires initial irrigation production situations to be given. Solutions provide an optimal investment strategy which gives both the longer-term irrigation investment levels and the optimal path of adoption that should be pursued.

Results of the analysis indicate that investments in irrigation systems are quite sensitive to fuel price and crop price trends. Due to the level of sensitivity to prices, studies attempting to identify efficient irrigation investment decisions may provide erroneous results, if fuel and crop prices are ignored. Changes in pump lift over time also affect irrigation system adoption rates. The derived irrigation system investment strategies illustrate some ability for irrigated producers to maximize returns over a period of several years through irrigation system selection. Investment in more efficient irrigation systems can provide important irrigation cost reduction opportunities to Oklahoma High Plains irrigated producers.

It is recognized that specific recommendations from this research are unique to the production setting, but general prescriptions can be derived from the results. Information from this study should be useful to irrigators seeking to develop optimal strategies for converting existing systems to more efficient ones.

Limitations and Need for Further Research

In the process of conducting this research various difficulties were encountered. These problems provide several opportunities for future research and can be summarized as follows:

a) Availability of data on the effects that various irrigation systems and practices have on yields of wheat, corn, and sorghum was incomplete and necessitated estimates in several instances. More complete yield data, on a wider variety of irrigation technologies and practices would aid in more closely representing the actual farm production settings.

b) Crop production input requirements and costs were based upon Oklahoma State University enterprise budgets for northwestern Oklahoma. Actual data relating input requirements and costs to crop yields in a typical setting would solidify the production activity assumptions made.

c) Irrigation schedules and their respective yields were based upon crop simulation models for wheat, corn, and sorghum. Investment prescriptions appear to be quite sensitive to the irrigation activities derived from the simulation models. This result is especially apparent in the sorghum production activities where deficit irrigation schedules were optimal. While the feasibility of this is possible, the phenomenon is probably not practical year after year.

d) This study did not evaluate all possible irrigation systems that are available to producers. More detailed and complete information on new systems, such as the Multifunction Irrigation System (MIFS) and drip technologies is needed.

e) Benefits of low-pressure center pivot chemigation systems are valued as reduction in chemical requirements and application costs. Because of the difficulties in assessing yield consequences associated with improved chemical distribution, yield augmenting effects of chemigation are not included. Better information on chemical and application savings is also needed.

f) Irrigation plans derived from the model tend to employ the same system for irrigation of a particular crop. Crop rotation and weed control considerations may make this impractical.

g) Results presented are unique to the specific production setting. Changes in climatic conditions, soil types, etc. may dictate different investment prescriptions. Research is needed to evaluate the sensitivity of irrigation investments to these parameters.

h) The analysis is deterministic and does not consider risk implications of alternative investments. Additional research focusing on the implications of irrigation investment decisions on the level of risk experienced by producers would be beneficial.

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APPENDICES

APPENDIX A

ACRE INCH OPERATING COSTS AND TERMINAL VALUES

TABLE XX

ACRE INCH OPERATING COSTS OF THE BASE SYSTEMS
AT THREE ALTERNATIVE PUMP LIFTS,
$2.00/mcf FUEL PRICE, 900 GPM

	Pump Lift (feet)		
	100	200	300
	dollars		
Surge-flow			
Fuel	.57	1.01	1.44
Lubrication	.09	.14	.20
Repairs	.37	.38	.40
Labor	.76	.76	.76
Total	1.79	2.29	2.80
Tailwater reuse			
Fuel	.57	1.01	1.44
Lubrication	.09	.14	.20
Repairs	.42	.43	.45
Labor	.77	.77	.77
Total	1.85	2.35	2.86
Cablegation			
Fuel	.57	1.01	1.44
Lubrication	.09	.14	.20
Repairs	.34	.35	.37
Labor	.60	.60	.60
Total	1.60	2.10	2.61
High-pressure			
Fuel	1.13	1.56	1.99
Lubrication	.15	.21	.27
Repairs	.46	.49	.50
Labor	.35	.35	.35
Total	2.06	2.56	3.05
Low-pressure			
Fuel	.83	1.26	1.70
Lubrication	.11	.17	.23
Repairs	.43	.44	.44
Labor	.35	.35	.35
Total	1.72	2.22	2.72
Corner system			
Fuel	.82	1.25	1.69
Lubrication	.11	.17	.23
Repairs	.53	.53	.53
Labor	.35	.35	.35
Total	1.81	2.31	2.80

TABLE XX (Continued)

	Pump Lift (feet)		
	100	200	300
	dollars		
Chemigation			
Fuel	.83	1.26	1.70
Lubrication	.11	.17	.23
Repairs	.43	.44	.44
Labor	.35	.35	.35
Total	1.72	2.22	2.72
LEPA			
Fuel	.61	.98	1.35
Lubrication	.09	.15	.21
Repairs	.59	.59	.60
Labor	.30	.30	.30
Total	1.59	2.02	2.46

TABLE XXI

ACRE INCH OPERATING COSTS OF THE BASE SYSTEMS
AT THREE ALTERNATIVE PUMP LIFTS,
$2.00/mcf FUEL PRICE, 800 GPM

	Pump Lift (feet)		
	100	200	300
	dollars		
Low-pressure			
Fuel	.81	1.25	1.68
Lubrication	.11	.17	.23
Repairs	.45	.48	.49
Labor	.37	.37	.37
Total	1.74	2.27	2.77
Corner system			
Fuel	.79	1.23	1.67
Lubrication	.11	.17	.23
Repairs	.58	.58	.58
Labor	.37	.37	.37
Total	1.85	2.35	2.85
Chemigation			
Fuel	.81	1.25	1.68
Lubrication	.11	.17	.23
Repairs	.45	.48	.49
Labor	.37	.37	.37
Total	1.74	2.27	2.77
LEPA			
Fuel	.59	.96	1.33
Lubrication	.09	.15	.21
Repairs	.63	.64	.64
Labor	.32	.32	.32
Total	1.63	2.07	2.50

TABLE XXII

TERMINAL VALUES

Change to	from	Period 4	5	6	7
		--------------------dollars--------------------			
	Gated-pipe				
Surge-flow			549	2,196	3,843
Tailwater		1,749	3,498	5,247	6,996
Cablegation			200	800	1,400
High-pressure		6,701	13,416	20,124	26,832
Low-pressure		7,109	14,220	21,330	28,440
Corner sys.		10,608	21,216	31,824	42,432
LEPA		8,509	17,016	25,524	34,032
	Surge-flow				
Tailwater		1,549	3,096	4,644	6,192
High-pressure		6,509	13,020	19,530	26,040
Low-pressure		6,909	13,818	20,727	27,636
Corner sys.		10,410	20,820	31,230	41,640
LEPA		8,309	16,620	24,930	33,240
	Tailwater				
High-pressure		6,609	13,218	19,827	26,436
Low-pressure		7,009	14,016	21,024	28,032
Corner sys.		10,509	21,018	31,527	42,036
LEPA		8,409	16,818	25,227	33,636
	High-pressure				
Low-pressure		440	882	1,323	1,764
Corner sys.		3,939	7,878	11,817	15,756
LEPA		1,651	3,300	4,950	6,600
	Low-pressure				
Corner sys.		3,501	7,002	10,503	14,004
Chemigation		600	1,200	1,800	2,400
LEPA		1,400	2,802	4,203	5,604

APPENDIX B

SELECTED OPTIMAL SOLUTIONS

TABLE XXIII

OPTIMAL IRRIGATION PLAN, GP100-1 SCENARIO

	INITIAL SYSTEM Gated-pipe			INITIAL PUMP LIFT 100 Feet		FUEL PRICE $/mcf 1.00	
	PERIOD						
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	310.00	310.00	310.00	310.00	310.00	310.00	310.00
SYSTEM, PRACTICE	GP	GP	GP	GP	SF	SF	SF
WATER/ACRE (AI)	20.00	20.00	20.00	20.00	17.10	17.10	17.10
DRY WHEAT ACRES	29.40	29.40	29.40	29.40	29.40	29.40	29.40
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICE	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	155.00	155.00	155.00	155.00	155.00	155.00	155.00
SYSTEM, PRACTICE	GP	GP	GP	GP	GP	GP	GP
WATER/ACRE (AI)	12.72	12.72	12.72	12.72	12.72	12.72	12.72
WATER/YEAR (AI)	10181.20	10181.20	10181.20	10181.20	9282.20	9282.20	9282.20
INCOME $/YR	132564.14	132564.14	132564.14	132564.14	132564.14	132564.14	132564.14
PROD. COSTS $/YR	57730.18	57730.18	57730.18	57730.18	57730.18	57730.18	57730.18
IRR. COSTS $/YR	8492.88	8669.09	8845.31	9021.53	8712.04	8858.51	9004.98
LABOR COSTS $/YR	6911.11	6911.11	6911.11	6911.11	6229.11	6229.11	6229.11
TOTAL COSTS $/YR	73134.17	73310.38	73486.60	73662.82	72671.33	72817.81	72964.28
INVESTMENT $/PERIOD	41184.00	0.00	0.00	0.00	34923.00	41184.00	0.00
DISC. NET RET. $/PERIOD	131840.00	151965.53	134692.53	119287.11	86948.00	73714.94	84866.77

OBJ. FUNCTION $ 798149.39

TABLE XXIV

OPTIMAL IRRIGATION PLAN, GP200-2 SCENARIO

	INITIAL SYSTEM Gated-pipe			INITIAL PUMP LIFT 200 Feet		FUEL PRICE $/mcf 2.00	
	PERIOD						
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	310.00	310.00	310.00	310.00	310.00	251.20	251.20
SYSTEM, PRACTICE	SF	SF	SF	SF	SF	LP,D	LP,D
WATER/ACRE (AI)	17.10	17.10	17.10	17.10	17.10	12.60	12.60
DRY WHEAT ACRES	29.40	29.40	29.40	29.40	29.40	88.20	88.20
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICE	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	155.00	155.00	155.00	155.00	155.00	155.00	155.00
SYSTEM, PRACTICE	GP	GP	GP	GP	GP	SF	SF
WATER/ACRE (AI)	12.72	12.72	12.72	12.72	12.72	10.90	10.90
WATER/YEAR (AI)	9282.20	9282.20	9282.20	9282.20	9282.20	6864.22	6864.22
INCOME $/YR	132564.14	132564.14	132564.14	132564.14	132564.14	127730.78	127730.78
PROD. COSTS $/YR	57730.18	57730.18	57730.18	57730.18	57730.18	52739.03	52739.03
IRR. COSTS $/YR	15435.98	15728.92	16021.86	16314.81	16607.75	13685.34	13845.53
LABOR COSTS $/YR	6229.11	6229.11	6229.11	6229.11	6229.11	2944.42	2944.42
TOTAL COSTS $/YR	79395.27	79688.22	79981.16	80274.10	80567.04	69368.79	69528.98
INVESTMENT $/PERIOD	52158.00	0.00	0.00	10563.00	0.00	131550.00	1290.00
DISC. NET RET. $/PERIOD	103226.00	135608.58	119885.41	98767.19	93697.74	23246.19	82263.71

OBJ. FUNCTION $ 690284.08

TABLE XXV

OPTIMAL IRRITATION PLAN, GP300-3 SCENARIO

	INITIAL SYSTEM		INITIAL PUMP LIFT			FUEL PRICE $/mcf	
	Gated-pipe		300 Feet			3.00	
	PERIOD						
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	251.20	251.20	251.20	251.20	251.20	251.20	251.20
SYSTEM, PRACTICE	LP,D	LP,D	LP,D	LP,D	LP,D	LP,D	LP,D
WATER/ACRE (AI)	12.60	12.60	12.60	12.60	12.60	12.60	12.60
DRY WHEAT ACRES	88.20	88.20	88.20	88.20	88.20	88.20	88.20
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICE	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	155.00	155.00	155.00	155.00	155.00	155.00	155.00
SYSTEM, PRACTICE	SF	SF	SF	SF	SF	SF	SF
WATER/ACRE (AI)	10.90	10.90	10.90	10.90	10.90	10.90	10.90
WATER/YEAR (AI)	6864.22	6864.22	6864.22	6864.22	6864.22	6864.22	6864.22
INCOME $/YR	127730.78	127730.78	127730.78	127730.78	127730.78	127730.78	127730.78
PROD. COSTS $/YR	52739.03	52739.03	52739.03	52739.03	52739.03	52739.03	52739.03
IRR. COSTS $/YR	21385.66	21621.25	21856.83	22092.42	22328.01	22563.60	22799.18
LABOR COSTS $/YR	2944.42	2944.42	2944.42	2944.42	2944.42	2944.42	2944.42
TOTAL COSTS $/YR	77069.11	77304.70	77540.28	77775.87	78011.46	78247.05	78482.63
INVESTMENT $/PERIOD	137037.00	0.00	0.00	9246.00	0.00	131550.00	1290.00
DISC. NET RET. $/PERIOD	14373.95	129325.58	114430.71	94927.13	89593.23	9024.45	69514.23

OBJ. FUNCTION $ 554778.54

TABLE XXVI

OPTIMAL IRRIGATION PLAN, GP100-1P SCENARIO WITH DECREASING CROP PRICES

	INITIAL SYSTEM			INITIAL PUMP LIFT		FUEL PRICE $/mcf	
	Gated-pipe			100 Feet		1.00	
	PERIOD						
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	310.00	310.00	310.00	310.00	310.00	310.00	0.00
SYSTEM, PRACTICES	GP	GP	GP	SF	SF	SF	NONE
WATER/ACRE (AI)	20.00	20.00	20.00	17.10	17.10	17.10	0.00
DRY WHEAT ACRES	29.40	29.40	29.40	29.40	29.40	29.40	339.40
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	155.00	155.00	155.00	155.00	155.00	155.00	0.00
SYSTEM, PRACTICES	GP	GP	GP	GP	GP	GP	NONE
WATER/ACRE (AI)	12.72	12.72	12.72	12.72	12.72	12.72	0.00
DRY SORGHUM ACRES	0.00	0.00	0.00	0.00	0.00	0.00	155.00
WATER/YEAR (AI)	10181.20	10181.20	10181.20	9282.20	9282.20	9282.20	2009.60
INCOME $/YR	132564.14	124437.65	116311.16	108184.67	100058.17	91931.68	55394.20
PROD. COSTS $/YR	57730.18	57730.18	57730.18	57730.18	57297.71	57297.71	39435.51
IRR. COSTS $/YR	8492.88	8669.09	8845.31	8551.39	8697.86	8844.33	2437.67
LABOR COSTS $/YR	6911.11	6911.11	6911.11	6229.11	6229.11	6229.11	703.36
TOTAL COSTS $/YR	73134.17	73310.38	73486.60	72510.68	72224.67	72371.15	42576.54
INVESTMENT $/PERIOD	41184.00	0.00	0.00	10974.00	0.00	41184.00	0.00
DISC. NET RET. $/PERIOD	131840.52	131123.87	97636.90	64838.86	50155.41	9342.91	18251.61

OBJ. FUNCTION $ 514034.58

TABLE XXVII

OPTIMAL IRRIGATION PLAN, GP200-2P SCENARIO WITH DECREASING CROP PRICES

	INITIAL SYSTEM Gated-pipe			INITIAL PUMP LIFT 200 Feet		FUEL PRICE $/mcf 2.00	
	PERIOD						
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	251.20	251.20	251.20	251.20	251.20	0.00	0.00
SYSTEM, PRACTICES	LP,D	LP,D	LP,D	LP,D	LP,D	NONE	NONE
WATER/ACRE (AI)	12.60	12.60	12.60	12.60	12.60	0.00	0.00
DRY WHEAT ACRES	88.20	88.20	88.20	88.20	88.20	339.40	339.40
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	155.00	155.00	155.00	155.00	155.00	0.00	0.00
SYSTEM, PRACTICES	GP	GP	GP	GP	GP	NONE	NONE
WATER/ACRE (AI)	12.72	12.72	12.72	12.72	12.72	0.00	0.00
DRY SORGHUM ACRES	0.00	0.00	0.00	0.00	0.00	155.00	155.00
WATER/YEAR (AI)	7146.32	7146.32	7146.32	7146.32	7146.32	2009.60	2009.60
INCOME $/YR	127730.78	119886.53	112042.28	104198.03	96353.77	60093.69	55394.20
PROD. COSTS $/YR	52739.03	52739.03	52739.03	52739.03	52739.03	39435.51	39435.51
IRR. COSTS $/YR	12952.05	13125.68	13299.32	13472.96	13646.60	4208.08	4221.81
LABOR COSTS $/YR	3153.67	3153.67	3153.67	3153.67	3153.67	703.36	703.36
TOTAL COSTS $/YR	68844.75	69018.38	69192.02	69365.66	69539.30	44346.95	44360.68
INVESTMENT $/PERIOD	131550.00	0.00	0.00	0.00	0.00	41184.00	0.00
DISC. NET RET. $/PERIOD	43375.78	130459.32	97695.50	70542.60	48319.16	3233.75	15711.11

OBJ. FUNCTION $ 420181.71

TABLE XXVIII

OPTIMAL IRRIGATION PLAN, GP300-3P SCENARIO
WITH DECREASING CROP PRICES

	INITIAL SYSTEM Gated-pipe		INITIAL PUMP LIFT 300 Feet			FUEL PRICE $/mcf 3.00	
	PERIOD						
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	251.20	251.20	251.20	251.20	125.60	0.00	0.00
SYSTEM, PRACTICES	LP,D	LP,D	LP,D	LP,D	LP,D	NONE	NONE
WATER/ACRE (AI)	12.60	12.60	12.60	12.60	12.60	0.00	0.00
DRY WHEAT ACRES	88.20	88.20	88.20	88.20	231.80	339.40	339.40
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	155.00	155.00	155.00	155.00	125.60	0.00	0.00
SYSTEM, PRACTICES	GP	SF	SF	SF	LP,D	NONE	NONE
WATER/ACRE (AI)	12.72	10.90	10.90	10.90	7.75	0.00	0.00
DRY SORGHUM ACRES	0.00	0.00	0.00	0.00	29.40	155.00	155.00
WATER/YEAR (AI)	7146.32	6864.22	6864.22	6864.22	4565.56	2009.60	2009.60
INCOME $/YR	127730.78	119886.53	112042.28	104198.03	85049.46	60093.69	55394.20
PROD. COSTS $/YR	52739.03	52739.03	52739.03	52739.03	47830.03	39435.51	39435.51
IRR. COSTS $/YR	22089.55	21630.93	21866.52	22102.10	15341.73	6977.63	6997.82
LABOR COSTS $/YR	3153.67	2944.42	2944.42	2944.42	1475.80	703.36	703.36
TOTAL COSTS $/YR	77982.25	77314.38	77549.97	77785.55	64647.56	47116.50	47136.69
INVESTMENT $/PERIOD	131550.00	5487.00	0.00	0.00	0.00	41184.00	0.00
DISC. NET RET. $/PERIOD	17016.02	104492.18	78639.98	53490.60	36763.82	-1202.69	11758.22

OBJ. FUNCTION $ 311802.65

TABLE XXIX

OPTIMAL IRRIGATION PLAN, CP100-1 SCENARIO

	INITIAL SYSTEM Low-Presure Center Pivot		INITIAL PUMP LIFT 100 Feet			FUEL PRICE $/acf 1.00	
	PERIOD						
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	251.20	251.20	251.20	251.20	251.20	251.20	251.20
SYSTEM, PRACTICES	CP	CP	LP,D	LP,D	LP,D	LP,D	LP,D
WATER/ACRE (AI)	16.00	16.00	12.60	12.60	12.60	12.60	12.60
DRY WHEAT ACRES	88.20	88.20	88.20	88.20	88.20	88.20	88.20
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	9.82	9.82	9.82	9.82	9.82	9.82	9.82
DRY SORGHUM ACRES	29.40	29.40	29.40	29.40	29.40	29.40	29.40
WATER/YEAR (AI)	7262.19	7262.19	6408.11	6408.11	6408.11	6408.11	6408.11
INCOME $/YR	124023.17	124023.17	124023.17	124023.17	124023.17	124023.17	124023.17
PROD. COSTS $/YR	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52
IRR. COSTS $/YR	7682.55	7772.21	7361.99	7431.80	7501.61	7571.41	7641.22
LABOR COSTS $/YR	2543.40	2543.40	2091.24	2091.24	2091.24	2091.24	2091.24
TOTAL COSTS $/YR	59665.47	59755.13	58892.75	58962.56	59032.37	59102.18	59171.98
INVESTMENT $/PERIOD	6000.00	0.00	172734.00	0.00	0.00	0.00	0.00
DISC. NET RET. $/PERIOD	179888.76	164825.44	17218.97	131760.91	117112.14	103994.35	92344.35

OBJ. FUNCTION $ 807144.92

TABLE XXX

OPTIMAL IRRIGATION PLAN, CP200-2 SCENARIO

	INITIAL SYSTEM Low-Presure Center Pivot		INITIAL PUMP LIFT 200 Feet			FUEL PRICE $/mcf 2.00	
			PERIOD				
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	251.20	251.20	251.20	251.20	251.20	251.20	251.20
SYSTEM, PRACTICES	CP,DC	CP,DC	LP,D	LP,D	LP,D	LP,D	LP,D
WATER/ACRE (AI)	15.00	15.00	12.60	12.60	12.60	12.60	12.60
DRY WHEAT ACRES	88.20	88.20	88.20	88.20	88.20	88.20	88.20
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	9.82	9.82	9.82	9.82	9.82	9.82	9.82
DRY SORGHUM ACRES	29.40	29.40	29.40	29.40	29.40	29.40	29.40
WATER/YEAR (AI)	7010.99	7010.99	6408.11	6408.11	6408.11	6408.11	6408.11
INCOME $/YR	124023.17	124023.17	124023.17	124023.17	124023.17	124023.17	124023.17
PROD. COSTS $/YR	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52
IRR. COSTS $/YR	13956.32	14123.44	12748.60	12888.21	13027.83	13167.45	13307.07
LABOR COSTS $/YR	2455.48	2455.48	2091.24	2091.24	2091.24	2091.24	2091.24
TOTAL COSTS $/YR	65851.32	66018.45	64279.36	64418.98	64558.59	64698.21	64837.83
INVESTMENT $/PERIOD	6000.00	0.00	172734.00	0.00	0.00	0.00	0.00
DISC. NET RET. $/PERIOD	162043.89	148762.19	4937.89	120710.56	107153.99	95030.29	84276.52

OBJ. FUNCTION $ 722915.32

TABLE XXXI

OPTIMAL IRRIGATION PLAN, CP300-3 SCENARIO

	INITIAL SYSTEM Low-Presure Center Pivot		INITIAL PUMP LIFT 300 Feet			FUEL PRICE $/mcf 3.00	
			PERIOD				
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	251.20	251.20	251.20	251.20	251.20	251.20	251.20
SYSTEM, PRACTICES	CP,DC	CP,DC	LP,D	LP,D	LP,D	LP,D	LP,D
WATER/ACRE (AI)	15.00	15.00	12.60	12.60	12.60	12.60	12.60
DRY WHEAT ACRES	88.20	88.20	88.20	88.20	88.20	88.20	88.20
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	LP,D	LP,D	LP,D	LP,D	LP,D
WATER/ACRE (AI)	9.82	9.82	7.75	7.75	7.75	7.75	7.75
DRY SORGHUM ACRES	29.40	29.40	29.40	29.40	29.40	29.40	29.40
WATER/YEAR (AI)	7010.99	7010.99	6148.12	6148.12	6148.12	6148.12	6148.12
INCOME $/YR	124023.17	124023.17	124023.17	124023.17	124023.17	124023.17	124023.17
PROD. COSTS $/YR	49439.52	49439.52	49763.57	49763.57	49763.57	49763.57	49763.57
IRR. COSTS $/YR	23340.40	23586.17	20101.51	20290.51	20479.51	20668.50	20857.50
LABOR COSTS $/YR	2455.48	2455.48	1953.08	1953.08	1953.08	1953.08	1953.08
TOTAL COSTS $/YR	75235.40	75481.17	71818.16	72007.16	72196.16	72385.15	72574.15
INVESTMENT $/PERIOD	6000.00	0.00	176733.00	0.00	0.00	0.00	0.00
DISC. NET RET. $/PERIOD	134972.81	124493.55	-15289.18	105342.95	93391.25	82716.88	73260.44

OBJ. FUNCTION $ 598888.70

TABLE XXXII

OPTIMAL IRRIGATION PLANS, CP100-1P SCENARIO WITH DECREASING CROP PRICES

	INITIAL SYSTEM Low-Presure Center Pivot			INITIAL PUMP LIFT 100 Feet		FUEL PRICE $/mcf 1.00	
			PERIOD				
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	251.20	251.20	251.20	251.20	251.20	251.20	251.20
SYSTEM, PRACTICES	CP	CP	CP	CP	CP	CP	CP
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
DRY WHEAT ACRES	88.20	88.20	88.20	88.20	88.20	88.20	88.20
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	9.82	9.82	9.82	9.82	9.82	9.82	9.82
DRY SORGHUM ACRES	29.40	29.40	29.40	29.40	29.40	29.40	29.40
WATER/YEAR (AI)	7262.19	7262.19	7262.19	7262.19	7262.19	7262.19	7262.19
INCOME $/YR	123110.40	115643.96	108177.52	100711.07	93244.63	85778.19	78311.74
PROD. COSTS $/YR	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52
IRR. COSTS $/YR	7682.55	7772.21	7861.86	7951.52	8041.18	8130.84	8220.49
LABOR COSTS $/YR	2543.40	2543.40	2543.40	2543.40	2543.40	2543.40	2543.40
TOTAL COSTS $/YR	59665.47	59755.13	59844.79	59934.44	60024.10	60113.76	60203.41
INVESTMENT $/PERIOD	6000.00	0.00	158733.00	0.00	0.00	0.00	0.00
DISC. NET RET. $/PERIOD	177255.63	143335.65	-10438.12	82560.93	59862.74	41110.83	25785.22

OBJ. FUNCTION $ 519492.88

TABLE XXXIII

OPTIMAL IRRIGATION PLAN, CP200-2P SCENARIO
WITH DECREASING CROP PRICES

	INITIAL SYSTEM Low-Presure Center Pivot		INITIAL PUMP LIFT 200 Feet			FUEL PRICE $/mcf 2.00	
			PERIOD				
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	251.20	251.20	251.20	251.20	251.20	251.20	251.20
SYSTEM, PRACTICES	CP,DC	CP,DC	LP,D	LP,D	LP,D	LP,D	LP,D
WATER/ACRE (AI)	15.00	15.00	12.60	12.60	12.60	12.60	12.60
DRY WHEAT ACRES	88.20	88.20	88.20	88.20	88.20	88.20	88.20
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	9.82	9.82	9.82	9.82	9.82	9.82	9.82
DRY SORGHUM ACRES	29.40	29.40	29.40	29.40	29.40	29.40	29.40
WATER/YEAR (AI)	7010.99	7010.99	6408.11	6408.11	6408.11	6408.11	6408.11
INCOME $/YR	123110.40	115643.96	100743.25	100711.07	93244.63	85778.19	78311.74
PROD. COSTS $/YR	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52
IRR. COSTS $/YR	13956.32	14123.44	12748.60	12888.21	13027.83	13167.45	13307.07
LABOR COSTS $/YR	2455.48	2455.48	2091.24	2091.24	2091.24	2091.24	2091.24
TOTAL COSTS $/YR	65851.32	66018.45	64279.36	64418.98	64558.59	64698.21	64837.83
INVESTMENT $/PERIOD	6000.00	0.00	172734.00	0.00	0.00	0.00	0.00
DISC. NET RET. $/PERIOD	159410.76	127272.40	-48138.64	73498.85	51691.67	33767.17	19186.08

OBJ. FUNCTION $ 416688.29

TABLE XXXIV

OPTIMAL IRRIGATION PLAN, CP300-3P SCENARIO WITH DECREASING CROP PRICES

	INITIAL SYSTEM Low-Presure Center Pivot		INITIAL PUMP LIFT 300 Feet			FUEL PRICE $/acf 3.00	
	PERIOD						
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	251.20	251.20	0.00	0.00	0.00	0.00	0.00
SYSTEM, PRACTICES	CP,DC	CP,DC	NONE	NONE	NONE	NONE	NONE
WATER/ACRE (AI)	15.00	15.00	0.00	0.00	0.00	0.00	0.00
DRY WHEAT ACRES	88.20	88.20	339.40	339.40	339.40	339.40	339.40
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	125.60	125.60	0.00	0.00	0.00	0.00	0.00
SYSTEM, PRACTICES	CPC	CPC	NONE	NONE	NONE	NONE	NONE
WATER/ACRE (AI)	9.82	9.82	0.00	0.00	0.00	0.00	0.00
DRY SORGHUM ACRES	29.40	29.40	155.00	155.00	155.00	155.00	155.00
WATER/YEAR (AI)	7010.99	7010.99	2009.60	2009.60	2009.60	2009.60	2009.60
INCOME $/YR	123110.40	115643.96	74192.15	69492.67	64793.18	60093.69	55394.20
PROD. COSTS $/YR	49439.52	49439.52	44428.08	44428.08	44428.08	44428.08	44428.08
IRR. COSTS $/YR	23340.40	23586.17	6793.92	6814.12	6834.31	6854.50	6874.69
LABOR COSTS $/YR	2455.48	2455.48	703.36	703.36	703.36	703.36	703.36
TOTAL COSTS $/YR	75235.40	75481.17	51925.37	51945.56	51965.75	51985.94	52006.14
INVESTMENT $/PERIOD	6000.00	0.00	41184.00	0.00	0.00	0.00	0.00
DISC. NET RET. $/PERIOD	132339.68	103003.76	19467.82	35536.44	23114.77	12987.48	4824.41

OBJ. FUNCTION $ 331274.36

TABLE XXXV

OPTIMAL IRRIGATION PLAN, HP100-1 SCENARIO

	INITIAL SYSTEM High-Presure Center Pivot		INITIAL PUMP LIFT 100 Feet			FUEL PRICE $/mcf 1.00	
			PERIOD				
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	251.20	251.20	251.20	251.20	251.20	251.20	251.20
SYSTEM, PRACTICES	CP	CP	LP,D	LP,D	LP,D	LP,D	LP,D
WATER/ACRE (AI)	16.00	16.00	12.60	12.60	12.60	12.60	12.60
DRY WHEAT ACRES	88.20	88.20	88.20	88.20	88.20	88.20	88.20
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	9.82	9.82	9.82	9.82	9.82	9.82	9.82
DRY SORGHUM ACRES	29.40	29.40	29.40	29.40	29.40	29.40	29.40
WATER/YEAR (AI)	7262.19	7262.19	6408.11	6408.11	6408.11	6408.11	6408.11
INCOME $/YR	124023.17	124023.17	124023.17	124023.17	124023.17	124023.17	124023.17
PROD. COSTS $/YR	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52
IRR. COSTS $/YR	7682.55	7772.21	7361.99	7431.80	7501.61	7571.41	7641.22
LABOR COSTS $/YR	2543.40	2543.40	2091.24	2091.24	2091.24	2091.24	2091.24
TOTAL COSTS $/YR	59665.47	59755.13	58892.75	58962.56	59032.37	59102.18	59171.98
INVESTMENT $/PERIOD	12600.00	0.00	172734.00	0.00	0.00	0.00	0.00
DISC. NET RET. $/PERIOD	173542.23	164825.44	17218.97	131760.91	117112.14	103994.35	92344.35

OBJ. FUNCTION $ 800798.38

TABLE XXXVI

OPTIMAL IRRIGATION PLAN, HP200-2 SCENARIO

	INITIAL SYSTEM High-Presure Center Pivot		INITIAL PUMP LIFT 200 Feet			FUEL PRICE $/mcf 2.00	
	PERIOD						
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	251.20	251.20	251.20	251.20	251.20	251.20	251.20
SYSTEM, PRACTICES	CP,DC	CP,DC	LP,D	LP,D	LP,D	LP,D	LP,D
WATER/ACRE (AI)	15.00	15.00	12.60	12.60	12.60	12.60	12.60
DRY WHEAT ACRES	88.20	88.20	88.20	88.20	88.20	88.20	88.20
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	9.82	9.82	9.82	9.82	9.82	9.82	9.82
DRY SORGHUM ACRES	29.40	29.40	29.40	29.40	29.40	29.40	29.40
WATER/YEAR (AI)	7010.99	7010.99	6408.11	6408.11	6408.11	6408.11	6408.11
INCOME $/YR	124023.17	124023.17	124023.17	124023.17	124023.17	124023.17	124023.17
PROD. COSTS $/YR	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52
IRR. COSTS $/YR	13956.32	14123.44	12748.60	12888.21	13027.83	13167.45	13307.07
LABOR COSTS $/YR	2455.48	2455.48	2091.24	2091.24	2091.24	2091.24	2091.24
TOTAL COSTS $/YR	65851.32	66018.45	64279.36	64418.98	64558.59	64698.21	64837.83
INVESTMENT $/PERIOD	12600.00	0.00	172734.00	0.00	0.00	0.00	0.00
DISC. NET RET. $/PERIOD	155697.36	148762.19	4937.89	120710.56	107153.99	95030.29	84276.52

OBJ. FUNCTION $ 716568.78

TABLE XXXVII

OPTIMAL IRRIGATION PLAN, HP300-3 SCENARIO

	INITIAL SYSTEM High-Presure Center Pivot		INITIAL PUMP LIFT 300 Feet			FUEL PRICE $/mcf 3.00	
	PERIOD						
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	251.20	251.20	251.20	251.20	251.20	251.20	251.20
SYSTEM, PRACTICES	CP,DC	CP,DC	LP,D	LP,D	LP,D	LP,D	LP,D
WATER/ACRE (AI)	15.00	15.00	12.60	12.60	12.60	12.60	12.60
DRY WHEAT ACRES	88.20	88.20	88.20	88.20	88.20	88.20	88.20
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	LP,D	LP,D	LP,D	LP,D	LP,D
WATER/ACRE (AI)	9.82	9.82	7.75	7.75	7.75	7.75	7.75
DRY SORGHUM ACRES	29.40	29.40	29.40	29.40	29.40	29.40	29.40
WATER/YEAR (AI)	7010.99	7010.99	6148.12	6148.12	6148.12	6148.12	6148.12
INCOME $/YR	124023.17	124023.17	124023.17	124023.17	124023.17	124023.17	124023.17
PROD. COSTS $/YR	49439.52	49439.52	49763.57	49763.57	49763.57	49763.57	49763.57
IRR. COSTS $/YR	23340.40	23586.17	20101.51	20290.51	20479.51	20668.50	20857.50
LABOR COSTS $/YR	2455.48	2455.48	1953.08	1953.08	1953.08	1953.08	1953.08
TOTAL COSTS $/YR	75235.40	75481.17	71818.16	72007.16	72196.16	72385.15	72574.15
INVESTMENT $/PERIOD	12600.00	0.00	176733.00	0.00	0.00	0.00	0.00
DISC. NET RET. $/PERIOD	128626.28	124493.55	-15289.18	105342.95	93391.25	82716.88	73260.44

OBJ. FUNCTION $ 592542.17

TABLE XXXVIII

OPTIMAL IRRIGATION PLAN, HP100-1P SCENARIO WITH DECREASING CROP PRICES

	INITIAL SYSTEM High-Presure Center Pivot			INITIAL PUMP LIFT 100 Feet		FUEL PRICE $/mcf 1.00	
	PERIOD						
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	251.20	251.20	251.20	251.20	251.20	251.20	251.20
SYSTEM, PRACTICES	CP	CP	CP	CP	CP	CP	CP
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
DRY WHEAT ACRES	88.20	88.20	88.20	88.20	88.20	88.20	88.20
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	9.82	9.82	9.82	9.82	9.82	9.82	9.82
DRY SORGHUM ACRES	29.40	29.40	29.40	29.40	29.40	29.40	29.40
WATER/YEAR (AI)	7262.19	7262.19	7262.19	7262.19	7262.19	7262.19	7262.19
INCOME $/YR	123110.40	115643.96	108177.52	100711.07	93244.63	85778.19	78311.74
PROD. COSTS $/YR	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52
IRR. COSTS $/YR	7682.55	7772.21	7861.86	7951.52	8041.18	8130.84	8220.49
LABOR COSTS $/YR	2543.40	2543.40	2543.40	2543.40	2543.40	2543.40	2543.40
TOTAL COSTS $/YR	59665.47	59755.13	59844.79	59934.44	60024.10	60113.76	60203.41
INVESTMENT $/PERIOD	12600.00	0.00	158733.00	0.00	0.00	0.00	0.00
DISC. NET RET. $/PERIOD	170909.10	143335.65	-10438.12	82580.93	59862.74	41110.83	25785.22

OBJ. FUNCTION $ 513146.34

TABLE XXXIX

OPTIMAL IRRIGATION PLAN, HP200-2P SCENARIO WITH DECREASING CROP PRICES

	INITIAL SYSTEM High-Presure Center Pivot			INITIAL PUMP LIFT 200 Feet		FUEL PRICE $/mcf 2.00	
	PERIOD						
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	251.20	251.20	251.20	251.20	251.20	251.20	251.20
SYSTEM, PRACTICES	CP,DC	CP,DC	LP,D	LP,D	LP,D	LP,D	LP,D
WATER/ACRE	15.00	15.00	12.60	12.60	12.60	12.60	12.60
DRY WHEAT ACRES	88.20	88.20	88.20	88.20	88.20	88.20	88.20
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	9.82	9.82	9.82	9.82	9.82	9.82	9.82
DRY SORGHUM ACRES	29.40	29.40	29.40	29.40	29.40	29.40	29.40
WATER/YEAR (AI)	7010.99	7010.99	6408.11	6408.11	6408.11	6408.11	6408.11
INCOME $/YR	123110.40	115643.96	108177.52	100711.07	93244.63	85778.19	78311.74
PROD. COSTS $/YR	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52	49439.52
IRR. COSTS $/YR	13956.32	14123.44	12748.60	12888.21	13027.83	13167.45	13307.07
LABOR COSTS $/YR	2455.48	2455.48	2091.24	2091.24	2091.24	2091.24	2091.24
TOTAL COSTS $/YR	65851.32	66018.45	64279.36	64418.98	64558.59	64698.21	64837.83
INVESTMENT $/PERIOD	12600.00	0.00	172734.00	0.00	0.00	0.00	0.00
DISC. NET RET. $/PREIOD	153064.23	127272.40	-31189.05	73498.85	51691.67	33767.17	19186.08

OBJ. FUNCTION $ 427291.34

TABLE XL

OPTIMAL IRRIGATION PLAN, HP300-3P SCENARIO
WITH DECREASING CROP PRICES

	INITIAL SYSTEM High-Presure Center Pivot		INITIAL PUMP LIFT 300 Feet			FUEL PRICE $/mcf 3.00	
	PERIOD						
	1	2	3	4	5	6	7
IRR. WHEAT ACRES	251.20	251.20	0.00	0.00	0.00	0.00	0.00
SYSTEM, PRACTICES	CP,DC	CP,DC	NONE	NONE	NONE	NONE	NONE
WATER/ACRE (AI)	15.00	15.00	0.00	0.00	0.00	0.00	0.00
DRY WHEAT ACRES	88.20	88.20	339.40	339.40	339.40	339.40	339.40
IRR. CORN ACRES	125.60	125.60	125.60	125.60	125.60	125.60	125.60
SYSTEM, PRACTICES	CPC	CPC	CPC	CPC	CPC	CPC	CPC
WATER/ACRE (AI)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
IRR. SORGHUM ACRES	125.60	125.60	0.00	0.00	0.00	0.00	0.00
SYSTEM, PRACTICES	CPC	CPC	NONE	NONE	NONE	NONE	NONE
WATER/ACRE (AI)	9.82	9.82	0.00	0.00	0.00	0.00	0.00
DRY SORGHUM ACRES	29.40	29.40	155.00	155.00	155.00	155.00	155.00
WATER/YEAR (AI)	7010.99	7010.99	2009.60	2009.60	2009.60	2009.60	2009.60
INCOME $/YR	123110.40	115643.96	74192.15	69492.67	64793.18	60093.69	55394.20
PROD. COSTS $/YR	49439.52	49439.52	44428.08	44428.08	44428.08	44428.08	44428.08
IRR. COSTS $/YR	23340.40	23586.17	6793.92	6814.12	6834.31	6854.50	6874.69
LABOR COSTS $/YR	2455.48	2455.48	703.36	703.36	703.36	703.36	703.36
TOTAL COSTS $/YR	75235.40	75481.17	51925.37	51945.56	51965.75	51985.94	52006.14
INVESTMENT $/PERIOD	12600.00	0.00	41184.00	0.00	0.00	0.00	0.00
DISC. NET RET. $/PERIOD	125993.15	103003.76	19467.82	35536.44	23114.77	12987.48	4824.41

OBJ. FUNCTION $ 324927.82

VITA

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