AN ECONOMIC ANALYSIS OF WATER-USE REGULATION IN THE CENTRAL OGALLALA FORMATION

By

HARRY PARKS MAPP, JR.

Bachelor of Science
Virginia Polytechnic Institute
Blacksburg, Virginia
1962

Master of Science
Virginia Polytechnic Institute
Blacksburg, Virginia
1964

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
May, 1972

AN ECONOMIC ANALYSIS OF WATER-USE REGULATION IN THE CENTRAL OGALLALA FORMATION

Thesis Approved:

Vernon R. Eidman
Thesis Adviser

L. A. Parcher

Odell L. Walker

James M. Davidson

N Durham
Dean of the Graduate College

PREFACE

This dissertation is concerned with the economic consequences of regulating water use within the Central Basin of the Ogallala Formation. A simulation model is utilized to obtain the effects on a representative irrigated farm firm of alternative methods of regulation. Crop yields are computed probabilistically as a function of soil moisture and atmospheric stress during the critical stages of plant development. Three regulatory alternatives, including no restrictions on pumping, a restriction on the number of acre inches pumped per year and a graduated tax on water usage, are simulated over a 20-year period under conditions of a declining water supply. The effects of each policy on the rate of water use, net farm income, variability of net farm income and net worth are analyzed. Implications are drawn for representative farms in two resource situations and for the study area.

I am deeply grateful to Dr. Vernon R. Eidman for his valuable guidance and counseling during the initial phases of my graduate program, and for his assistance, encouragement, patience and understanding during the final phases of this research project. Appreciation is also extended to the other members of my advisory committee, Dr. James M. Davidson, Dr. Loris A. Parcher and Dr. Odell L. Walker for valuable suggestions and comments.

Many other persons made significant contributions to the completion of this project. Special appreciation is extended to Dr. Solomon Bekure, Haile Selassie I University, Ethiopia, for his valuable assistance in

compiling the basic soils and water information; to Dr. John F. Stone, Department of Agronomy, for helpful suggestions regarding the agronomic aspects of the study; to Larry R. Peters and James V. Howell, Oklahoma State University Extension staff, Guymon, Oklahoma, for assistance in developing budgets and irrigation strategies, and critically evaluating the production model; to Wyatte L. Harmon for valuable suggestions and comments regarding representative farms and irrigation practices; to Ron E. Shaffer for adapting his program to compute pumping and investment costs for the irrigation systems used in this study; and to James D. McGee, University Computer Center, for programming and data processing assistance.

Acknowledgement is made of the assistance received from the statistical and secretarial staff of the Department of Agricultural Economics. Special thanks are due to Mrs. Rita Flory for her dedication in typing preliminary drafts of this dissertation and to Mrs. Linda Dalton for her excellence in typing the final manuscript.

I am grateful to the Office of Water Resources Research for partial funding of this project under Grant 14-01-0001-1539 and to the Department of Agricultural Economics for financial assistance.

Special recognition is given to my wife, Jane, and daughter, Jennifer, for assuming the many sacrifices and hardships during the course of this study with patience, faith and understanding.

TABLE OF CONTENTS

Chapter Page

V. (Continued)

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The discovery of significant quantities of high quality underground water coupled with technological advances leading to economical methods of withdrawing the water and delivering it to the plant root system has had a significant impact on farming in the Great Plains. Irrigation farming has become a way of life. An apparent abundance of water has affected the psychology of farming, the combination and levels of inputs utilized in agricultural production, the size and structure of each local economy and the legal and institutional framework within which irrigators operate. The number of irrigated acres in the Great Plains doubled in the period 1949-1964.[1] Recent rates of development have continued to be rapid.

Rapid irrigation development has led to increased capital expenditures within the study area. To illustrate the potential impact, consider the seven Texas Panhandle counties included in this study as a distinct regional economy. From 1955 to 1965, the number of irrigation wells increased from approximately 900 wells to approximately 3,300 wells--an increase of about 2,400 wells in the ten-year period.[2] If an average of 240 wells were drilled per year and the average investment per well, including a pump and engine, was a conservative $5,000, the addition of irrigation wells alone contributed a total of $1,200,000 per year to the economy. Over the ten year period, a minimum of $12,000,000 was expended for irrigation wells. Since January, 1971, a minimum of 120 wells have been drilled in the same region.[3] Current prices of irrigation components (see Appendix D) indicate that the average investment per well ranges from about $8,000 to $16,000 depending upon the depth of well, size of pump and motor and length of distribution system, and may average at least $10,000. Thus, a direct investment of as much as $1,200,000 in irrigation systems has probably occurred during the first eight months of 1971. These figures ignore additional expenditures for higher rates of seeding, fertilizer, herbicide and insecticide applications accompanying the high irrigation application rates. The increased expenditures for irrigation equipment and other production inputs are subject to a multiplier effect within the local economy. That is, the equipment dealers spend additional income generated from sales of their goods on consumption, service and recreational items in addition to replinishing inventories. Sellers of consumption, service and recreational items also spend their additional income. The end result is an impact on the local economy of significantly greater magnitude than the original expenditures for irrigation equipment.

The vast majority of water pumped for irrigation purposes in the Great Plains is drawn from underground aquifers. It is clear that past development has already resulted in overdraft in certain portions of the area. Continued irrigation expansion will lead to serious overdraft problems in larger portions of it. That is, withdrawals of irrigation water from the aquifer exceed natural recharge. The result is declining water levels, declining well yields and increased-pumping costs. Eventually, the cost of pumping and delivering water to the surface will exceed the value of additional production resulting from the irrigation application. At this point, the aquifer is exhausted from an economic standpoint. The alternatives facing irrigation farmers whose water supply has been exhausted are a return to dryland farming or a retreat from farming.

The overall objectives of this study are to simulate the effects on the individual farm firm of operating under conditions of a declining water supply, to investigate alternative means of restraining water use and to evaluate the effects on the firm and region.

Description of the Study Area

The Ogallala Formation is the major underground aquifer underlying a large portion of the Great Plains. The Ogallala extends from South Dakota through western Nebraska, western Kansas and eastern Colorado, underlies the Oklahoma and Texas Panhandles and extends through the Southern High Plains into southwestern Texas.[4]

Boundaries of the Study Area

Geologists agree that the entire Ogallala Formation is divided into three separate and distinct sections. The Arkansas River in southwestern Kansas and the Canadian River in the Texas Panhandle penetrate the formation to bedrock. The study area is encompassed by the "Central Basin" of the Ogallala Formation. It is bounded on the north by the Arkansas River in Kansas and on the south by the Canadian River in Texas. The eastern boundary is approximately the 100th. meridian, which establishes the eastern edge of the Oklahoma Panhandle. The western boundary extends into southeastern Colorado and follows the eastern border of New Mexico to the Canadian River. The study area includes eight counties in southwestern Kansas, portions of two counties in southeastern Colorado, the three Oklahoma Panhandle counties and seven counties in the Northern High Plains of Texas.

Characteristics of the Ogallala Formation

The Ogallala Formation was named by Darton in 1898 for a locality in southwestern Nebraska.[5] It underlies the surface of the Great Plains and was deposited by stream action from the Rocky Mountains on underlying Cretaceous, Jurassic, Triassic and Permain rocks. The deposition of the Ogallala by the stream action has resulted in an irregular distribution of sand, silt and clay throughout the formation as well as variations in depth and thickness of the formation.[6] Similar wells in adjacent fields may yield quite different quantities of irrigation water because of these irregularities.

The natural gradient of the Ogallala Formation is from west to east. While very little water enters the formation from the west, or from the rivers that penetrate the formation, some water movement does occur. Movement along the natural gradient of the formation is estimated to be about 250 feet per year.[7] At that rate, 21 years are required for water to move one mile. A different type of water movement occurs in connection with drawdown of the static water level in the vicinity of a pumping well. In areas of intensive irrigation development, significant lowering of the static water table occurs. Water is drawn from nearby areas into the influence of the intensively irrigated areas. As a consequence, the water level of a property owner adjoining an intensively irrigated area may be declining despite the fact that he is not irrigating. Water movement of this type has not been significant, however, most states have water law provisions to require proper well spacing.

The Ogallala Formation may be described as a closed basin of water. Additions to the water supply are the result of natural precipitation. Rainfall averages from 15 to 19 inches as one moves from west to east across the study area. Average annual recharge has been estimated as 0.3 inches per year.[8] Multiplying the amount of surface area in the Central Basin of the Ogallala by 0.3 inches per year results in an estimate of annual recharge of approximately 270,000 acre feet.[9] The following section traces the development of irrigation and relates recent water withdrawals to annual average recharge and the rate of depletion of the water supply.

Development of Irrigation

The major irrigation development in the study area has occurred since 1950, accelerating during the dry years of 1952 through 1956 and during the dry years of the 1960's.[10] Between 1950 and 1965 the number of study area acres irrigated increased from 9,000 to 29,000 in Colorado, from 34,000 to 379,000 in Kansas, 1,000 to 117,000 in Oklahoma and 17,000 to 1,003,000 in Texas.[11] Texas has had the greatest absolute increase, as well as the greatest percentage increase in irrigated acres.

Estimated average annual recharge exceeded annual withdrawals prior to 1954. However, withdrawals have exceeded average annual recharge by amounts ranging from about 113,000 acre feet in 1954 to 2.7 million acre feet in 1964.[12] Assuming that withdrawals have increased by approximately 30 percent since 1965, current withdrawals may exceed average annual recharge by as much as 3.5 million acre feet per year and the rate is likely to continue to grow. Bekure estimated the volume of water in storage within the Central Basin as of 1965 to be in excess of 369 million acre feet.[13] The link between withdrawals and volume in storage is obvious. As more and more water is withdrawn from the closed basin, it appears the stock resource of water is being exhausted.

Exhaustion of the water supply should be defined from two viewpoints. The first is physical and the second is economic. Due to the cohesion of water to soil particles, physical exhaustion of the aquifer is not a realistic possibility. Economic exhaustion, however, can occur long before any hint of physical exhaustion appears. Economic exhaustion is related to the pumping and distribution cost of a unit of water, and to the value of production forthcoming from that unit of water. Economic exhaustion occurs when the per unit value in use of ground water becomes less than the cost of applying the unit of water. The possibility of economic exhaustion appears very real when viewed in the light of current conditions in portions of the Central Basin of the Ogallala Formation. Wood and Hart indicate that in areas of intensive development in Texas County, Oklahoma, static water levels declined from five to 30 feet during the period 1938-1966.[14] Declining water levels result in a corresponding reduction in the number of gallons per minute a given irrigation pump and well can deliver to the surface.[15] Declining water levels and pump yields interact to increase the per unit cost of irrigation water and, other things equal, to reduce net returns per acre of irrigated crop production over time. Sooner or later it will become uneconomical to pump water for irrigation purposes in parts of the study area--those parts with the smallest saturated thickness of the water-bearing formation will be affected first.

It should be emphasized that even if it becomes uneconomical to pump water from the Ogallala Formation for purposes of irrigation, sufficient water will remain to satisfy municipal and industrial demands for an indefinite period. The marginal value product of the remaining water supply is relatively higher for non-agricultural uses. Thus, it will continue to be economic to pump for municipal and industrial purposes.

The Current Institutional Framework

Water laws vary from state to state within the study area. In the state of Texas landowners also own the water which lies beneath their land. While irrigation districts have been formed and play an active role in attempting to conserve the water resources of the district, individual irrigators pump their water without restraints or restrictions of any kind. The other states with counties in the study area have water laws tied to the Doctrine of Prior Appropriation. That is, the states own the water, but upon application by interested individuals, appropriate specified quantities to be put to beneficial use. The Doctrine of Prior Appropriation applies the principle "first in time, first in right". Each approved application is dated and the right to withdraw water is determined by the priority in time.

It is the declared policy of Oklahoma Ground Water Law to conserve and protect the ground water resources of the state.[16] Water must be put to beneficial use, with beneficial use being ordinarily interpreted in a legal sense to mean any use having an economic value greater than zero.[17] Water law prohibits "waste" where waste is defined as (1) using ground water in any matter so that it is lost for beneficial use, (2) transporting water in such a way that there is excessive loss in transit, (3) permitting ground water to be lost into cavenous or pervious materials in a well, (4) pumping water in excess of natural recharge, or (5) drilling wells in locations which substantially reduce the yield of water from existing wells drilled by prior appropriators.[18] Because water is being pumped in excess of natural recharge, and has been since about 1954, waste is occurring constantly.

Oklahoma water law provides the necessary mechanisms for preventing excessive withdrawals. The Water Resources Board may refuse to grant a permit to pump in areas where withdrawals exceed recharge. The Board is authorized to require spacing of wells and metering of wells to insure an orderly withdrawal of water in relation to average annual recharge.[19] Also, if withdrawals are deemed excessive, the Board has the power to require persons to cease excessive withdrawals in reverse order of their priority of rights.

Colorado water laws likewise empower the Water Resources Board to regulate the drilling and construction of all wells in the state. Such regulation is provided to the extent necessary to prevent waste of water.

The chief engineer of the Kansas Resources Board is given the power to enforce and administer the laws pertaining to beneficial use of water in accordance with the rights of priority of appropriation. The law forbids any person from using excessive quantities of water or to waste water, and empowers the chief engineer to require metering of wells to control excessive withdrawals.[20]

It may be argued that current water laws encourage inefficient use of irrigation water. Oklahoma water law requires that within five years after filing an application for water rights, 100 percent of the water applied for must be put to beneficial use. If less than the amount applied for is actually used, the application is effective only for that amount of ground water actually taken and placed to beneficial use.[21] Irrigators thus tend to apply for greater quantities than currently needed as a hedge against strict enforcement of water laws and possible future expansion in irrigated acres. Once the application is approved, irrigators pump near capacity to establish a water use record in accordance with their application.

This institutional framework combined with the stock water supply of the Central Ogallala provide the setting for the problem analyzed in this thesis. The following sections summarize the problematic situation and specify the purposes and objectives of this study.

Problematic Situation

Rapid irrigation development over the past decade and the prospect of continued expansion of irrigated acres are expected to further reduce the static water level. In portions of the study area characterized as poor water regions (saturated thicknesses of 100 feet or less) the effects of further declines in saturated thickness will have an immediate and significant impact on well yields and pumping costs. Continued expansion will likely lead to economic exhaustion of the water supply in these areas within the next 20 years. Irrigators in adequate water situations (saturated thicknesses averaging 325 feet) may continue to pump for an extended period without significantly reducing well yields or increasing irrigation costs. Due to the irregularities of the Ogallala Formation, effects of the declining water supply will not be uniformly distributed among either individual irrigators or economic areas within the study area.

Potential Solutions

There appear to be several alternatives to the overdraft problem. One alternative, which is actually the course of action presently being followed, is to do nothing. This has been the general course followed by most states until the situation develops into a critical problem.[22]

A second alternative is to reduce total pumping in the Central Basin to the level of average annual recharge. This alternative would result in one of two outcomes. (1) Only the first irrigators who applied for water rights would remain as active irrigators, or (2) each irrigator would have so little water to apply during the crop year that the investment and operating costs of irrigation equipment could not be recovered. Either event would have significant adverse effects on the great majority of the irrigators, as well as on the entire economy of the Central Basin. Rather than reducing pumping to the level of average annual recharge, a feasible alternative might be to reduce pumping by approximately 25 percent of the current level to perhaps 1.5 acre feet per acre of irrigation rights.[23] Such a quantity limitation could be handled within the existing legal and institutional framework of the study area.

A third alternative is to continue pumping at the present rate, allowing exhaustion to occur over time, but to import water via surface sources. The imported water would either be recharged into the aquifer or stored in surface lakes or reserviors for distribution. This alternative would require significant alterations in the current legal and institutional framework. Justifying the construction of a means of transporting water to the study area quickly enters the political arena. Distribution of and payment for imported water add a dimension of complexity with which Water Resource Boards and irrigators are currently unprepared to deal.

A fourth alternative is to apply a form of graduated taxation on irrigation water pumped above a certain limit. Perhaps a per unit tax could be imposed on each acre inch of water pumped above the quantity limitation discussed as the second alternative. Taxing water does not fit within the current legal or institutional structure of the study area. However there is ample authority for the imposition of taxes on water users.[24] The mechanism for establishing a tax rate and administering it must be established by the respective water resource boards, however, it seems to be a feasible alternative and one that provides a real economic incentive to conserve water use.

Objectives of the Study

The specific objectives of this study are:

(1) To construct a model of a representative farm firm capable of simulating the effects of soil moisture and atmospheric stress during critical stages of plant development on final yields of the major irrigated and dryland crops of the study area,

(2) To simulate, for poor and adequate water resource situations, over a 20-year period, several alternative methods of regulating water-use including

  (a) Continued pumping at the present rate with no restraints on water use;

  (b) Restricting the quantity of water pumped per crop year to 1.5 acre feet per acre of water rights; and

  (c) Restricting the quantity of water pumped per crop year to 1.5 acre feet per acre of water rights, but allowing the irrigator to apply additional irrigation water if it is economically feasible to pay a graduated per unit tax of \$.50 per acre inch for each acre inch pumped above the quantity limitation.

(3) To compare the effects of the three methods of water-use regulation on net farm income, variability of net farm income, net worth, variability of net worth, quantity of water pumped and availability of water for future periods.

(4) To evaluate the alternative methods of restraining water use by discounting the streams of net returns and comparing present values of those net income streams.

The remainder of this dissertation is organized to present a logical flow from the theoretical framework to model development, assumptions and procedures, results and summary and conclusions. The theoretical concepts pertinent to this study are discussed in Chapter II. The initial sections relate to society's allocative goals and static theory of the firm. Subsequent sections treat the implications and problems inherent in allocating a common property resource and the stock resource value of water.

The analytical models utilized in the study are developed and discussed in Chapter III. First, the General Agricultural Firm Simulator is discussed and its role in the analysis outlined. Next, a new Production Subset is developed to circumvent some of the restrictive assumptions of the Simulator. Coefficients relating the effects of soil moisture and atmospheric stress during critical stages of plant development on final crop yield are presented and their derivation is discussed. Development of the Production Subset is designed to accomplish the initial objective of this study. In the final section of Chapter III, the Simulator and Production Subset are integrated to form a model capable of accomplishing the remaining objectives of the study.

Initial sections of Chapter IV detail the assumptions required in constructing a representative farm firm for the study area, define two basic resource situations and discuss prices, government programs and irrigation investment and pumping costs. Next, general irrigation strategies are developed for analysis of continued pumping with no restraints on water use. The last portion of the chapter discusses alterations of irrigation strategies to permit accomplishment of the last two parts of the second objective--simulating the quantity restriction and a graduated tax on water use.

The final two objectives of this study are approached in Chapters V and VI. Chapter V discusses a portion of the results of the analysis. Initial sections present the effects of unrestricted pumping, a quantity restriction and graduated taxation on water use for representative farms in Resource Situation 1. Statistical comparisons are made of mean values of acre inches pumped, net farm income and net worth under the three alternatives. In final sections, the same analysis is made for representative farms in Resource Situation 2. Chapter VI contains an analysis of the importance of government payments as a component of net farm income for both Resource Situations. Then, a comparison is made of the present values of net farm income streams under the three alternative water-use regulatory alternatives. Finally, implications are drawn of the effects of each alternative on aggregate net farm income for Resource Situations 1 and 2, and for the study area.

The important aspects of the study are summarized in Chapter VII. Conclusions are drawn based upon the results, and implications, both for policy makers and irrigators are elaborated. Limitations of the study are presented. Finally, suggestions are made for future research in the study area.

FOOTNOTES

[1] M. L. Cotner, et. al., *Soil and Water Use Trends in the Great Plains -- Their Implications*, Great Plains Agricultural Council, Publication No. 34 (1969), p. 197.

[2] J. W. Buchanan, *Geology and Ground-Water Resources of the North Plains Ground-Water Conservation District No. 2* (Texas, 1967), p. 40, and *Panhandle Economic Program*, Texas Agricultural Experiment Station (College Station, 1965), p. 111.

[3] *North Plains Water News*, Vol. 15, No. 2 (April, 1971), p. 1, and Vol. 15, No. 3 (July, 1971), p. 1.

[4] G. W. Stoe and O. A. Ljungstedt, *Geologic Map of the United States*, U. S. Geologic Survey, 1932, Reprinted, 1960.

[5] P. T. Voegeli and L. A. Hershey, *Geology and Ground-Water Resources of Prowers County, Colorado*, Geological Survey Water Supply Paper 1772 (Washington, 1965), p. 82 and Buchanan, p. 7.

[6] Buchanan, p. 8.

[7] Ibid., p. 8.

[8] S. W. Fader, et. al., *Geohydrology of Grant and Stanton Counties, Kansas*, State Geological Survey of Kansas, Bulletin 168 (Lawrence, 1964), p. 46.

[9] Solomon Bekure, "An Economic Analysis of the Intertemporal Allocation of Ground Water in the Central Ogallala Formation," (unpub. Ph.D. Dissertation, Oklahoma State University, 1971), p. 193.

[10] Ibid., p. 7 and R. W. Beck and Associates, *Ground Water Resources Study Relating to Portions of Prowers, Baca and Las Animas Counties, Colorado*, prepared for Colorado Ground Water Commission (Denver, 1967), p. 8.

[11] Bekure, p. 11.

[12] Ibid., p. 8.

[13] Ibid., p. 52.

[14] P. R. Wood and D. L. Hart, J., *Availability of Ground Water in Texas County, Oklahoma*, Hydrologic Investigations Atlas HA-250, U. S. Geological Survey (Washington, 1967), Sheet 3.

[15] The relationship between declines in saturated thickness and corresponding declines in well yields are documented in Chapter IV and will not be discussed further here.

[16] *Oklahoma Ground Water Law*, Chapter 11, 1961, Title 82, Section 1003.

[17] V. R. Eidman, "Framework for Analysis of Irrigation Development," *Irrigation as a Factor in the Growth, Operation and Survival of Great Plains Farms*, Great Plains Agricultural Council, Publication No. 30 (Washington, 1967), p. 91.

[18] *Oklahoma Ground Water Law*, Chapter 11, 1961, Title 82, Section 1003.

[19] Ibid., Section 1013.

[20] *Kansas Ground Water Law*, Title 82, Section 404.

[21] *Oklahoma Ground Water Law*, Chapter 11, 1961, Title 82, Section 1013.

[22] *A Hydrologic Ground-Water Study*, Kansas Water Resources Board (Topeka, 1967), p. 33.

[23] Ibid., p. 32. This study indicates that, on the average, two acre feet of water are appropriated for each acre to be irrigated. Higher rates may be justified when a crop to be grown requires a greater quantity of water.

[24] J. L. Sax, *Water Law, Planning and Policy, Cases and Materials* (New York, 1968), p. 276.

CHAPTER II

THEORETICAL CONSIDERATIONS

Annual water use in the Great Plains and the semi-arid West is increasing at a rapid rate. Most of the increase in recent years is related to continued rapid expansion of irrigated acres in agricultural production. Not to be overlooked is the additional expansion of water usage by municipalities and industrial concerns. In the Central Basin of the Ogallala Formation, water of suitable quality to meet the many and varied needs of agriculture, industry and municipalities is a scarce resource. Abstracting from some of the complexities of the real world situation, the basic concepts of traditional economic theory provide criteria by which an efficient allocation of the scarce resource may be achieved.

The initial sections of this chapter briefly consider society's allocative goals and traditional static theory of the firm, assuming water is a scarce resource in the production process, but neglecting the complexities caused by the exhaustability and commonality of the water supply. Then the problems of commonality of resource use and the implications of institutionally restricting water use are discussed and the theoretical consequences examined. Finally, the value of water as a stock resource is discussed and a discounting model for decision making based on the present value of alternative income streams presented.

Society's Allocative Goals

From a public viewpoint, the maximization of long-run social benefits from the use of water represents the dominant goal of water resource use.[1] This goal can be accomplished by efficient allocation of water among competing uses in present and future time periods. In the present period, efficient allocation between two competing uses, as production and consumption, occurs when the marginal rate of substitution in production of alternative commodities equals the marginal rate of substitution in consumption of the same commodities. In allocating a scarce resource, such as water, for the production of two commodities, equilibrium occurs where the production possibilities curve for water in production of commodities Y_1 and Y_2 is just tangent to society's indifference curve for those two commodities. These concepts are illustrated in Figure 1. The slope of the production possibilities curve (PP') represents the marginal rate of substitution between the two products (the number of units of Y_1 sacrificed for each unit of Y_2 gained as resources are shifted from Y_1 to Y_2). The slope of society's indifference curve (II') represents the marginal rate of substitution between the two commodities in consumption (the amount of Y_1 consumers would be willing to give up to get an additional unit of Y_2). At the point of tangency (Q) the slopes of the two curves are equal and thus the marginal rate of substitution in production equals the marginal rate of substitution in consumption. Since these curves are also tangent to the price ratio line (RR'), which reflects consumers desires, the efficiency criteria of resource allocation is met. The optimum allocation of water occurs when oa of commodity Y_1 and ob of commodity Y_2 are being produced. This allocation implies that the marginal

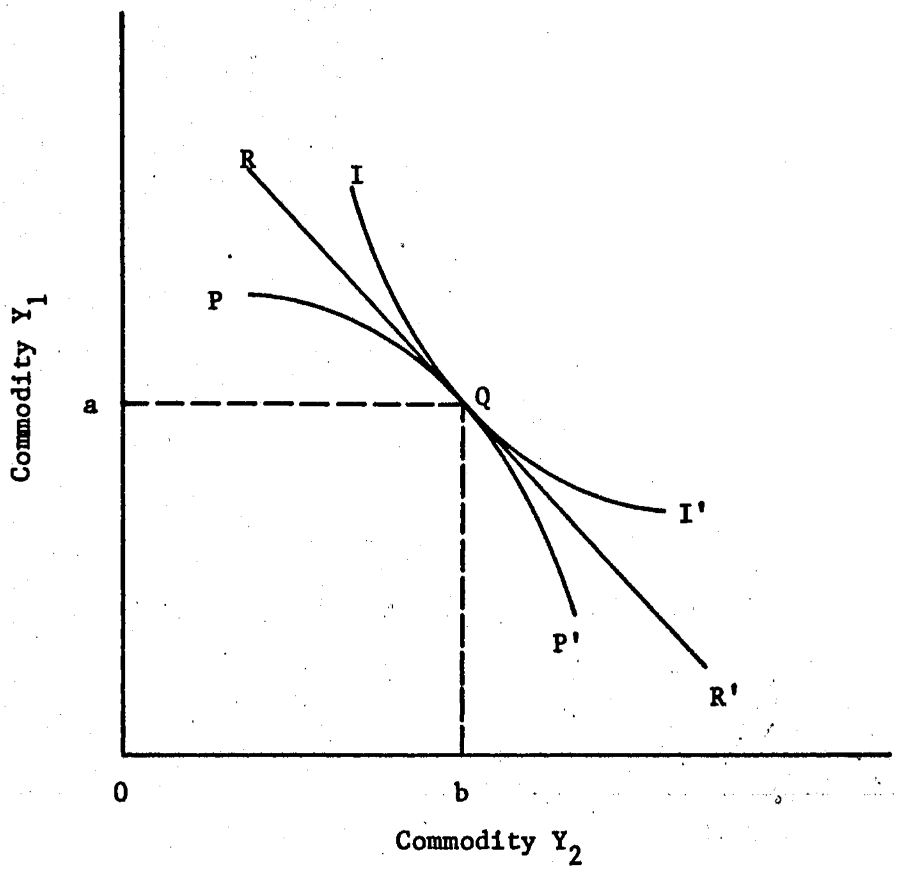


Figure 1. Production Possibilities Curve and Society's Indifference Curve

value product of the resource is equal in all of its uses. Alternative resource allocations would not enable society to reach a higher indifference curve.

Optimal Allocation of Resources in a Static Production Framework

Static economic theory assumes that the individual producer attempts to allocate his scarce resources in such a way that profits, or net returns, are maximized. Net returns (NR) represent the difference between total revenue (TR) and total cost (TC) for the firm, as expressed in Equation (2-1).

$$NR = TR - TC \tag{2-1}$$

Assume that the firm is a multiproduct firm operating under conditions of pure competition, facing constant factor and product prices. Assume also that the production function for each product, or crop, is of the form

$$Y_i = f(X|Z_1, \ldots, Z_n) \tag{2-2}$$

where Y_i is the output of product i; X is a variable factor of production, such as irrigation water; and $Z_1, \ldots, Z_n$ are fixed factors of production.

Total revenue is found by multiplying the output of each product (Y_i) by its price (P_{y_i}). Total cost is the sum of variable cost (X times its price, P_x) and costs of the factors held constant (FC). Thus, the net returns equation (2-1) may be rewritten as (2-3) for a firm producing m products utilizing a single variable input.

$$NR = \sum_{i=1}^{m} Y_i P_{y_i} - X P_x - FC \tag{2-3}$$

To maximize net returns, Equation (2-3) is differentiated with respect to each of m products and equated to zero, as in (2-4) through (2-6).

$$\frac{\partial NR}{\partial Y_1} = \frac{\partial P_{y_1}}{\partial Y_1} Y_1 + \frac{\partial Y_1}{\partial Y_1} P_{y_1} - \frac{\partial X}{\partial Y_1} P_x + X \frac{\partial P_x}{\partial Y_1} = 0 \tag{2-4}$$

$$\frac{\partial NR}{\partial Y_2} = \frac{\partial P_{y_2}}{\partial Y_2} Y_2 + \frac{\partial Y_2}{\partial Y_2} P_{y_2} - \frac{\partial X}{\partial Y_2} P_x + X \frac{\partial P_x}{\partial Y_2} = 0 \tag{2-5}$$

$$\begin{matrix} \vdots & \vdots & \vdots & \vdots & \vdots \end{matrix}$$

$$\frac{\partial NR}{\partial Y_m} = \frac{\partial P_{y_m}}{\partial Y_m} Y_m + \frac{\partial Y_m}{\partial Y_m} P_{y_m} - \frac{\partial X}{\partial Y_m} P_x + X \frac{\partial P_x}{\partial Y_m} = 0 \tag{2-6}$$

The partial derivative of Y_m with respect to itself ($\partial Y_m/\partial Y_m$) is equal to one. Since prices are assumed constant regardless of the amount of input used or product produced, $\partial P_{y_i}/\partial Y_i = 0$ and $\partial P_x/\partial Y_i = 0$. Thus, Equation (2-4) reduces to

$$P_{y_1} = \frac{\partial X}{\partial Y_1} P_x. \tag{2-7}$$

Multiplying both sides of the equation by $Y_1/\partial X$ results in (2-8).

$$\frac{\partial Y_1}{\partial X} P_{y_1} = P_x. \tag{2-8}$$

A series of m such equations can be developed for products Y_2 through Y_m. Each equation equates the marginal value product of X in the production of one of the Y_i products to the price of X. Solution of the set of m equations reveals the optimal allocation of the variable resource X in the production of products Y_1, Y_2, ..., Y_m, and represents the profit maximizing conditions for a multiproduct firm employing a single variable resource.

In the previous example, X was a single factor of production. If X represents irrigation water, it is required in several different periods of the crop year. Hence, it may be argued that X is actually several variables, X_1, X_2, ..., X_n, depending upon the time period in which it is being allocated. To represent the multiproduct firm attempting to maximize net returns by optimally allocating X_1, X_2, ..., X_n, Equation (2-3) is rewritten as

$$NR = \sum_{i=1}^{m} Y_i P_{y_i} - \sum_{j=1}^{n} X_j P_{x_j} - FC. \qquad (2\text{-}9)$$

Equation (2-9) is differentiated with respect to products Y_1 through Y_m for each of X_1, X_2, ..., X_n inputs which represent the use of X in n time periods. Solution of the resulting set of equations reveals the optimum allocation of X_1, X_2, ..., X_n in production of products Y_1, Y_2, ..., Y_m. The equimarginal criterion, given unlimited resources, which reflects the optimum amounts of X_1, X_2, ..., X_n used in producing Y_1, Y_2, ..., Y_m, is expressed as follows:

$$\frac{MVP_{x_1y_1}}{P_{x_1}} = \frac{MVP_{x_1y_2}}{P_{x_1}} = \cdots = \frac{MVP_{x_1y_m}}{P_{x_1}} = \frac{MVP_{x_2y_1}}{P_{x_2}} = \frac{MVP_{x_2y_2}}{P_{x_2}} = \cdots$$

$$= \frac{MVP_{x_2y_m}}{P_{x_2}} = \frac{MVP_{x_ny_1}}{P_{x_n}} = \frac{MVP_{x_ny_2}}{P_{x_n}} = \cdots = \frac{MVP_{x_ny_m}}{P_{x_n}} = 1 \qquad (2\text{-}10)$$

The equimarginal criterion states that the marginal value product of X_j must be equal in each of its Y_i uses and, in the case of an unlimited supply, must equal the marginal cost, or price, of the resource.

An additional theoretical formulation allows consideration of the problem of defining optimum resource allocations for a multiproduct firm utilizing the variable inputs X_1, X_2, ..., X_n, subject to a quantity restraint on the total amount of X to be allocated. Such a situation may occur when an irrigation operator attempts to optimally allocate water resources among competing crops, subject to a restriction on the quantity of water that can be pumped during a given time period. The mathematical formulation for maximizing net returns subject to a constraint on water use is presented in (2-11).

$$NR = \sum_{i=1}^{m} Y_i P_{y_i} + \lambda (X^0 - X_{11} - X_{12} - \cdots - X_{1n} - X_{21} - X_{22} - \cdots$$

$$- X_{2n} - \cdots - X_{m1} - X_{m2} - \cdots - X_{mn} - FC) \qquad (2\text{-}11)$$

Equation (2-11) is differentiated with respect to Y_1, Y_2, ..., Y_m for each of the X_{11}, ..., X_{1n}, X_{21}, ..., X_{2n}, ..., X_{m1}, ..., X_{mn} inputs and λ. The form of the derivatives is shown in (2-12) and (2-13).

$$\frac{\partial NR}{\partial Y_i} = P_{y_i} + \lambda \frac{\partial X_{ij}}{\partial Y_i} = 0 \qquad (2\text{-}12)$$

$$\frac{\partial NR}{\partial \lambda} = X^0 - X_{11} - \ldots - X_{mn} = 0 \qquad (2\text{-}13)$$

Solution of two of the equations implied by (2-12), and division of one by the other results in the relevant revenue maximizing criteria.

$$\frac{P_{y_1}}{P_{y_2}} = - \frac{\dfrac{\partial X_{11}}{\partial Y_1}}{\dfrac{\partial X_{11}}{\partial Y_2}} \qquad (2\text{-}14)$$

Since $\partial X_{11}/\partial Y_i$ is $1/MPP_{x_{11}y_i}$, (2-14) may be rewritten in terms of the marginal physical product of X_{11} in production of Y_1 and Y_2 as follows:

$$\frac{MPP_{x_{11}y_2}}{MPP_{x_{11}y_1}} = - \frac{P_{y_1}}{P_{y_2}} \qquad (2\text{-}15)$$

or

$$MRS_{y_1y_2} = - \frac{P_{y_1}}{P_{y_2}} \qquad (2\text{-}16)$$

This criteria states that the marginal rate of substitution of Y_1 for Y_2 must equal the ratio of product prices. This criteria views the production process from the output side, but is essentially the same criteria which leads to an optimal allocation of resources from the input side.[2] That is, allocating resources between products to maximize net returns leads the producer to allocate resources between products so that the marginal value product is the same for each use.

Solution of the entire set of equations implied by (2-12) and (2-13) reveals the optimum combination of m products produced and the optimum allocation of resources in production of those products. The solution for a given restriction, X^0, locates one point on the marginal value product curve of the resource for the firm. By varying the quantity restriction from X^0 to X^1, X^2, ..., X^n, and solving the resulting set of equations for each quantity restriction, points along the marginal value product curve of the resource may be defined for the firm. Such an MVP curve for water, as viewed by the firm, is utilized in subsequent discussions of commonality of resource use.

The magnitude and complexity of formulating and solving the sets of equations required to trace out the MVP curve for water for the firm utilizing marginal analysis are obvious. Even so, derivation of conditions for optimal resource allocation under static assumptions represents the simplest application of economic concepts to the water allocation problem. The analysis is greatly complicated by introduction of time and random weather variables into the model, and compounded by the theoretical and practical complexities of utilizing a stock resource with commonality properties. However, presentation of traditional static theory of resource allocation is a useful prelude to the ensuing analysis for several reasons. First, much of the terminology used in later sections has been introduced and may now be used without further elaboration. Second, difficulty of translating marginal analysis from the theoretical to the practical is emphasized. That is, the marginal analysis formulations discussed must be modified to make them operational in solving problems involving farm and institutional manager decision making in the real world.

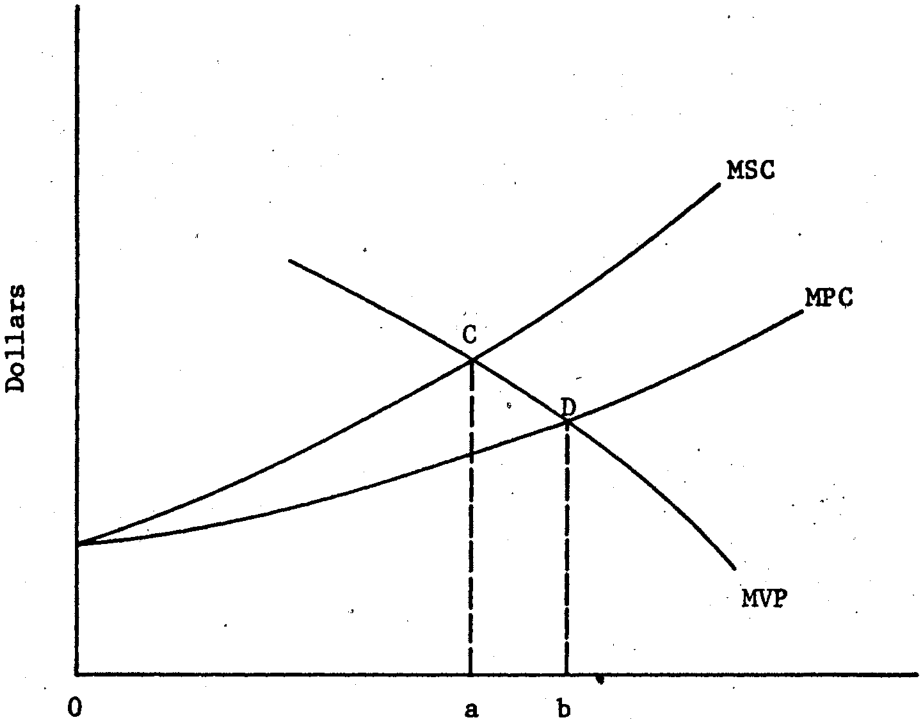
The Problem of Commonality of Resource Use and Consideration of Water as a Stock Resource

As long as the quantity of water available for pumping from an underground aquifer greatly exceeds demand, problems of common usage and timing of water usage do not arise. However, the Central Basin of the Ogallala Formation contains a finite quantity of water. Average annual recharge is negligible. Irrigators pumping from the Central Basin are essentially engaged in a water mining operation.

A stock resource is one whose total quantity does not increase significantly with time. In fact, each rate of use diminishes some future rate of use.[3] Water in the Central Basin of the Ogallala Formation may be classified as a stock resource possessing many of the characteristics of commonality.[4] That is, all irrigators draw from the common source and each has his own self-interests in mind. Irrigators pumping from a "poor water" situation feel an immediate effect on current and future pumping costs and future water supplies. Irrigators pumping from an "adequate water" situation feel that current pumping will have a negligible effect on future pumping costs and future supplies from their standpoint. Under the present institutional framework, water laws fail to provide an individual the right to "save" a portion of his water in the current period for use in future periods. The Doctrine of Prior Appropriation insures the irrigator the right to put a specified number of acre feet of water per year to beneficial use. Failure to put the entire amount allocated to beneficial use within five years results in a reduction in water rights to the amount actually being put to beneficial use.[5] Thus, irrigators are encouraged by the institutional framework to act as if the value of water, while in the underground aquifer, is zero. The irrigator acts to maximize returns to the scarce water resource from year to year without reference to future years. For all irrigators as a group, their collective actions increase future pumping costs and reduce the availability of future water supplies.

The problem of commonality of water use leads to "spill-over" costs arising from two sources.[6] The first of these costs arises when all the costs of extra pumping are not borne by the individual irrigator, but fall upon other pumpers in the basin and society in general. The second type of spill-over cost results when one irrigator pumps sufficient water to lower the water table, reduce well yields and increase pumping costs. The increased cost of pumping must eventually be borne partly by all irrigators pumping from the basin. The first of these costs arises because the individual irrigator, without water rights which are valid in future periods, has no incentive to maximize the present value of water use over time. The second arises because irrigators continue to irrigate as long as the current marginal value productivity of the water resource exceeds the variable costs of pumping and delivering water to plants in the current period.

These "spill-over" costs result in a divergence of private and social costs. The difference in optimal water allocations caused by the divergence of private and social costs is illustrated in Figure 2. The marginal social cost curve (MSC) lies above the marginal private cost curve (MPC). The marginal value product curve (MVP) represents the value of water in use. The individual irrigator in seeking to optimally allocate his water resources considers only marginal private costs. Thus, the optimal allocation of water resources for the



Acre Feet

Figure 2. Illustration of the Divergence of Private and Social Costs and the Resulting Resource Allocations

individual occurs where the MPC of pumping the incremental unit of water equals the MVP of that unit of water, or at point D in Figure 2. Each individual pumps ob acre feet of irrigation water.

The socially optimal allocation of water results only when marginal social costs are considered in the allocative process. Each producer should equate MSC and MVP (point C in Figure 2) with the socially optimal allocation of water being oa acre feet. Thus, if the individual producer does not consider the full social and private cost of irrigation water used in production, his decisions tend to push water use beyond socially optimum levels by an amount equal to ab.

Alternative Institutional Restraints

Even though rights in water exist through the Doctrine of Prior Appropriation, Water Resource Boards maintain a measure of control over water use. For example, the declared policy of Oklahoma Ground Water Law is to preserve and protect the ground water resources from waste. Since water is being pumped in excess of average annual recharge, "waste" is already occurring. The Oklahoma Water Resources Board has the power to order proper spacing of wells to insure an orderly withdrawal of water in relation to average annual recharge. It can also require metering of wells to record amounts pumped and can require persons to cease excessive withdrawals in reverse order of their water rights. It is empowered to restrict the rate of water use to one cubic foot of water per second for each seventy acres, or equivalent thereof, delivered on the land, for a specified time in each year.[7] By not indicating the intended length of "a specified time in each year," water use may be restricted to any amount desired by the Water Resources Board.

The existence of regulatory power and exercising this power are two different matters. Many questions require answers before policy makers could suggest water control measures as a feasible alternative to withdrawals at the current rate. First, the effect of continued withdrawals at the current rate needs documentation. Second, the relevant alternative water use constraints must be established. Third, the effect of each alternative control measure on water use, net farm income, private versus social costs, the pattern of regional production and the impact on regional income needs to be evaluated. Fourth, the present value of streams of income resulting from the alternative water-use restraints must be computed before policy makers can recommend a course of action.

Two institutional alternatives appear capable of more closely aligning marginal private and marginal social costs. The first of these is limiting the quantity of water each irrigator is allowed to pump per year. The socially optimal limitation, as depicted in Figure 3, is oa acre feet per individual. By limiting individual pumpers to oa acre feet, the objective of forcing alignment of MSC and MVP is achieved and a socially optimal allocation of water resources results.

Theoretically, limiting water use to socially optimal levels through the use of a quantity limitation is sound. From a practical standpoint, several problems arise. First, a quantity limitation works best when annual recharge is large relative to water use. The limitation can be set to a "safe yield" for the aquifer and socially optimal resource allocations achieved. However, if recharge is negligible relative to current water usage, and such is the case in the study area, limitation of water use to a safe yield, or to the amount of average

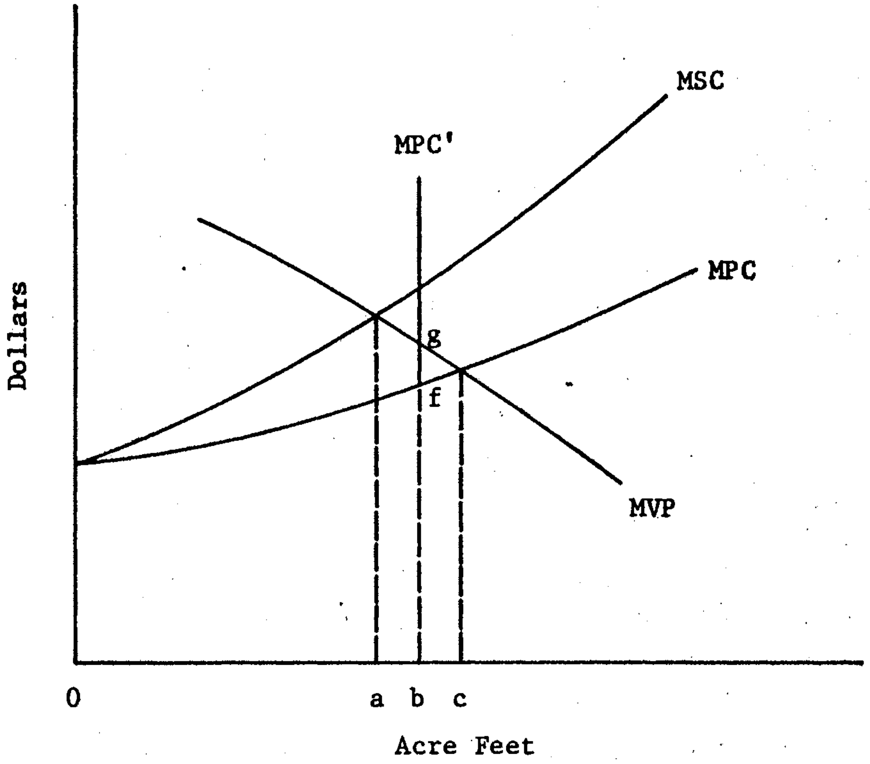


Figure 3. The Effect of a Quantity Limitation on Divergence of Private and Social Costs and Resource Allocation

annual recharge, would not be economic. A realistic quantity limitation might be ob acre feet per year in Figure 3. If the irrigator is forced to observe the quantity restriction, with the alternative being a severe penalty in the form of a fine or assessment, he will consider only MPC out to ob acre feet of irrigation water per year. Then, however, the marginal private cost curve becomes vertical. At point f, the MVP of additional irrigation water exceeds the MPC of that water. However, a fine or assessment equal to or greater than fg will provide sufficient incentive for the irrigator to consider marginal private cost curve MPC' and restrict pumping to ob acre feet per year. Water use is greater than the socially optimal level of oa acre feet per year, but less than oc acre feet per year under unrestricted pumping.

A second institutional alternative is for the Water Resource Board to place a tax on each acre inch or acre foot of irrigation water pumped during the crop year. The effect on the optimal allocation of irrigation water by an individual producer is shown in Figure 4. Since the analysis is static, the MVP curve remains constant. A per unit tax on each acre foot of irrigation water pumped shifts the marginal private cost (MPC) curve upward. If the tax is a constant rate per unit equal to hk in Figure 4, the new marginal private cost curve (MPC') is parallel to and above the old MPC curve. Rather than pumping oc acre feet per year, the individual irrigator equates MPV and MPC', reducing the number of acre feet pumped to ob. However, ob acre feet exceeds the socially optimal oa acre feet by an amount equal to ab. By raising the constant tax rate to de dollars per acre foot, the producer considers the full private and social costs of pumping irrigation water. The tax rate de per unit shifts the MPC curve upward to MPC".

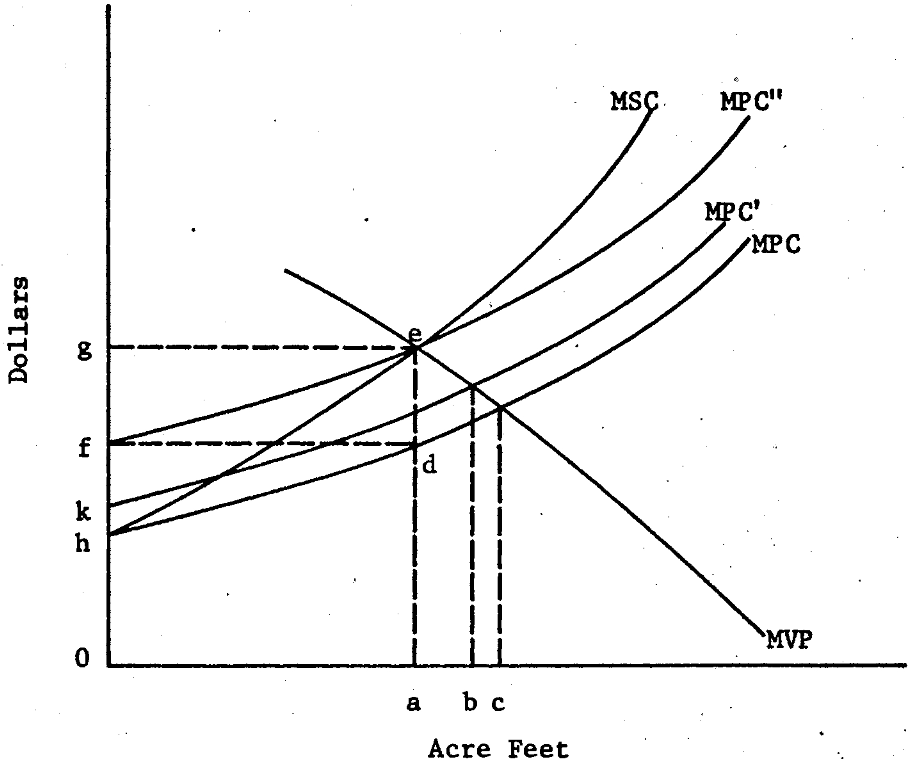


Figure 4. Illustration of the Effects of Alternative Tax Measures on the Divergence of Private and Social Costs and Resource Allocation

This tax rate induces the producer to optimally allocate water by equating MVP and MPC", resulting in the socially optimal oa acre feet of irrigation water being pumped. A per unit tax of de would generate revenue for the controlling agency equal to the rectangle fged. The excess of social over private cost is only hed. Clearly revenue generated exceeds the divergence of private and social costs when the tax rate is de per unit. Several alternatives exist to utilize the revenue. One is to return a portion of the revenue collected to pumpers as a bonus unrelated to the quantity of water pumped. This approach would involve an income transfer from the larger to the smaller pumpers. A second alternative is to return a portion of the revenue to pumpers with payments being inversely related to the quantity pumped. This method of payments provides an incentive to reduce pumping.

The optimal per unit tax for all water users is not the constant de per unit of water pumped. This tax rate is optimal only for the marginal unit at oa acre feet. For units less than oa, the optimal rate would be a graduated tax which, for any point between o and a, equates MPC and MSC.[8]

A slightly different approach to taxing water use is taken in this study. No attempt was made to impose a tax of sufficient magnitude to align MPC and MVP at the socially optimal level of water use. Instead, the individual irrigator is allowed to pump without taxation until a quantity limitation, such as the limitation discussed in Figure 3, is reached. Once the quantity limitation is attained, additional water is pumped only if the irrigator is willing to pay a substantial tax on each unit of water pumped above the quantity limitation. This situation is presented graphically in Figure 5. Quantity oa represents the

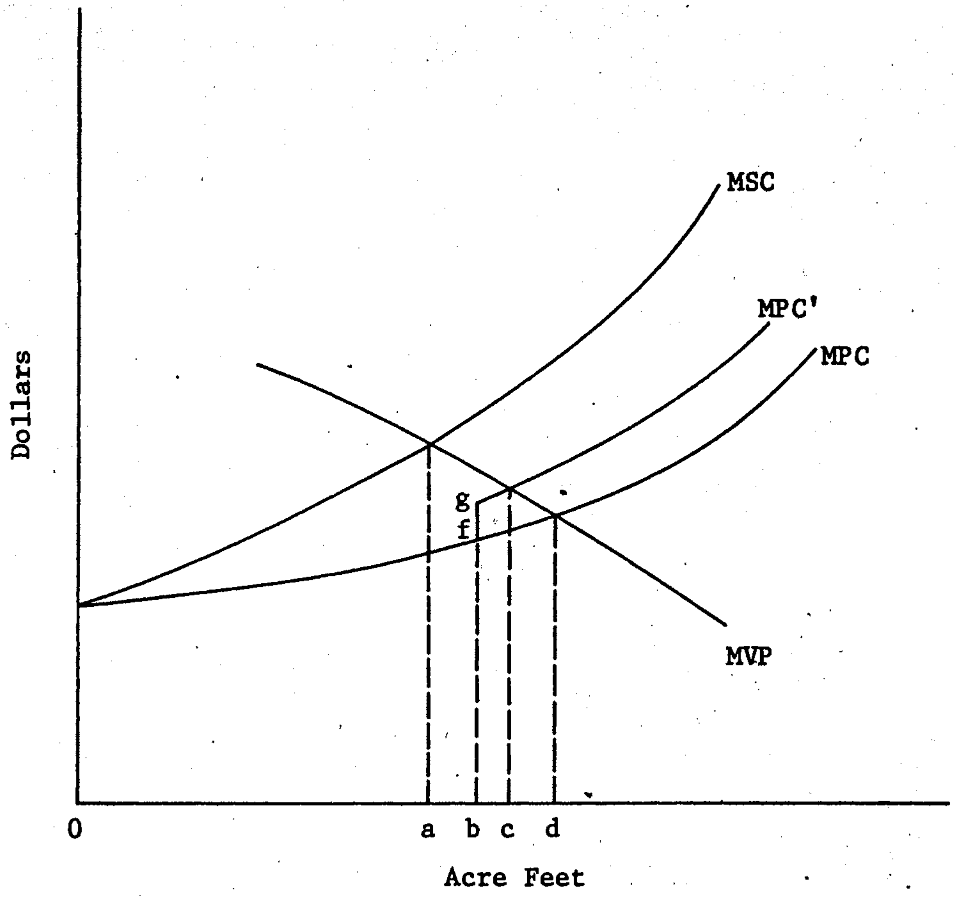


Figure 5. The Effect of a Graduated Tax per Unit Pumped Above a Quantity Limitation on Divergence of Private and Social Costs and Resource Allocation

socially optimal allocation of the water resource at the point where MVP equals MSC. Quantity od represents the optimal allocation of water by the individual producer who considers only private costs in equating MVP and MPC. Quantity ob represents the number of units of water pumped by an individual irrigator under the quantity restriction depicted in Figure 3. Assume that once ob units have been pumped, the irrigator must pay a per unit tax equal to fg on the marginal unit pumped above ob units. In effect the irrigator must now consider marginal private cost curve MPC'. At ob units of water pumped, MPC' is less than MVP. The economically rational producer will expand water use to oc units where MPC' equals MVP.

Both ob and oc are less than quantity od pumped with restrictions, but both exceed the socially optimal rate of oa acre feet per year. Thus, neither the quantity restriction nor graduated per unit tax considered here will successfully force a socially optimal allocation of irrigation water. However, from society's standpoint, both are to be preferred over unrestricted pumping because both reduces the divergence of private and social costs.

The institutional alternatives by no means exhaust the possibilities. Additional restraints might include (1) a lump sum tax or well tax on each irrigation well; (2) a limit on the number of wells per section or per farm; (3) a limit on well spacing, etc. Time does not permit evaluation of every possible alternative. However, one might say that those alternatives which do not force the irrigator to consider marginal social costs as well as marginal private costs will do little to eliminate the divergence of private and social costs.

This section treats problems of resource allocation and institutional alternatives from the standpoint of static economic theory. It should be emphasized that weather uncertainty adds a degree of complexity to the analysis. The actual situation is dynamic rather than static. That is, the marginal value product curve for the water resource has an expected value and variance. Irrigators attempting to optimally allocate the resource act upon the expected value, however, do not know whether the allocation is optimal until the growing season is complete. A dynamic MVP curve complicates specification of the optimal allocation of water under the various water-use regulatory alternatives. No attempt is made here to incorporate dynamics into the analysis. The reader should be aware of the complexities inherent in the transition from static theory to dynamics.

Maximization of long-run social benefits from the use of water was previously cited as the dominant goal of water resource use. From society's standpoint, water is optimally allocated when individual irrigators consider marginal social costs rather than marginal private costs in allocating water resources. The water-use regulatory alternatives suggested herein are admittedly not designed to force irrigators to consider the full marginal social costs of water use. However, they do provide policy makers with viable alternatives to unrestricted water use while inducing irrigators to narrow the divergence between private and social costs.

Aside from society's interests, how can the irrigator evaluate various water-use regulatory devices? The economic problem facing the irrigator and an appropriate decision model are presented in the next section.

The Value of Water as a Stock Resource

Water in the Central Basin of the Ogallala Formation has been described as a stock resource because its quantity is being depleted, and future water-use rates are being diminished as well. The real economic problem is one of the factor-factor substitution. Water represents both factors, however, water in the current time period is considered a different factor than the same water in a later time period.[9] The allocation problem is to determine in which time interval the marginal value product of water is the greatest. The decision is made by comparing the present value of discounted streams of net returns resulting from alternative water application rates.

The discounting model is composed of several essential components. First, a stream of net returns from each institutional alternative considered is necessary. Second, the appropriate discount rate must be provided. The discount rate reflects the irrigator's time preference for income, the degree of uncertainty which exists in his mind regarding the future, and the operator's opportunity cost for alternative investments. Third, the number of years over which the analysis is to be conducted must be provided. The model may be written as

$$PV_{NR} = \frac{NR_1}{(1 + i)} + \frac{NR_2}{(1 + i)^2} + \dots + \frac{NR_n}{(1 + i)^n} = \sum_{j=1}^{n} \frac{NR_j}{(1 + i)^n} \quad (2\text{-}17)$$

where PV_{NR} equals the present value of a stream of net returns, discounted and summed, NR_j equals net returns for years $j = 1, 2, \dots, n$, and i equals the appropriate discount rate.

To evaluate alternative restraints, the present value of the stream of net returns from each must be computed. The choice criterion for the individual irrigator is that the alternative with the greatest present value of net returns is to be preferred over all other alternatives.

Consider the three institutional alternatives to be evaluated. (1) Under the alternative of unrestricted pumping, those irrigators pumping from poor water situations are likely to experience higher net returns in initial periods. However, in later years, as the water table declines rapidly, pumping costs rise and acres are converted to dryland production, net returns will likely fall more rapidly than under the other two alternatives. Irrigators pumping from an adequate water situation will likely maintain high levels of net returns throughout the period. (2) Under the quantity restriction, net returns for irrigators in a poor water situation should be lower than under unrestricted pumping because the rate of water application is correspondingly lower. However, reasonable net returns should be sustained for a somewhat longer period since water levels are slower to fall and pumping costs slower to rise. Irrigators in adequate water situations should experience lower levels of net returns, throughout the period of analysis, than under unrestricted pumping. (3) The effect of the graduated tax alternative is much more difficult to predict. The irrigator pumps relatively more water in early periods than under the quantity limitation, but less than under the unrestricted alternatives. The water table and well yields decline more rapidly than under the quantity limitation, but less rapidly than under the unrestricted alternative. Net returns should be high in early periods, but fall in later periods as the water table declines and pumping costs rise. The relative relationships that will exist among net income for the graduated tax alternative versus the quantity restriction and unrestricted pumping is subject to speculation. There is a possibility that the net returns under the tax alternative may approach or exceed net returns under the unrestricted alternative to water use. This possibility rests upon two conditions. First, that irrigators pumping without restrictions utilize the water resource to the point where its marginal value product is very low. Second, that the marginal value product of irrigation water on which the tax is charged is quite high. This combination of factors, coupled with a more rapid pumping rate and rapidly rising pumping costs for the unrestricted alternative, could lead to nearly the same, or even higher, net returns for the graduated tax alternative. Net returns under the graduated tax alternative should exceed those under the quantity restriction.

The effects of alternative institutional water use restraints on regional income is of great interest to policy makers and businessmen within the region. The effects of a declining water supply, up to the point where farms are forced to return to dryland farming, will be mixed within the region. As the water table declines and pumping costs rise, net farm income will decline. However, this decline in net farm income is a reflection of higher costs of production in the form of higher costs of pumping water. In general, the increased expenditures in the form of higher pumping costs will be reflected in regional income. As long as the cause of declining net farm income can be traced to increased production costs for items purchased within the regional economy, it seems reasonable to assume that the expenditures will retain their power to generate personal income in the community.[10] Thus, the impact on regional income of irrigating from a declining water supply may not be significant until farm operators are forced to convert irrigated acres to dryland acres and abandon irrigation farming as a way of life.

The intent of this chapter has been to present a portion of the theoretical framework relevant to the current analysis. Static economic theory of the firm is presented as it relates to an optimal allocation of resources in the production process. The problems which develop due to commonality of resources use are elucidated. The effects of alternative institutional restraints on water use and the divergence of social and private costs are depicted verbally and graphically. Finally, the value of water as a stock resource is discussed. The time dimension of factor-factor substitution is seen as the central economic problem. A discounting model is presented to allow comparisons of the present value of streams of net returns resulting from alternative institutional restraints. The choice criterion is that the alternative with greatest present value of net returns is preferred over other alternatives.

The next chapter develops the analytical models used in simulating alternative institutional restraints on water use through time.

FOOTNOTES

[1] J. F. Timmons, "Theoretical Considerations of Water Allocation Among Competing Uses and Users," *Journal of Farm Economics*, Vol. 38, No. 5 (1956), p. 1248.

[2] J. P. Doll, et. al., *Economics of Agricultural Production, Markets and Policy* (Illinois, 1968), p. 139.

[3] M. M. Kelso, "The Stock Resource Value of Water," *Journal of Farm Economics*, Vol. 43, No. 5 (1961), p. 1112.

[4] For a more complete discussion of the economics of commonality see H. S. Gordon, "The Economic Theory of a Common-Property Resource: The Fishery," *The Journal of Political Economy*, Vol. 42, No. 2 (1954), pp. 124-142; J. Hirshleifer, et. al., *Water Supply: Economics, Technology and Policy* (Chicago, 1960), pp. 59-73; and J. W. Milliman, "Commonality, the Price System and Use of Water Supplies," *The Southern Economic Journal*, Vol. 22, No. 4 (1956), pp. 426-437.

[5] *Rules, Regulations and Modes of Procedure and Water Laws From the Oklahoma Statutes*, Oklahoma Water Resources Board Publication No. 8 (Oklahoma, 1964), p. 14.

[6] Milliman, pp. 428-429.

[7] *Rules, Regulations and Modes of Procedure and Water Laws From the Oklahoma Statutes*, p. 15.

[8] Milliman, p. 434.

[9] Kelso, p. 1118.

[10] Ibid., p. 1121.

CHAPTER III

THE ANALYTICAL MODELS

This chapter presents and discusses the basic model utilized in the analysis in subsequent chapters. The first portion of the model is the General Agricultural Firm Simulator developed by Hutton and Hinman.[1] The generality of this model permits is adaptation to many specific situations. The model is modified to simulate a representative farm firm for the Central Ogallala Formation study area. The second portion of the model utilized in the analysis is merely a new Production Subset for the General Agricultural Firm Simulator. This new Production Subset is designed to overcome some of the shortcomings of the General Agricultural Firm Simulator while adding a dimension of sophistication and realism in the production process not previously attained in simulation models designed primarily to solve economic problems. Each portion of the model is discussed in turn followed by a section which integrates the parts into a single unit for purposes of the current analysis.

The Farm Firm Simulation Model

The basic purpose of the General Agricultural Firm Simulator is to provide a general framework or structure within which any number of problems may be solved without the researcher being required to develop a computer program specific to each problem.[2] The program consists of a Master program and Subroutines INPUT, CAPITAL, CAP, NEEDS, PROD and

REPORT. The logic of the program is traced following discussion of data input requirements.

Many types of information are required to describe the production possibilities and market conditions within which the firm operates. This information is first arranged in a series of tables and subsequently punched on computer cards to be read into the General Agricultural Firm Simulator as data. The tables containing input data for this analysis are presented in Appendix A. Input allowances for each crop enterprise considered in the model are presented in Table XXXVI. Column headings represent the crops or crop blocks to be produced. Row titles indicate the input services required in the production process. Coefficients in the body of the table indicate the number of units of input service (row) required to produce an acre of any crop (column). Output per acre, output prices and government payments per acre of each activity are presented in Table XXXVII, Appendix A. Table XXXVIII contains the characteristics of input services. Each input service is listed in the appropriate row. Characteristics of input services, reflected by column headings, include for each input service, rental rate per unit, purchase costs, units of service provided, total life, security class for borrowing purposes, minimum number of units purchased or rented at one time, property tax on capital assets, insurance cost per dollar of value and repair costs. In addition, current income tax rates for a joint return are specified in column 16 of the same table. Twenty-five entries are contained, one for each $1,000 breakdown up to $25,000 of taxable income.

Table XXXIX of Appendix A contains the current inventory of capital assets. Numbers in column 1 correspond to rows of input services in

Table XXXVI or Table XXXVIII. Entries in column 2 represent the number of units of capital embodied in each class of input service in column 1. Column 3 entries indicate the age of each capital asset at the beginning of the simulation run. Table XL, Part 1, contains the organization of production for the representative farm firm being simulated. Entries in the reference row correspond to column entries in Table XXXVI, Table XL, Part 2 allows entries for purchase or sale of capital assets.

Table XLI of Appendix A contains a profusion of data ranging from amounts of real estate, chattle and other debts outstanding, to the "safe" proportion of asset value to debt, the amount of withdrawals per year for current consumption. The interested reader is referred to Table XLI where each coefficient is labeled.

Each coefficient entered in a table of the General Agricultural Firm Simulator may be altered by merely addressing the appropriate row and column of that table. That is, each coefficient has a five-digit code of the form "TRRCC" which specifies its location. The T refers to the appropriate table while RR and CC denote the proper row and column within the table. For example, the first coefficient of Table XXXVI, which specifies input allowances, contains the five-digit identification code 10101. By simply reading in a card containing the code 10101 and a new coefficient, subsequent years of a multiperiod run will retain the value of the new coefficient. This feature of the model was used extensively in the current analysis, as will be explained following discussion of the Production Subset.

Once the input data contained in Tables XXXVI through XLI of Appendix A have been read into the General Agricultural Firm Simulator, certain steps or computations are performed in logical order. Hutton outlines the logic of these steps and his dialogue is followed closely in this section.[3] The first major step performed at the beginning of each year of a multiperiod run involves capital management operations. These operations are performed in Subroutines CAPITAL and CAP and include increasing or decreasing of debts as prescribed by the input data. Capital goods are purchased and added to inventory or sold and dropped from inventory. Assets which have been depreciated out are dropped from inventory. All depreciation computations are made on a straight-line basis assuming no salvage value. After capital transactions have been enacted, the debt structure is subject to automatic adjustment to bring it into conformity with security requirements and the maintenance of cash balances. That is, if the cash balance falls below that minimum acceptable level specified as part of the input data, automatic short-term borrowing occurs to restore the cash balance to the minimum level.

The second major computational step, which is accomplished within subroutine NEEDS, determines the quantities of inputs required to operate the activities at levels specified in the program. Input allowance shortages are handled by hiring in input services at a price specified in the input data. Excess input services may be hired out if deemed desirable and practical.

The third major step computes the output of products. If determination of output is probabilistic, a random deviate is drawn, multiplied by the standard deviation and added to the mean value. The General Agricultural Firm Simulator assumes that crop yields are normally and independently distributed. This feature of the model is seen as a major shortcoming for this study. The yields of two summer crops growing in adjacent fields under the same soil moisture and atmospheric conditions are unlikely to behave as independent random variables over a period of years. Low yields for one crop are likely to correspond to low yields for the other crop. A procedure is available which makes the assumption of independence among crop yields unnecessary. Eidman applied the procedure to the correlation of two product prices.[4] Clements, Mapp and Eidman extended the procedure from the two-event case to the four-event case and presented generalized equations which permit correlation of n-events at the desired level.[5] However, to the author's knowledge, the procedure has not been tested with probability distributions other than the normal distribution. Because of this output limitation, yields for the current analysis are calculated within the Production Subset to be explained in the next section of this chapter.

The fourth step of the General Agricultural Firm Simulator, accomplished in Subroutine PROD, computes the quantity of input services available from capital inventory. Age of all capital assets is incremented by one year. Assets which have exceeded their useful life are dropped from inventory during this step. The quantity of input service required is deducted from the input services available. If a shortage exists that cannot be met by intermediate products, it is met by direct purchase. Next, prices and costs are applied to yields and input services and the financial statement is prepared.

The financial statement covers the simulated years operation. A copy of the output generated by the General Agricultural Firm Simulator is attached to Appendix A. Included in the financial statement are current value of total assets, total debts and net worth. Family and hired labor are also enumerated. The financial summary includes cash operating income from crops being produced and from government payments. The sum of inventory increases and cash operating income is gross farm income. Operating expenses include repairs and maintenance, property taxes, insurance, interest, labor and cash costs for the whole operation. Cash operating expense plus capital purchases equals gross farm expense. Net farm income is the difference between gross farm income and gross farm expense. On a cash flow basis, net cash operating income is the difference between cash operating income and cash operating expense. Out of net cash operating income must come payments for income and social security taxes, payment on debt principle and withdrawals for current consumption. If a positive cash balance remains, it is added to the existing cash balance and assets are increased by the amount of the excess cash reserve. If a negative cash balance remains, short-term borrowing is automatically implemented to restore cash to the minimum specified as part of the input data for the Simulator.

After each year of a multiperiod simulation run, a copy of the financial statement for the firm is written on disk. Each year this copy is updated to reflect changes in the financial status of the firm. At the end of the simulation run, results for each year are written sequentially so that the financial condition of the firm is reflected at the end of each year and the current condition at the end of the multiperiod run is elaborated in the financial statement of the final year of the run.

The Production Subset

The General Agricultural Firm Simulator is, as the name implies, quite general in nature. Many types of agricultural firms may be simulated, and many types of problematic situations investigated, by modifying the input data to reflect the desired situation. For this study, a model is needed that will permit evaluation of the effects on the farm firm of various water-use regulatory alternatives. It is essential to simulate the firm in a framework that considers variable rainfall, evapotranspiration and the effects of soil moisture stress during critical stages of plant development on final crop yield. The assumption of the General Agricultural Firm Simulator that yields are normally and independently distributed with given mean and standard deviation is inappropriate. Thus, the method of computing yields for both irrigated and dryland crops in the General Agricultural Firm Simulator is replaced with the Production Subset.

The basic idea embodied in the Production Subset is that crop yields can be estimated as a function of soil and atmospheric conditions, or soil moisture stress and atmospheric stress, during critical stages of plant development. If soil moisture and atmospheric conditions are ideal throughout the growing season, some potential yield is achieved for each crop. When sufficient water is not maintained in the plant root system, soil moisture stress occurs and the result is a reduction in crop yield. The amount of yield reduction depends upon the length and severity of moisture and atmospheric stress in relation to the stage of plant development. Even when soil moisture is adequate, severe atmospheric conditions can cause plant stress and reductions in crop yield. A combination of high temperature, low relative humidity and high wind movement creates a demand for more moisture than the plant is able to transpire. The resulting plant stress causes a reduction in final crop yield. Thus, yield reduction (YR_{ij}) for a crop is a function of daily soil moisture and atmospheric stress as they relate to the critical stages of plant development. In implicit form, this relationship may be expressed as

$$YR_{ij} = f(SM_{ij}, AS_{ij}) \tag{3-1}$$

where SM represents soil moisture stress, AS represents atmospheric stress and i and j represent the day and stage of plant development, respectively.

Soil moisture at any point in time is a function of daily rainfall (RN_{ij}); evapotranspiration (EV_{ij}), which represents evaporative losses of moisture to plants and the atmosphere; and, additions of moisture to the profile through irrigation applications (I_{ij}), or

$$SM_{ij} = h(RN_{ij}, EV_{ij}, I_{ij}) \tag{3-2}$$

Atmospheric demand for soil moisture is a function of pan evaporation (PE_{ij}), or

$$AS_{ij} = g(PE_{ij}) \tag{3-3}$$

Thus, crop yield reduction on day i of stage j is a function of the random variables rainfall, evapotranspiration, irrigation application rate and pan evaporation. Irrigation is considered a random variable since applications are governed by the other random variables mentioned above. The implicit function for crop yield reduction is derived by substituting (3-2) and (3-3) into (3-1) to get

$$YR_{ij} = f(RN_{ij}, EV_{ij}, I_{ij}, PE_{ij}). \qquad (3\text{-}4)$$

The implicit production function for yield of crop k (Y^k) is obtained by summing m daily yield reductions across n critical stages of plant development and subtracting the result from a potential yield under adequate moisture conditions (PY^k) as follows:

$$Y^k = PY^k - \sum_{j=1}^{n} \sum_{i=1}^{m} f(RN_{ij}, EV_{ij}{}^{k}, I_{ij}{}^{k}, PE_{ij}). \qquad (3\text{-}5)$$

A series of k such equations are required to fully describe k individual crops or crop blocks. By summing across the k crops or crop blocks, a net returns equation for the farm operation, similar to that specified in Chapter II, can easily be derived.

Prediction of crop yields based on available soil moisture at critical stages of plant development can be accomplished in at least two ways. One approach is to estimate a predictive equation in which crop yield is the dependent variable and the explanatory variables include rainfall, irrigation application, pan evaporation, some measure of evapotranspiration, temperature, wind movement and relative humidity during each critical stage of plant development for each crop being considered. This approach has definite appeal because regression analysis is a comparatively simple technique to use and the results can be evaluated in terms of significance level of regression coefficients, predictive ability of the equation and R^2. Though appealing, the approach is not without problems. The primary problem is that little research has been done to establish the relationships between soil moisture and atmospheric stress at critical stages of plant development for the major crops of the study area. Compounding the significant data problems are the difficulties of formulating appropriate functional forms for the equations, a lack of independence among the explanatory variables and the existence of a large random component not readily explainable through the use of measurable weather variables.

A second approach to estimating the effects of moisture stress on crop yield is to make independent studies of soil moisture and the yield effects of moisture stress during critical stages of plant development. Soil moisture may be studied within the context of a daily soil moisture balance system. In a separate analysis, the critical stages of plant development for each individual crop may be identified and the effects of moisture and atmospheric stress on yield during that stage evaluated. Then the two may be combined into a dynamic soil moisture-crop yield system capable of simulating soil moisture throughout the growing season, and determining final yield for each crop as a function of the level of moisture and atmospheric stress occurring during the critical stages of plant development. The latter approach is utilized in this study.

The Soil Moisture Balance

The soil moisture balance for this study is based upon the findings and ideas presented by Van Bavel,[6] Thornthwaite,[7] Thornthwaite and Mather,[8] Holmes and Robinson,[9] Denmead and Shaw,[10] and Ligon, et. al.[11] The balance provides daily adjustments to soil moisture to reflect additions through rainfall and subtractions through estimates of evapotranspiration. Daily net additions to soil moisture occur when rainfall exceeds actual evapotranspiration and depletions occur when the opposite is true.

A 51-inch soil profile is utilized in constructing the daily moisture balance. Based on experimental moisture release data for Richfield clay loam soil at Goodwell, Oklahoma, field capacity and permanent wilting point are estimated to be 16.32 and 8.69 inches of soil moisture, respectively.[12] The 51-inch profile is divided into an upper and lower layer. The upper layer consists of the top nine inches of soil which contains moisture most readily available for plant use. The upper layer holds 2.88 inches of soil moisture at field capacity and 1.53 inches at permanent wilting point. The lower 42 inches of the profile (from nine down to 51 inches) retains 13.44 inches of soil moisture at field capacity and 7.16 inches at permanent wilting point.[13]

When rainfall occurs, water is added to the upper nine inches of the soil profile. It is assumed that water percolates from the upper profile to the lower profile at a rate proportional to the amount of moisture in the upper zone.[14] Specifically, it is assumed that five percent of the water in the upper zone percolates to the lower zone each day until soil moisture in the upper zone reaches 1.53 inches of moisture (permanent wilting point). Then, water movement to the lower zone ceases.

Water is withdrawn from the soil profile as a result of evapotranspiration. There are two concepts of evapotranspiration. The first, potential evapotranspiration, refers to the quantity of moisture which would be evaporated and transpired under adequate soil moisture conditions for a particular crop and stage of plant development. Daily amounts of potential evapotranspiration are estimated as a function of daily pan evaporation readings.[15] The second, actual evapotranspiration, indicates the amount of evapotranspiration which actually occurs during a given day. It is a function of potential evapotranspiration and soil moisture conditions. Actual evapotranspiration is always equal to or less than potential evapotranspiration. The two are assumed equal only when soil moisture is at field capacity in the upper layer of the soil profile. Once soil moisture falls below field capacity in the upper zone, actual evapotranspiration is assumed proportional to the amount of moisture remaining in the upper zone. All actual evapotranspiration occurs from the upper zone until soil moisture reaches permanent wilting point of 1.53 inches. Then moisture is drawn from the lower layer with actual evapotranspiration being proportional to the amount of soil moisture remaining in the lower zone of the profile. Once soil moisture in the lower zone of the profile reaches permanent wilting point of 7.16 inches, actual evapotranspiration is assumed to cease.

The following series of equations describes, in mathematical notation, the system used to calculate actual evapotranspiration on a daily basis.

$$AE_i = EP_i \frac{SMU_i}{2.88}, \quad 1.53 \leq SMU_i \leq 2.88 \tag{3-6}$$

$$AE_i = EP_i \frac{SML_i}{13.44}, \quad SMU_i = 1.53; \quad 7.16 \leq SML_i \leq 13.44 \tag{3-7}$$

$$AE_i = 0, \quad SMU_i = 1.53, \quad SML_i = 7.16 \tag{3-8}$$

where AE_i equals actual evapotranspiration, day i; EP_i equals potential evapotranspiration, day i; SMU_i equals inches of soil moisture, upper (0-9 inch) layer, day i; SML_i equals inches of soil moisture, lower (9-51 inch) layer, day i.

Equation (3-6) states that if moisture in the upper layer of the soil profile is between field capacity and the permanent wilting point of 1.53 inches, then actual evapotranspiration from the upper layer is a function of potential evapotranspiration and is proportional to the amount of water remaining in the upper layer. Equation (3-7) indicates that once soil moisture in the upper layer of the soil profile has been depleted to the minimum 1.53-inch level, actual evapotranspiration is a function of potential evapotranspiration and occurs from the lower profile at a rate proportional to the amount of soil moisture in the lower layer. Equation (3-8) indicates that evapotranspiration ceases when moisture in both layers of the soil profile reaches permanent wilting point.

Except for the variation in potential evapotranspiration for different crops at different stages of plant development, the primary variables composing the moisture balance are rainfall and pan evaporation. To simulate daily values of soil moisture throughout the growing season, daily values of rainfall and pan evaporation are required. Generating daily values for these two variables is considered in turn.

Rainfall Probability Distribution

Rainfall throughout the study area is characterized by two predominate features. First, yearly average rainfall is very low. It ranges from 15 inches in the western portion of the study area to 19 inches in the eastern part of the Oklahoma Panhandle. Second, daily and yearly rainfall are quite variable. During the 29 years from 1941 through 1969 daily rainfall at the U.S. Weather Bureau Station, Goodwell, Oklahoma, (approximately the center of the study area) ranges from zero to 5.38 inches. The long-term average number of days per year with zero rainfall is approximately 275.

To simulate soil moisture throughout the crop year, a means is needed to accurately represent the rainfall pattern which might be expected based on historical rainfall patterns. One alternative is to estimate a continuous probability density function, such as the gamma, incomplete gamma or beta, to represent the daily rainfall distribution. However, such a high proportion of the total probability is clustered at or near zero that no continuous probability distribution satisfactorily approximates the rainfall pattern. The only feasible alternative is to utilize discrete, empirical probability distributions based on actual daily observations of rainfall for the past 29 years. The growing season is divided into seven monthly periods, beginning on April 1 and ending on October 31. Each month is further divided into two periods. The first period of each month is 15 days long. The second period of each month is either 15 or 16 days long depending upon whether the month has 30 or 31 days. The discrete empirical probability distributions estimated for each of the 14 periods of the growing season are presented in Table I. Each distribution is independent of the other distributions. Generating daily rainfall events from a different distribution every two weeks takes into account differences in the actual distribution of rainfall during the growing season.

TABLE I

DISCRETE RAINFALL PROBABILITY DISTRIBUTIONS FOR FOURTEEN PERIODS OF THE CROP YEAR

Inches of Rainfall	Apr. 1-15	Apr. 16-30	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	Aug. 1-15	Aug. 16-31	Sept. 1-15	Sept. 16-30	Oct. 1-15	Oct. 16-31
.00	.851	.871	.782	.746	.733	.786	.743	.776	.759	.800	.846	.844	.878	.862
.01-.05	.041	.023	.071	.058	.051	.051	.044	.034	.039	.062	.034	.039	.030	.030
.06-.10	.039	.023	.018	.022	.051	.039	.021	.032	.037	.022	.032	.025	.014	.026
.11-.15	.023	.016	.011	.024	.011	.021	.025	.026	.021	.015	.018	.018	.014	.009
.16-.20	.007	.007	.018	.022	.021	.007	.014	.017	.016	.015	.011	.011	.005	.017
.21-.25	.005	.005	.009	.017	.018	.021	.016	.013	.007	.004	.007	.009	.011	.002
.26-.30	.007	.011	.002	.011	.011	.009	.002	.009	.018	.013	.007	.005	.002	.011
.31-.35	.002	.002	.009	.011	.011	.009	.002	.004	.007	.009	.007	.007	.002	.006
.36-.40	.002	.002	.007	.009	.009	.007	.009	.009	.007	.007	.007	.002	.002	.004
.41-.45	.007	.005	.005	.011	.011	.005	.023	.011	.014	.007	.002		.005	.006
.46-.50	.005	.007	.007	.011	.009	.005		.002	.009	.004		.007	.005	.002
.51-.55		.007	.018	.011	.009	.002	.018	.004	.005	.002		.002	.005	
.56-.60	.005		.005	.015	.007	.002	.005	.004	.002	.004			.002	.004
.61-.65	.002	.005		.002	.005		.005	.009	.005	.002				.002
.66-.70		.002		.002			.005		.007	.002		.002		
.71-.75			.007	.002			.007	.002	.002			.005	.002	.002
.76-.80	.002	.005	.002		.005	.007		.002	.005	.002			.005	.002
.81-.85			.002	.002	.007		.005	.002	.002		.002	.005	.005	
.86-.90			.002	.002	.002		.002	.006	.002	.002	.002	.002	.002	
.91-.95	.002				.002	.009	.005	.006	.005	.002	.002		.002	.002
.96-1.00			.002	.002		.002	.007	.004	.002	.002				
1.01-1.05		.002	.005	.002	.005		.005	.002	.002	.002	.002	.002		
1.06-1.10			.002		.002		.005	.009			.002			
1.11-1.15	.002		.002	.004		.002	.002					.005		
1.16-1.20		.002	.002		.002		.005		.007		.005	.002		.002

TABLE I (Continued)

Inches of Rainfall	Apr. 1-15	Apr. 16-30	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	Aug. 1-15	Aug. 16-31	Sept. 1-15	Sept. 16-30	Oct. 1-15	Oct. 16-31
1.21-1.25							.005			.002	.002	.005		
1.26-1.30		.002							.002					
1.31-1.35		.002		.006			.005	.002	.005					
1.36-1.40			.002			.002				.007				.002
1.41-1.45			.002		.005	.005	.005						.002	
1.46-1.50						.002							.002	
1.51-1.55			.002				.002	.002	.002					
1.56-1.60									.002					
1.61-1.65							.002							
1.66-1.70								.002		.004	.002			.002
1.71-1.75			.002				.002			.002			.002	
1.76-1.80														
1.81-1.85					.002			.004		.002	.002			
1.86-1.90				.002	.002									
1.91-1.95				.002	.002				.002					
1.96-2.00				.004							.002			
>2.00					.002	.007	.005	.004	.007	.004	.002	.002	.002	.004

Generating daily rainfall values from a discrete probability distribution can present a problem because of the computer storage and time required. However, a very fast procedure developed by Marsaglia is utilized to generate random variates from each discrete probability density function.[16]

Pan Evaporation Probability Distributions

Pan evaporation, like rainfall, is an integral component of the soil moisture balance system. To simulate soil moisture throughout the growing season, daily pan evaporation values must be generated for each period of the growing season.

Pan evaporation measurements taken from a Class A weather pan are recorded at the U.S. Weather Bureau Station, Goodwell, Oklahoma. Sufficient information is available to estimate pan evaporation probability density functions for 12 periods, the first beginning on May 1 and the last ending on October 31. These periods correspond exactly to the rainfall periods, except that no pan evaporation distributions are estimated for April.

Daily pan evaporation values are generally small during the early portion of the growing season, increase to a peak level during July and August and decline to a low level in October. Plottings of daily pan evaporation observations for each period of the growing season reveal several outstanding characteristics. First, the sample data indicates that the pan evaporation distributions are positively skewed. Second, all observations are equal to or greater than zero. Third, the symmetry or skewness of the distribution changes from period to period during the growing season.

The lognormal distribution is used to describe pan evaporation in this study. It is a continuous positively skewed probability density function having all values equal to or greater than zero. It is easily derived, being completely defined by the mean and variance and is easy to manipulate in the analysis.

Aitchinson and Brown discuss alternative methods of estimating the parameters of a lognormal distribution. Parameters of each distribution are estimated by the method of maximum likelihood.[17] Estimates of the mean, variance and standard deviation for each of the pan evaporation distributions are given in Table II.

Equation (3-9) may be used to generate a series of n random pan evaporation observations from a lognormal distribution with mean m_1 and standard deviation s_1.

$$x_i = e^{m_1+s_1Z_i} \tag{3-9}$$

where m_1 and s_1 are the mean and standard deviation of the lognormally distributed transformed variable and Z_i represents a series of n random normal deviates. Generating pan evaporation values from a different distribution for each two-week period accounts for the changing distribution of pan evaporation throughout the growing season.

Simulating Soil Moisture During the Crop Year

Utilizing the rainfall and pan evaporation distributions, daily values for each are generated throughout the growing season. The absence of pan evaporation data for the November through April period necessitates estimation of soil moisture at the beginning of May based

TABLE II

SUMMARY OF MEAN, VARIANCE AND STANDARD DEVIATION FOR LOGARITHMICALLY TRANSFORMED PAN EVAPORATION DATA BY PERIODS OF THE YEAR

	x is Distributed Lognormally			y=log x is Distributed Normally		
	Mean	Variance	St.d Dev.	Mean	Variance	Std. Dev.
May 1-15	.38023	.06025	.24546	-1.11687	.31021	.55696
May 16-31	.34863	.04668	.21606	-1.21614	.44774	.66913
June 1-15	.40382	.06009	.24513	-1.02709	.31102	.55769
June 16-30	.46678	.06091	.24680	-.83398	.22946	.47902
July 1-15	.45500	.07547	.27472	-.95027	.49978	.70695
July 16-31	.46152	.06323	.25145	-.89505	.36145	.60121
Aug. 1-15	.39789	.04926	.22194	-1.22882	.25953	.50944
Aug. 16-31	.37178	.04750	.21795	-1.10846	.30757	.55459
Sept. 1-15	.32364	.04720	.21725	-1.27964	.40251	.63444
Sept. 16-30	.27510	.03548	.18835	-1.43233	.35790	.59825
Oct. 1-15	.28648	.05066	.22508	-1.33889	.37783	.61468
Oct. 16-31	.20776	.02673	.16350	-1.71473	.33835	.58168

on available weather data for the previous month or months. Equation (3-10), estimated by multiple linear regression, adequately predicts soil moisture at the beginning of May based upon rainfall during the month of April.

$$SM_{bm} = 8.69 + \underset{(0.26)}{0.22R_{ma}} + \underset{(1.05)}{2.33R_{1wa}} \tag{3-10}$$

where SM_{bm} represents the soil moisture at the beginning of May, in inches; R_{ma} represents the rainfall during the month of April, in inches; and R_{1wa} represents the rainfall during the last week in April, in inches. Standard errors of the regression coefficients appear in parentheses below the equation. The R^2 for Equation (3-10) is 0.90.

Stated in words, the soil moisture balance works as follows: Given beginning soil moisture on May 1, the soil moisture balance generates daily rainfall and pan evaporation values. Potential evapotranspiration is calculated based on pan evaporation and the particular stage of plant development for each crop. Actual evapotranspiration is calculated based upon potential evapotranspiration and soil moisture in the upper profile as long as soil moisture in that layer exceeds permanent wilting point, and then from the lower profile until soil moisture in that layer reaches permanent wilting point. Next, rainfall is compared with actual evapotranspiration. If rainfall exceeds actual evapotranspiration, the difference between the two is added to the upper layer of the soil profile, with five percent of the upper layer moisture percolating to the lower profile. If the upper profile reaches field capacity, additions of soil moisture are made to the lower profile. If both layers reach field capacity, excess water is considered runoff. If, when rainfall is compared with actual evapotranspiration, the latter exceeds the former, soil moisture is reduced by the amount of the difference between the two. Soil moisture declines in the upper profile, with soil moisture also percolating from the upper to lower profile, until permanent wilting point in the upper profile is reached. Then, soil moisture is drawn from the lower profile until soil moisture in that layer reaches permanent wilting point. Once both layers of the profile have reached permanent wilting point, depletion of moisture ceases. Each day of the growing season, a similar set of computations is made based on soil moisture, rainfall and evapotranspiration.

This soil moisture balance is programmed in Fortran IV and appears as Subroutine SMBAL in the Production Subset. The interested reader may trace through the various alternatives and computations presented in Subroutine SMBAL which is attached to Appendix C. A description of the array names, their dimensions and uses also appears in Appendix C.

Testing the Soil Moisture Balance

Prior to using the soil moisture balance to maintain a record of soil moisture throughout the growing season, a statistical test is made to insure that it is performing satisfactorily. To perform satisfactorily, the moisture balance must utilize probabilistic rainfall and pan evaporation readings and generate a distribution of soil moisture values that does not differ significantly from the actual distribution of soil moisture observed for the study area.

Soil moisture, which is a function of heavily skewed rainfall and lognormally distributed pan evaporation, is not normally distributed over the growing season. Thus, the frequently used parametric "t" test is inappropriate for testing the soil moisture distributions.

Fortunately, nonparametric statistical tests exist which may be used to test for statistical differences between two distributions without requiring assumptions about those distributions. The Mann-Whitney U test may be used to test whether two independent groups, A and B, come from the same population; that is, whether A and B have the same distribution. The null hypothesis, H_o, is that A and B have the same distribution. The alternative hypothesis is that A is larger than B.[18] The actual and simulated soil moisture values serve as the two groups, A and B, for the test. The procedures required to use the Mann-Whitney U test, details of the requisite computations and an explanation of the results are presented in Appendix B. The results of the test are stated here in probability terms. The computed value of the test statistic, Z, is 0.802, where Z is approximately normally distributed with zero mean and unit variance. The probability of a value of Z as extreme as 0.802 under the null hypothesis is 0.412. There is no statistical basis for rejecting the null hypothesis of no difference between the actual and simulated soil moisture distributions. Thus, the soil moisture balance system is judged satisfactory from a statistical standpoint. The next steps are to estimate the effects on final crop yield of soil moisture stress during each stage of plant development for each relevant crop. Then the moisture balance and stress-yield relationships are integrated into a dynamic moisture-yield system.

Crop Yields as a Function of Soil Moisture and Atmospheric Stress During Critical Stages of Plant Development

Considerable research has been undertaken to study the effects of various factors, including row spacing, planting rates, seeding date, fertilizer levels, and irrigation rates, on the major crops of the study area, such as grain sorghum,[19] wheat,[20] and corn,[21] as well as on a few minor crops, including alfalfa and sugar beets.[22] However, relatively few studies attempted to establish empirical relationships between timing of water application and crop yield, and between various levels of moisture stress at different stages of plant development and the corresponding yield reductions. These studies have been limited to the major irrigated study area crops--grain sorghum, wheat and corn.[23]

Several general conclusions may be drawn from the results of these research efforts. First, reductions in crop yield may occur as a result of either soil moisture conditions or severe atmospheric conditions. Low soil moisture may subject plants to soil moisture stress resulting in growth retardation and yield reduction regardless of atmospheric conditions. Similarly, even if soil moisture is adequate for normal plant development, severe atmospheric conditions may demand more water than the plant is capable of transpiring and the result is growth retardation and yield reduction. The second general conclusion is that each crop has a unique set of critical stages of plant development which must be identified and studied. Third, the daily effects of moisture and atmospheric stress vary from stage to stage for a single crop and differ from crop to crop.

Integration of the Soil Moisture Balance With Crop Yield Reductions

Calculation of soil moisture on a daily basis as a function of rainfall and evapotranspiration permits consideration of the effects of soil moisture and atmospheric demands on crop yields on a daily basis. If, on day i of stage j of crop k development, soil moisture is inadequate, the plant is subjected to moisture stress and final yield is reduced. Also, if on the same day atmospheric demands for moisture are greater than the plant's ability to transpire moisture to the atmosphere, plant stress occurs and final yield is further reduced. The combined effects of soil moisture and atmospheric stress acting to reduce yield is assumed to be additive and can be expressed as

$$YR_{ij}^{k} = \theta_j^{k}\, SMD_{ij} + b_j^{k}(P_{ij} - P_A) \qquad (3\text{-}11)$$

where Y_{ij}^{k} represents the yield reduction, day i, stage j, crop k; θ_j^{k} represents the coefficient reflecting yield reduction, in units per day, resulting from adverse soil moisture conditions, stage j, crop k; SMD_{ij} represents the soil moisture depletion in inches, day i, stage j; b_j^{k} represents the coefficient reflecting yield reduction in units per day due to severe atmospheric demands upon the plant, stage j, crop k; P_{ij} represents the pan evaporation in inches, day i, stage j; and P_A represents a critical pan evaporation level at or below which no yield reductions occur that are directly attributable to severe atmospheric conditions.

Equation (3-11) indicates that crop yield reductions for a given day and stage of plant development are the sum of soil moisture and atmospheric components. The coefficient θ_j^{k} must be estimated for j critical stages of plant development for each crop. The variable SMD_{ij} is assumed to have the form shown in (3-12) for Richfield clay loam soil.

$$SMD_{ij} = (13.8 - SMT_{ij})/5.11, \quad SMT_{ij} < 13.8 \qquad (3\text{-}12)$$

where 13.8 represents the inches of soil moisture for Richfield clay loam soil below which plants begin to suffer moisture stress and yield begins to be reduced; SMT_{ij} represents the inches of soil moisture which exist in the entire profile on day i of stage j, these values, as previously explained, are generated daily by the soil moisture balance; and 5.11 represents the difference between the critical moisture level of 13.8 inches and permanent wilting point of 8.69 inches.

Equation (3-12) states that as long as the soil moisture level is less than 13.8 inches, SMD_{ij} increases as soil moisture decreases, reaching 1.0 when soil moisture reaches the permanent wilting point of 8.69 inches. Thus, the daily reduction in crop yield due to soil moisture conditions is assumed to be a linear function of the level of soil moisture between the critical moisture point and permanent wilting point.

The portion of Equation (3-11) to the right of the plus sign represents the effect of atmospheric stress upon crop yield. The coefficient b_j^k must be estimated for each of j stages for k crops included in the model. Values of P_{ij} are generated daily (as part of the soil moisture balance) from lognormal distributions of pan evaporation. The value of P_A emphasizes the importance of excessive atmospheric demands upon the plant even though soil moisture may be above the permanent wilting point. If atmospheric demands exceed the plant's ability to transpire moisture to the atmosphere, the plant stresses and yields are reduced. The criteria for selection of a value for P_A, established in consultation with agronomists and agricultural engineers familiar with the area, is that the critical value of P_A should occur approximately 20 percent of the time during the vegetative stage of plant development for each crop. Study of pan evaporation patterns during the vegetative stages of plant development for each crop reveals that the value of P_A satisfying the criteria is approximately 0.40. It is assumed that unless pan evaporation for a given day exceeds 0.40, no yield reduction due to excessive atmospheric demand occurs. Equations (3-11) and (3-12) and the soil moisture balance complete the link between daily moisture readings and crop yield reductions due to moisture and atmospheric stress.

Critical Stages of Development, Water-Use Rates and Potential Yield Reduction for Grain Sorghum

The growing season for grain sorghum in the study area is divided into three critical stages defined as preboot, boot-heading and grain-filling. The actual dates on which these critical stages begin and end is quite variable. Factors that affect plant growth and the time at which each stage is reached include date of planting, moisture conditions at planting, fertilization level, the amount of stress which occurs at each stage of development, timing and amounts of rainfall and irrigation, etc. However, in simulating crop yield as a function of soil moisture during these critical stages, it is necessary to assume a specific beginning and ending date for each stage. Otherwise soil moisture and atmospheric stress coefficients vary, not only from stage to stage and crop to crop, but from year to year as well. Data to estimate such varying relationships is not available. Consequently, fixed length stages are assumed.

Grain sorghum is a summer crop. Farm operators begin preplant irrigations during May, often plant about June 1 and expect emergence by June 7. From June 7 until about mid-July, soil moisture and atmospheric stress have little effect on final yield if soil moisture is adequate during the critical stages of development. The preboot stage occurs between the 12-inch stage and boot stage. Preboot stage is assumed to begin on July 16 and end on August 4, lasting 21 days. The boot-heading stage is assumed to begin on August 5 and end on September 1, lasting 28 days. The grain-filling stage is assumed to begin on September 2 and end on September 22, lasting 21 days. From September 23 until maturity and harvest, moisture and atmospheric stress are assumed to have no effect on final crop yield.

In attempting to approximate the relationship between evapotranspiration and stages of grain sorghum development in the study area, it is assumed that pan evaportion, which is positively correlated with temperature and solar radiation, follows essentially the same pattern throughout the growing season as the concept of mean potential evapotranspiration plotted by Jensen and Sletten.[24] However, the distribution of pan evaporation values for the study area exceeds the distribution of mean potential evapotranspiration values by approximately 50 percent. A measure of daily potential evapotranspiration for grain sorghum is calculated as a function of pan evaporation values generated in the soil moisture balance. It is assumed that potential evapotranspiration equals 25 percent of pan evaporation from the beginning of the growing season on May 1 until plant emergence on June 7. From plant emergence until July 15, when approximately 80 percent ground cover has been reached, potential evapotranspiration is assumed to increase linearly from 25 percent to 55 percent of pan evaporation. (Pan evaporation increases during this period also, and daily values of potential evapotranspiration increase rapidly.) From July 15 until September 1, potential evapotranspiration remains a constant 55 percent of pan evaporation, however, both decline during this period. From September 1 until the end of the growing season, potential evapotranspiration is assumed to equal 50 percent of pan evaporation, with both values reaching low levels in late September and early October.

Dryland grain sorghum and irrigated grain sorghum are handled differently within the model. Water-use curves for irrigated grain sorghum are predicated upon the assumption that adequate soil moisture conditions exist throughout the growing season. Under adequate moisture conditions, potential evapotranspiration is much higher than under dryland conditions. Thus, approximation of water-use rates and potential evapotranspiration utilizing the curves developed for irrigated grain sorghum is inappropriate. Still, potential evapotranspiration changes during the growing season as grain sorghum develops from emergence to 80 percent of ground cover. Research to establish realistic values for dryland grain sorghum is sparce. It is assumed that potential evapotranspiration equals 25 percent of pan evaporation from the beginning of the growing season until the beginning of boot-heading stage of dryland grain sorghum development. From boot-heading stage to the end of grain-filling stage, potential evapotranspiration is assumed to equal 75 percent of pan evaporation. While the potential for evapotranspiration may be high, actual evapotranspiration is likely to be low because of low soil moisture on dryland grain sorghum. Considering the lack of empirical work on dryland grain sorghum water-use rates, one can say in defense of these values that they were judged realistic by the agronomists consulted, and generated realistic dryland grain sorghum yields when used in the Production Subset of the model.

Soil moisture and atmospheric yield reduction coefficients were developed for each of the three critical stages of grain sorghum development. The study conducted by Musick and Grimes at Garden City, Kansas, just north of the study area, provided valuable insights regarding the relative importance of each stage of development and the percentage reduction in yield that might be expected if grain sorghum is subjected to moisture stress for different lengths of time during different critical stages of development.[25] The relationships developed by Musick and Grimes were refined and adjusted in consultation with agronomists, agricultural engineers, farm management agents and irrigation specialists to fit the study area.

Coefficients are actually synthesized and tested rather than being estimated by the use of sophisticated mathematical procedures. While it might be argued that mathematical estimation is preferable, the almost complete lack of adequate data for the study area effectively eliminates that alternative. In addition, it is emphasized that the coefficients, while probably not as accurate as implied by the use of two places to the right of the decimal point, nevertheless represent the best available estimates until more experimentation is accomplished and more data are available.

Equation (3-13) presents soil moisture and atmospheric stress coefficients for the preboot stage of grain sorghum development.

Superscripts designating the crop have been eliminated since each crop is discussed individually.

$$YR_{ip} = 0.30\ SMD_{ip} + 1.30(P_{ip} - 0.40) \qquad (3\text{-}13)$$

A soil moisture stress coefficient of 0.30 for the preboot stage of grain sorghum development denotes that as soil moisture approaches wilting point, yield reduction approaches 0.30 bushels per day. Thus, if soil moisture remains near wilting point for the entire preboot stage, the potential yield reduction is approximately 6.3 bushels (0.30 x 21 days) per acre. Total yield reduction during the preboot stage is obtained by summing the 21 daily soil moisture and atmospheric reductions as indicated in (3-14).

$$YR_{p} = \sum_{i=1}^{21} 0.30 \left(\frac{13.8 - SMT_{ip}}{5.11}\right) + 1.30(P_{ip} - 0.40) \qquad (3\text{-}14)$$

Coefficients for the boot-heading stage are presented in Equation (3-15). Boot-heading is the most critical stage of grain sorghum development as reflected in the larger θ_j and b_j values. Potential yield reduction due to soil moisture stress increases to 57.12 bushels per acre.

$$YR_{ib} = 2.04\ SMD_{ib} + 1.65(P_{ib} - 0.40) \qquad (3\text{-}15)$$

Coefficients for the grain-filling stage of grain sorghum development, shown in Equation (3-16), indicate that adequate moisture during grain-filling is more critical to plant development and final yield than during the preboot stage, but less critical than during the boot-heading stage. Maximum potential yield reduction due to soil moisture stress is 26.67 bushels per acre.

$$YR_{ig} = 1.27\ SMD_{ig} + 1.50(P_{ig} - 0.40) \qquad (3\text{-}16)$$

Determination of the final yield reduction for grain sorghum is accomplished by summing N daily yield reductions for each of three stages of plant development, or

$$YR = \sum_{j=1}^{3} \sum_{i=1}^{N} YR_{ij}. \qquad (3\text{-}17)$$

Final yield is then computed by subtracting the grain sorghum yield from the yield that would be expected under adequate moisture conditions throughout the growing season. Under adequate moisture conditions, a potential irrigated yield of 145.0 bushels per acre (8,120 pounds) is assumed.

Farm operators raising dryland grain sorghum plant a different genotype. The dryland genotype is well suited to dryland production, but has a potential yield under adequate moisture conditions of about 100 bushels per acre (5,600 pounds). The same equations used to compute irrigated grain sorghum yield reductions are used to compute dryland yield reductions. However, one constraint is placed upon production of dryland grain sorghum. Since it receives no irrigation water, dryland acreage must have adequate soil moisture stored in the root zone, or receive sufficient rainfall during May or June, to achieve a stand. It is assumed that if between May 15 and June 25 soil moisture in the upper nine inches fails to reach one-half of its capacity (2.21 inches) or daily rainfall fails to reach 0.68 inches (that amount which will raise soil moisture in the upper profile from permanent wilting point to 2.21 inches), no stand is established and dryland grain sorghum yield is zero for the year. Such dryland grain sorghum crop failures occur about 20 percent of the time in the study area, or about one year in five.

Yield Reduction Coefficients for Wheat and Corn

Procedures similar to those for grain sorghum are utilized to synthesize soil moisture and atmospheric coefficients for the critical stages of wheat and corn development. For wheat, the basic source from which many of the relationships are developed is a study conducted by Musick, Grimes and Herron in southwestern Kansas.[26] The basic data from which the corn coefficients are synthesized are presented in studies conducted by Dale and Shaw, Denmead and Shaw, and Robins and Domingo.[27] Soil moisture and atmospheric stress coefficients for wheat and corn, by stage of plant development, were estimated in consultation with specialists in the area and appear in Table III.

Moisture stress is relatively unimportant during the preboot stage of wheat development. Potential yield reduction due to soil moisture stress is 6.75 bushels per acre. The atmospheric parameter of zero indicates that wheat is resistant to atmospheric stress during the preboot stage. During the boot stage, potential yield reduction due to soil moisture stress increases to 13.26 bushels per acre. Thereafter, soil moisture stress is less important. The magnitude of soil moisture stress coefficients continues to rise, however, each stage is progressively shorter. Thus potential yield reduction due to soil moisture stress is 12.40 and 11.62 bushels per acre during flower and milk stages, respectively.

TABLE III

SOIL MOISTURE AND ATMOSPHERIC STRESS COEFFICIENTS FOR WHEAT AND CORN BY STAGES OF DEVELOPMENT

	Preboot		Boot		Flower		Milk			
	S.M.	Atm.	S.M.	Atm.	S.M.	Atm.	S.M.	Atm.		
Wheat	0.45	0.00	1.02	1.10	1.55	1.20	1.66	1.50		
	Vegetative 1		Vegatative 2		Silking		Milk		Dough	
	S.M.	Atm.	S.M.	Atm.	S.M.	Atm.	S.M.	Atm.	S.M.	Atm.
Corn	0.20	0.10	1.15	0.60	3.05	1.60	1.14	0.40	1.57	0.10

Under adequate soil moisture conditions, a potential irrigated wheat yield of 75.0 bushels per acre is assumed. Wheat planted for dryland production is a different genotype--one which achieves a potential yield of approximately 55.0 bushels per acre under adequate moisture and atmospheric conditions.

As with dryland grain sorghum, an additional assumption is made to account for wheat crop failure. It is assumed that if on any day from September 1 to October 31 soil moisture in the upper profile fails to reach one-half of capacity, or rainfall fails to equal 0.68 inches, no wheat stand is achieved.

Moisture and atmospheric stress coefficients for corn in Table III indicate the effects of moisture stress are small during early vegetative development. Potential yield reduction due to moisture stress is only 6.00 bushels per acre. During the second vegetative stage, the importance of soil moisture stress increases significantly with potential yield reduction reaching 31.05 bushels per acre. The most critical stage, however, is boot stage where potential yield reduction due to moisture stress is 48.80 bushels per acre. The importance of moisture stress declines after boot stage to 25.08 and 23.55 bushels per acre during milk and dough stages, respectively. Potential yield for irrigated corn under adequate moisture and atmospheric conditions is assumed to equal 150.0 bushels per acre.

Corn Silage

Agronomists and area agents in the study area indicate that more and more corn grown for silage is primarily "grain type" corn. Cattle feeders are demanding more grain-type corn silage and producers are responding to market demand. Thus, it is assumed that corn grown for silage is a "grain type" corn and has the same critical stages of plant development and stress coefficients as corn grown for grain. Corn silage yields are estimated as a function of corn for grain yields. A corn silage yield comparable to the 150.0-bushel corn grain yield under adequate moisture conditions is 27.0 tons per acre. A coefficient relating corn grain and corn silage yields is obtained by dividing 27.0 tons by 150.0 bushels to get 0.18. Then corn silage yield (CSY) is computed as a linear function of corn grain yield (CGY) from the relation CSY = 0.18 CGY.

Small Grain Grazing and Native Pasture Yields

Small grain grazing is allowed on diverted acres except during the five principle months of the crop year. Lack of empirical data makes impossible estimation of soil moisture and atmospheric stress coefficients for small grain grazing and native pasture. Small grain grazing yields are positively correlated with dryland wheat yields because both are winter crops grown under dryland conditions. Consequently, a linear relationship is assumed between dryland wheat yield in bushels per acre and small grain grazing yield in animal unit months (AUM). A 14.0-bushel per acre dryland wheat yield is assumed equivalent to 1.8 AUM of small grain grazing.[28] A coefficient relating dryland wheat yield and small grain grazing yield is derived by dividing 1.8 by 14.0 to get 0.12857. Then, small grain grazing yield in AUM (SGPY) is computed as a linear function of dryland wheat yield (DWY) in the relation SGPY = 0.12857 DWY.

The relationships between native pasture yield and either dryland wheat or small grain grazing yield have not been established. Therefore, native pasture yield is assumed constant at one AUM per acre.

Integrating the Production Subset With the General Agricultural Firm Simulator

The Production Subset serves two basic purposes. First, it introduces variability into the production process by computing yields as a function of daily soil moisture and atmospheric stress in relation to the critical stages of crop development. Second, the output from the Production Subset serves as input data for the General Agricultural Firm Simulator. Three output options are available within the

Production Subset. The user may obtain only printed output, a sample of which is attached to Appendix C; only punched output; or, both printed and punched output. Punched output is in the proper form to be read into the Simulator as input data. That is, each card contains a five digit code of the form "TRRCC" which specifies the Simulator table, row and column location of the coefficient punched in the next field.

Output produced by the Production Subset consists of several blocks of data. The initial block specifies the input requirement, by implement in the machinery complement, per unit (acre) of each crop activity included in the model. The form of this block of data is exactly as specified in rows 1 through 12 of Table XXXVI, Appendix A, which presents input allowances for the Simulator. The second block of output consists of the total hours of labor required per acre for each crop during each of eight labor periods. This data set corresponds to rows 17 through 24 of Table XXXVI, Appendix A. Total hours of labor include family plus hired labor for field operations and irrigation applications.

The third block of output reflects the number of acre inches of irrigation water pumped per acre for each crop during each of the five critical irrigation periods, plus the month of April. This block of output corresponds to rows 25 through 30 of Table XXXVI, Appendix A. The fourth output block consists of a single row containing cash costs, or variable costs, per acre for each crop included in the model. This block corresponds to row 31 in Table XXXVI. The fifth block of output contains the number of hours per year each irrigation system is utilized to irrigate each crop activity. All components of every irrigation system are assumed used an equal number of hours per year. This block of output corresponds to rows 33 through 44 of Table XXXVI, Appendix A. Thus, the first five blocks of output from the Production Subset correspond to rows and columns in the table of input allowances for the Simulator.

Two additional sets of output produced by the Production Subset are utilized directly as input data for the General Agricultural Firm Simulator. The first of these, which is the sixth output block, consists of final crop yield for each crop, computed on the basis of soil moisture and atmospheric stress conditions throughout the crop year. This block appears as a single row in printed output of the Production Subset, but corresponds to the matrix of values contained in 15 rows and 14 columns of Table XXXVII, Appendix A. The seventh data set contains the per acre value of government payments for each crop activity included in the model. This data set corresponds to rows 16 and 17 in Table XXXVII, Appendix A. The seven sets of output data are punched on cards and read into the Simulator as input data. One year's output from the Production Subset provides one year's input data for the Simulator. Given assumptions regarding the operator's actions in response to water-use regulatory measures, the effects of each alternative can be simulated over a 20-year time horizon.

In addition to output directly applicable as input data for the Simulator, the Production Subset also prints net returns per acre above total variable costs, the number of acres of each crop planted each year and crop yield reductions due to soil moisture stress and atmospheric stress by critical period of the year for each crop. In addition, the following information is presented regarding the irrigation system and water supply: Beginning and ending pumping capacity by periods of the year, total acre inches pumped, beginning and ending saturated thickness, feet decline in saturated thickness, pumping capacity for each well and the total system, days of annual use and variable pumping costs per acre inch.

Appendix C contains an explanation of the important aspects of the Production Subset, definitions and dimensions of matrices, arrays and variables, and includes a listing of the program and sample output.

FOOTNOTES

[1] R. F. Hutton and H. R. Hinman, *A General Agricultural Firm Simulator*, Agricultural Experiment Station, The Pennsylvania State University, A.E. & R.S. #72 (University Park, 1968).

[2] Ibid., p. 1.

[3] R. F. Hutton, "Introduction to Simulation," *Agricultural Production Systems Simulation*, Vernon R. Eidman, ed., Oklahoma State University (Stillwater, 1971), pp. 14-18.

[4] Vernon R. Eidman, "Optimum Production Plans for California Turkey Growers with Chance--Constrained Programming," (unpub. Ph.D. dissertation, University of California, Berkeley, 1965), pp. 153-154.

[5] Alvin M. Clements, Jr., Harry P. Mapp, Jr. and Vernon R. Eidman, *A Procedure for Correlating Events in Farm Firm Simulation Models*, Agricultural Experiment Station, Oklahoma State University, Technical Bulletin T-131 (Stillwater, 1971).

[6] C. H. M. Van Bavel, "A Drought Criterion and Its Application in Evaluating Drought Incidence and Occurrence," *Agronomy Journal*, Vol. 45 (1953), pp. 167-171.

[7] C. W. Thornthwaite, "An Approach Toward a Rational Classification of Climate," *Geographical Review*, 38 (1948), pp. 55-94.

[8] C. W. Thornthwaite and J. R. Mather, "The Water Balance," *Publications in Climatology*, Vol. VIII, No. 1, Drexel Institute of Technology, Centerton, New Jersey (1955).

[9] R. M. Holmes and G. W. Robertson, "A Modulated Soil Moisture Budget," *Monthly Weather Review*, 87 (1959), pp. 101-105 and "Application of the Relationships Between Actual and Potential Evapotranspiration in Dryland Agriculture," *Transactions of the American Society of Agricultural Engineers*, 6 (1963), pp. 65-67.

[10] O. T. Denmead and R. H. Shaw, "Availability of Soil Water to Plants as Affected by Soil Moisture Conditions and Meteorological Conditions," *Agronomy Journal* (1962), pp. 385-390.

[11] J. T. Ligon, G. R. Benoit and A. B. Elam, Jr., "A Procedure for Determining the Probability of Soil Moisture Deficiency and Excess," Department of Agricultural Engineering, Paper No. 64-211, University of Kentucky (Lexington, 1964), p. 3.

[12] Richfield clay loam soil was selected as the soil for which the moisture balance would be constructed for several reasons. The data on field capacity and permanent wilting point were readily available. It is the predominant irrigable clay loam soil in the study area. Irrigable clay and clay loam soils compose 6,167,500 acres (76.7 percent) of the 8,040,915 irrigable acres in the study area.

[13] Data pertaining to field capacity, permanent wilting point and available soil moisture were obtained in consultation with Dr. James M. Davidson and Dr. John F. Stone, Department of Agronomy, Oklahoma State University, Stillwater, Oklahoma.

[14] In a study by Winton Covey and M. E. Bloodworth, "Mathematical Study of the Flow of Water to Plant Roots," Texas Agricultural Experiment Station, MP-599 (College Station, 1962), empirical evidence indicates that moisture diffusivity of a soil may be assumed an exponential function of soil moisture content. The exponential relationship may be expressed as $D = r\ e^{\theta\beta}$, where D is diffusivity, θ is volumetric water content and both r and β are constants. A serious drawback to the use of an exponential function to approximate water movement within the soil profile is that the constants r and β must be estimated empirically for each soil and have not been estimated for the soils of the study area.

[15] W. O. Pruitt, "Empirical Method of Estimating Evapotranspiration Using Primary Evaporation Pans," *Conference Proceedings on Evapotranspiration and Its Role in Water Resource Management*, American Society of Agricultural Engineers (1966).

[16] G. Marsaglia, "Generating Discrete Random Variables in a Computer," *Communications of the ACM* (January, 1963), pp. 37-38.

[17] The method of computation is set forth in J. Aitchinson and J. A. C. Brown, *The Lognormal Distribution* (New York, 1957), p. 39.

[18] Sidney Siegel, *Nonparametric Statistics*, McGraw Hill Book Company (New York, 1956), pp. 116-127.

[19] Grain sorghum studies include the following: R. R. Allen, et. al., *Grain Sorghum Yield Response to Row Spacing in Relation to Seeding Date, Days to Maturity and Irrigation Level in the Texas Panhandle*, Texas Agricultural Experiment Station, PR-2697 (College Station, 1969); M. E. Jensen and W. H. Sletten, *Evapotranspiration and Soil Moisture-Fertilizer Interrelations with Irrigated Grain Sorghum in the Southern Great Plains*, USDA Conservation Research Report No. 5 (Washington, 1965); J. T. Musick, *Irrigating Grain Sorghum with Limited Water*, Proceedings of the Texas A & M University Soil Conservation Service Conservation Workshop (College Station, 1968); J. T. Musick and D. A. Dusek, *Grain Sorghum Row Spacing and Planting Rates Under Limited Irrigation in the Texas High Plains*, Texas Agricultural Station, MP-932 (College Station, 1969); J. T. Musick and D. A. Dusek, *Grain Sorghum Response to Number, Timing and Size of Irrigations in the Southern High Plains* (unpub. manuscript, USDA Southwestern Grain Plains Research Center, Bushland, Texas, 1969); J. T. Musick, D. W. Grimes and G. M. Herron, "Irrigation Water Management and Nitrogen Fertilization of Grain

Sorghums," *Agronomy Journal*, Vol. 55 (1968), pp. 295-298; J. T. Musick and W. H. Sletten, "Grain Sorghum Irrigation-Water Management on Richfield and Pullman Soils," *Transactions of the ASAE*, Vol. 9, No. 3 (1966); J. T. Musick, W. H. Sletten and D. A. Dusek, *Irrigating Grain Sorghum for Efficient Use of Limited Water*, Annual Meeting of Agricultural Engineers, Paper No. 64-208 (Ft. Collins, 1964); T. S. Nakoyama and C. H. M. Van Bavel, "Root Activity Distribution Patterns of Sorghum and Soil Moisture Conditions," *Agronomy Journal*, Vol. 55 (1963), pp. 271-274; K. B. Porter, M. E. Jensen and W. H. Sletten, "The Effect of Row Spacing, Fertilizer and Planting Rate on the Yield and Water Use of Irrigated Grain Sorghum," *Agronomy Journal*, Vol. 52 (1960), pp. 431-434; John Shipley and Cecil Regier, "Water Response in the Production of Irrigated Grain Sorghum, High Plains of Texas, 1969," (unpub. manuscript, USDA Southwestern Great Plains Research Center, Bushland, Texas, 1969); J. F. Stone, R. H. Griffen and B. J. Ott, *Irrigation Studies of Grain Sorghum in the Oklahoma Panhandle, 1958 to 1962*, Oklahoma Agricultural Experiment Station, Bulletin B-619 (Stillwater, 1964); *Summary, Agronomy Research Projects*, Panhandle Agricultural Experiment Station (Goodwell, 1962-1969); J. S. Wehrly, J. T. Shipley and C. Regier, *Wheat Response to Spring Irrigation, Northern High Plains of Texas*, Texas Agricultural Experiment Station, Consolidated PR-2546-2555 (College Station, 1968); and J. S. Wehrly, W. H. Sletten and M. E. Jensen, *Economic Decisions in Producing Irrigated Grain Sorghum on the Northern High Plains of Texas*, Texas Agricultural Experiment Station, MP-747 (College Station, 1964).

[20] Wheat studies include the following: M. E. Jensen and W. H. Sletten, *Evapotranspiration and Soil Moisture--Fertilizer Interrelations with Irrigated Winter Wheat in the Southern High Plains*, USDA Conservation Research Report No. 4 (Washington, 1965); W. C. Johnson, "Some Observations on the Contribution of an Inch of Seeding--Time Soil Moisture to Wheat Yield in the Great Plains," *Agronomy Journal* (1963), pp. 29-35; J. S. Robins and C. E. Domingo, "Moisture and Nitrogens Effects on Irrigated Spring Wheat," *Agronomy Journal*, Vol. 54 (1962), pp. 135-138; A. D. Schneider, J. T. Musick and D. A. Dusek, "Efficient Wheat Irrigation with Limited Water," *Transactions of the ASAE*, Vol. 12 (1969); and *Summary, Agronomy Research Projects*, Panhandle Agricultural Experiment Station (Goodwell, 1962-1969).

[21] Corn experiments include the following: O. T. Denmead and R. E. Shaw, "Evaporation in Relation to the Development of the Corn Crop," *Agronomy Journal*, Vol. 51 (1959), pp. 725-726; O. T. Denmead and R. H. Shaw, "Availability of Soil Water to Plants as Affected by Soil Moisture Conditions and Meteorological Conditions," *Agronomy Journal* (1962), pp. 385-390; R. T. Holt, et. al., "Importance of Stored Soil Moisture to the Growth of Corn in Dry to Moist Subhumid Climatic Zone," *Agronomy Journal* (1963), pp. 82-85; and R. H. Shaw, *Estimation of Soil Moisture Under Corn*, Iowa Agricultural Experiment Station, Research Bulletin 520 (Ames, 1963).

[22] A Study on alfalfa is G. Ogata, L. A. Richards and W. R. Gardner, "Transpiration of Alfalfa Determined From Soil Water Content Changes," *Soil Science*, Vol. 89, No. 4 (1960), pp. 179-182. Sugar beets were studied by A. D. Schneider and A. C. Mathers, *Water Use by Irrigated*

Sugar Beets in the Texas High Plains, Texas Agricultural Experiment Station, MP-935 (College Station, 1969).

[23] Grain sorghum moisture stress studies have been accomplished by J. T. Musick and D. W. Grimes, Water Management and Consumptive Use by Irrigated Grain Sorghum in Western Kansas, Kansas Agricultural Experiment Station (Garden City, 1961) and J. L. Shipley, C. Regier and J. S. Shipley, Soil Moisture Depletion Levels as a Basis for Timing Irrigation of Grain Sorghum, Texas Agricultural Experiment Station, Consolidated PR-2546-2555 (College Station, 1968). Wheat moisture stress relationships have been studied by J. T. Musick, D. W. Grimes and G. M. Herron, Water Management, Consumptive Use, and Nitrogen Fertilization of Irrigated Winter Wheat in Western Kansas, USDA Production Research Report No. 75 (Washington, 1963). Effects of moisture stress on corn yields has been studied by R. F. Dale and R. H. Shaw, "Effect on Corn Yield of Moisture Stress and Stand at Two Fertility Levels," Agronomy Journal (1965), pp. 475-479; O. T. Denmead and R. H. Shaw, "The Effects of Soil Moisture Stress at Different Stages of Growth on the Development and Yield of Corn," Agronomy Journal, Vol. 52 (1960), pp. 272-274; and J. S. Robins and C. E. Domingo, "Some Effects of Severe Soil Moisture Deficits at Specific Growth Stages on Corn," Agronomy Journal (1953), pp. 618-621.

[24] Jensen and Sletten, Evapotranspiration and Soil Moisture-Fertilizer Interrelations with Irrigated Grain Sorghum in the Southern Great Plains, p. 8 ff.

[25] See footnote 23.

[26] See footnote 23.

[27] See footnote 23.

[28] J. W. Green, V. R. Eidman, and L. R. Peters, Alternative Irrigated Crop Enterprises on Clay and Sandy Loam Soils of the Oklahoma Panhandle: Resource Requirements, Costs and Returns, Oklahoma Agricultural Experiment Station, Processed Series P-554 (Stillwater, 1967), pp. 9-10.

CHAPTER IV

REPRESENTING RESOURCE SITUATIONS AND OUTLINING INSTITUTIONAL ALTERNATIVES

This chapter serves several purposes. First, the basis for defining typical resource situations is outlined and two resource situations are developed. Second, the concept of a representative farm is developed for the study area. Third, assumptions regarding the farm organization, machinery complement, overhead costs, government programs, prices, irrigation wells and pumping costs are elaborated. Fourth, general irrigation strategies for the representative farm firm are specified. Finally, the framework is laid within which the three water-use alternatives postulated for the study are to be analyzed.

Defining Typical Resource Situations

The primary basis for selecting typical resource situations is the saturated thickness of the Ogallala Formation. Saturated thickness is a critical determinant of both the quantity of water in storage and the yield of an irrigation well or system in gallons per minute. The Ogallala Formation is not a uniform aquifer. Saturated thickness varies from a few feet near the boundaries of the formation to over 500 feet in portions of the Oklahoma and Texas Panhandles. Well drilling and pumping costs vary considerably with the amount of saturate thickness. These cost variations affect the profitability of irrigation farming for individual irrigators. Over time, as saturated thickness declines, its importance increases relative to other factors upon which typical resource situations might be built. The land area and amount of water in storage is summarized by saturated thickness interval in Table IV. The number of acres overlying each saturated thickness interval and the percent of the total study area represented by each saturated thickness interval are presented in the first two rows. The third and fourth rows indicate the acre feet of water in storage by saturated thickness interval and the percentage of total water contained in each interval.[1]

Two basic resource situations, designed to represent "poor" and "adequate" water positions are defined for this study. The saturated thickness intervals ≤ 100 and 101-200 feet are combined to represent the poor water situation. The remaining four saturated thickness intervals are combined to represent the adequate water situation. The two basic resource situations are defined in Table V.

Resource Situation 1 represents 46.59 percent of the total land area, however, the underlying formation contains only 20.88 percent of the available water. Resource Situation 2 represents 53.41 percent of the surface area, however, overlies 79.12 percent of the available water. The weighted average saturated thickness of underground formation for Resource Situation 1 is approximately 100 feet and for Resource Situation 2, is approximately 325 feet. Each resource situation is characterized by a representative farm firm and the effects of continued pumping on saturated thickness and well yield are simulated through time.

TABLE IV

AGGREGATE ACRES WITHIN EACH SATURATED THICKNESS INTERVAL AND VOLUME OF WATER IN STORAGE, 1965

	Feet of Saturated Thickness					
	≤100	101-200	201-300	301-400	401-500	>500
Acres Within Each Interval	2,645,414	2,548,554	2,869,472	1,965,454	714,603	405,841
Percent of Total Acres in Each Interval	23.73	22.86	25.73	17.63	6.41	3.64
Acre Feet of Water in Storage	19,841,954	57,342,467	108,274,800	102,486,996	48,235,704	33,481,883
Percent of Total Water in Each Interval	5.37	15.51	29.29	27.72	13.05	9.06

TABLE V

DEFINITION OF TWO BASIC RESOURCE SITUATIONS FOR THE STUDY AREA

Resource Situation	Weighted Ave. Feet of Sat. Thickness	Acres Within Each Resource Situation	Percent of Study Area Acres	Acre Feet of Water Within Each Resource Situation	Percent of Study Area Water
1	100	5,193,968	46.59	77,184,421	20.88
2	325	5,955,370	53.41	292,479,383	79.12

Over time, the incidence and distribution of benefits and costs of irrigating from the Central Ogallala Formation will not be uniform. Irrigation wells in Resource Situation 1 will not yield 1,000 gallons per minute when pumped from 100 feet of saturated thickness of Ogallala Formation, assuming average permeability.[2] Thus, irrigators in this resource situation will be faced with the necessity of expanding irrigation facilities to maintain their historic production pattern. As saturated thickness declines, well yields decline and pumping costs per acre inch rise. The irrigator eventually is forced to reduce irrigated acreage and return to dryland farming. The return to dryland farming comes not as a result of physical exhaustion of the aquifer, but as a direct result of rapidly rising irrigation costs. Irrigation operators pumping with 325 feet of saturated thickness do not experience the immediate decline in well yields and rising pumping costs of irrigators in Resource Situation 1. Properly designed irrigation wells yield 1,000 gallons per minute until the saturated thickness declines from

325 feet to approximately 125 feet. Assuming an average rate of decline of five feet per year, approximately 40 years of adequate water may be experienced by irrigators in Resource Situation 2 before well yields decline appreciably and pumping costs rise rapidly. An average rate of decline of five feet per year is excessive except for the most intensively developed irrigation areas. Consequently, the estimate of 40 years pumping prior to appreciable well yield declines may be conservative. Even though pumping cost and well yield differences between Resource Situations 1 and 2 are relatively small in the beginning, a rapid divergence occurs as the water level drops and operators in Resource Situation 1 combat declining water levels by expanding irrigation facilities. The divergence of benefits is accentuated through time.

A Representative Farm for the Study Area

The concept of a representative producer was introduced by Alfred Marshall.[3] He viewed a representative farm as, in a sense, an average firm, but a firm which has had fair success and is managed with normal ability. The representative farm firm has been the basis for much of the linear programming work in recent years. The dangers in selecting representative farm firms and in aggregating the results are well documented in the literature and will not be discussed here.[4]

One might argue that there is no truly representative farm operation for the study area. Farm operations vary in size from less than 30 acres to more than 30 sections. Farm types exhibit considerable variation as well. Many are strictly dryland operations and some are fully irrigated. Cropping patterns and farm organizations vary considerably. Some farms are strictly cash grain operations while a large number of farms incorporate livestock to utilize grazing from cash grain crops. One common characteristic of virtually all cash grain farms is that the primary crops grown are wheat, grain sorghum and corn, with wheat and grain sorghum acreages being much greater than corn acreage. In addition to cash grain farms, there are many ranches with hundreds or thousands of acres of rangeland for grazing by various livestock enterprises.

Time, human resources and computer problems act as significant constraints when defining a manageable number of representative farms or resource situations to be programmed. In the previous section, two basic resource situations are defined. Since each resource situation must be subjected to three institutional alternatives with respect to water use, one modal representative irrigated farm operation is defined for the study area. This modal operation is synthesized from individual farm surveys taken from a random sample of 78 irrigation operators in the study area during the summer of 1970.[5]

The distribution of farm sizes for the 78 operations reveals that the modal farm size is between 500 and 1,000 acres and that the farm sizes representing the greatest number of farms tend to be associated with intervals containing multiples of 640 acres--full sections. Closer examination reveals that the largest number of farms range in size from 601 to 700 acres. Since farms have a tendancy to be even sections in size, a modal representative farm of 640 acres, or one section, is defined for this study.

Organization of Production for the Representative Farm

Surveys from the 78 randomly sampled farm operations were utilized to develop an organization for the representative farm. Cropland composes 595 of the 640 acres. Of the remaining 45 acres, 40 are in dryland non-tillable pasture and five in the home, farm buildings and roads. The organization of production is presented in Table VI. A total of 315 acres of cropland are irrigated. Grain sorghum and corn compose 230 acres of irrigated summer crops and the remaining 85 irrigated acres are planted in winter wheat. There are 30 acres of dryland grain sorghum and 85 acres of dryland wheat.

Each of the above crops is divided into one or more crop blocks. For example, each dryland crop is planted in a single crop block. Irrigated wheat and corn are each planted in two crop blocks. Irrigated grain sorghum is planted in four crop blocks. The acreage in each block appears in parentheses in Table VI. Each crop block has its own soil moisture balance to maintain a daily record of stress conditions. The farm operator is assumed to irrigate each crop block by block. Thus, if pumping capacity is insufficient to irrigate an entire crop, perhaps only one block suffers severe moisture stress rather than the entire crop suffering moderate stress.

All grain sorghum is assumed harvested for grain. Two-thirds of the corn is harvested for grain and one-third for silage. The remaining 165 acres of cropland is divided among three land use categories--66 acres are idle or fallow, 84 acres are diverted and 15 acres are assumed lost due to turnrows, etc. Graze-out small grain is assumed planted on the diverted acres and may be grazed from November 1 until May 15

TABLE VI

THE ORGANIZATION, WHEAT AND FEED GRAIN ALLOTMENTS AND CONSERVING BASE FOR REPRESENTATIVE CASH GRAIN FARM, CENTRAL OGALLALA FORMATION

Cropland	(Acres)
Irrigated Grain Sorghum	170
Block G1 (80)	
Block G2 (40)	
Block G3 (30)	
Block G4 (20)	
Irrigated Wheat	85
Block W1 (65)	
Block W2 (20)	
Irrigated Corn	60
Block C1 (40)	
Block C2 (20)	
Dryland Grain Sorghum	30
Block G5 (30)	
Dryland Wheat	85
Block W3 (85)	
Idle or Fallow	66
Diverted	84
Lost to Turnrows	15
Total Cropland	595
Pastureland	
Dryland Non-Tillable Pasture	40
Total Pastureland	40
Other Land	
Home, Buildings and Roads	5
Total Other Land	5
Total Land in Farm	640
Allotments	
Wheat	185
Feed Grain	120
Conserving Base	55

without penalty. The representative farm also contains 40 acres of native pasture. The homestead, buildings and roads are assumed to occupy the remaining five acres.

The representative farm firm has a 185-acre wheat allotment, 120-acre feed grain base and 55-acre conserving base. These allotments, the conserving base and use of diverted acres for graze-out small grain are discussed in detail in a subsequent section of this chapter concerning government payments.

The analytical models employed in this study make no attempt to determine an optimum organization of production. Thus, the organization of production developed from the random sample of farms is adopted as the starting point for simulation of both resource situations and each institutional alternative.

Machinery Complement, Overhead Costs and Labor Assumptions

The machinery complement consists of two 85-horsepower tractors and accompanying equipment. A list of the implements included appears in Table XXXVI, Appendix A. Overhead costs include depreciation and maintenance on machine storage and shop; fixed machinery costs for butane storage tank, shop tools, pickup, tool bar and irrigation pipe carrier; miscellaneous expenses for telephones, bookkeeping and tax services, insurance on buildings and workers and electricity. Annual overhead costs for the 640-acre cash grain farm total $3,380.

Family labor is assumed available at the rate of 200 hours per month for a total of 2,400 hours per year. Additional labor may be hired in eight-hour increments at $2.00 per hour.

Irrigation labor requirements and cost of irrigation labor are computed on a per-acre basis. The number of irrigations required per acre, rather than the number of acre inches applied, is the important determinant of irrigation cost per acre. For a surface irrigation system with underground pipe and gated pipe, the cost of irrigation labor per acre for any period is computed as follows:[6]

$$ILC_i = NI_i \times LH \times LCH \qquad (4\text{-}1)$$

where i refers to an irrigation period, ILC is irrigation labor cost per acre, NI is the number of irrigations per acre, LH equals the labor requirement per acre in hours and LCH equals labor cost per hour ($2.00). NI is determined within the Production Subset. A labor requirement of .75 hours per acre is assumed. Thus, irrigation cost per acre equals $1.50 times the number of irrigators required.

Price Assumptions

Prices used in the models are "adjusted normalized prices" issued by the Water Resources Council.[7] The price estimates are considered "normalized" since the use of long-term, nonlinear trend lines removes many of the abnormalities caused by weather and other short-term chance events. The normalized prices are then adjusted to reduce the influence of Government price support programs. Adjusted normalized prices for commodities are further adjusted to the State level through the use of a ratio of State to U.S. normalized prices received by farmers.

U.S. adjusted normalized prices are $1.30 per bushel for wheat, $0.95 per bushel for grain sorghum and $1.05 per bushel for corn. The average ratio of State to U.S. prices for the study area is 0.995, 0.985 and 1.06 for wheat, grain sorghum and corn, respectively. The adjusted normalized prices computed for use in this study are $1.20 per bushel for wheat, $0.94 per bushel for grain sorghum and $1.11 per bushel for corn. A price of $5.50 per ton is assumed for corn silage in the field. That is, the buyer performs the harvesting operation. Small grain pasture is assumed sold at $8.00 per AUM and native pasture at $3.00 per AUM.

Government Programs

Full participation in the 1971 Wheat and Feed Grain Programs is assumed for each of the resource situations. Of the 185-acre wheat allotment, 60 acres must be set aside in addition to the 55-acre conserving base, to qualify for wheat certificate payments. The face value of the wheat certificate, based on a $1.29 per bushel wheat price and $2.90 per bushel parity price, is $1.61 per bushel. Payments are made based on the domestic allotment (80 acres), face value of the wheat certificate and the projected yield per acre for the farm.

Of the 120-acre feed grain base, 24 acres, in addition to the conserving base must be set aside to qualify for feed grain payments. Payment rates of $0.32 per bushel for corn and $0.29 per bushel for grain sorghum are assumed. Feed grain payments are received on 50 percent of the base, or 60 acres. Grain sorghum payments are received on 46 acres and corn payments on 14 acres of the feed grain base. Payments are based upon the number of acres, payments rate and projected yield for the total acre planted. Projected yields for grain sorghum, corn and wheat are based on a five-year moving average of yields for all acres of each crop planted on the representative farm. The five-year moving average reduces the influence of yearly variations in yield, but permits yields and government payments to increase as irrigation pumping capacity is expanded.

Once compliance with the set-aside and conserving base features of the 1971 Wheat and Feed Grain Programs has been established, the remaining cropland may be planted in any crop. Free substitution between wheat and feed grains is permitted. Thus, when simulating the representative farm through time, planting a total of 295 acres (the total of wheat and feed grain allotments) to either wheat, grain sorghum or corn is sufficient to maintain government program history on the farm.

Irrigation Wells and Pumping Costs

An irrigation well is a hydraulic structure which, when properly constructed, permits economic withdrawal of water from an underground aquifer.[8] The amount of water that can be withdrawn per unit of time is dependent upon the characteristics of the aquifer and well, including the permeability of the aquifer, amount of drawdown, radius of the cone of depression, coefficient of transmissibility, radius of the well and saturated thickness.[9]

Estimates of permeability, radius of the cone of depression and radius of the well permit use of equilibrium well discharge formulas to compute well yield or the required feet of saturated thickness to yield a specified well capacity in gallons per minute. The formula for well yield under water table conditions is[10]

$$Q = \frac{P(H^2 - h^2)}{1055 \log R/r} \qquad (4\text{-}2)$$

where Q equals the well yield in gallons per minute (gpm); P equals the permeability of the aquifer in gallons per day (gpd) per square foot; H equals the saturated thickness of the aquifer before pumping, in feet; h equals the depth of water in the well during pumping, measured in this study as the distance in feet from the bottom of the well (redbed level) to the pump bowls; R equals the radius of the cone of depression, in feet; and r equals the radius of the well casing, in feet.

Derivation of (4-2) for water table conditions is based on several simplifying assumptions. It is assumed that (a) the water-bearing materials are uniformly permeable within the radius of influence; (b) the aquifer is not stratified; (c) saturated thickness is constant before pumping; (d) the well is 100 percent efficient; (e) the well is drilled to the bottom of the aquifer; (f) the water table has no slope; (g) laminar flow exists within the radius of influence; and (h) the cone of depression has expanded to equilibrium size. Assumptions (a), (c), (e) and (h) approximate the situation which exists within the study area for actively pumping irrigation wells. Assumptions (b), (d), (f) and (g), while admittedly not met, are thought to cause errors of minor proportions.[11]

Estimates of permeability, radius of influence and coefficient of transmissibility exhibit considerable variability within an aquifer such as the Ogallala Formation. Individual studies of ground water in Beaver County, Oklahoma,[12] Grant and Stanton Counties, Kansas,[13] and Prowers County, Colorado,[14] reveal estimates of permeability from 70 to 2,200 gpd per sq. ft.

Aquifer tests have been conducted by the U.S. Geological Survey in the Panhandle of Oklahoma for the past several years. These tests indicate the coefficient of transmissibility ranges from 50,000 gpd per foot to 10,000 gpd per foot with 150 feet of saturated thickness. Thus, permeability in these tests ranges from 333 gpd per sq. ft. to 67 gpd per sq. ft. However, a modal value of 300 gpd per sq. ft. is recommended as the permeability most representative of conditions throughout the study area.[15] After three weeks of continuous pumping, the radius of the cone of depression ranges from 1/2 to 3/4 mile. Well diameters for the study area average about 18 inches, giving a well radius of nine inches.

Equation (4-2) serves two purposes in this study. First, it is used to compute the well capacity which can be expected initially under a given set of assumptions regarding the irrigation well and saturated thickness of the aquifer. Second, it is used to compute the feet of saturated thickness required to maintain 1,000 gpm pumping capacity.

Resource Situation 1 overlies an average saturated thickness of 100 feet. Irrigation wells are drilled to the bedrock under the Ogallala Formation. The depth to water, computed as a weighted average for all saturated thickness intervals, is 150 feet. Thus irrigation wells for Resource Situation 1 are 250 feet deep. The pump bowls are placed at the bottom of the well to insure maximum yield. To compute well yield, Equation (4-5) is used with depth of water in the well (h) equal to zero. Permeability (P) is 300 gpd per sq. ft. The radius of the cone of depression (R) is assumed to be 3,300 feet. The radius of the well casing is nine inches or .75 feet. Substituting these values in (4-2) gives (4-3) for well yield in gallons per minute.

$$Q = \frac{300(100^2 - 0^2)}{1055 \log 3300/.75} = \frac{3,000,000}{1055(3.64345)} = 780.46958 \qquad (4\text{-}3)$$

Thus, given the above assumptions, the initial well yield for wells in Resource Situation 1 is approximately 780 gpm.

Resource Situation 2 overlies 325 feet of saturated thickness. Irrigation wells are drilled to the redbed under the Ogallala Formation at a depth of 475 feet. The pump bowls are set 50 feet from the bottom of the well and the well produces 1,000 gpm. Well yield remains constant until saturated thickness has declined to some minimum level which will support this capacity. Equation (4-2) is used to compute the saturated thickness above which 1,000 gpm well capacity can be sustained. The assumptions here are the same as those for (4-3) with three exceptions. First, H, the feet of saturated thickness, is unknown and is the value for which Equation (4-4) is to be solved. Second, the well yield, Q, equals 1,000 gpm. Third, h equals 50 feet indicating that the pump bowls are 50 feet from the bottom of the well. Equation (4-4) is solved for feet of saturated thickness as follows:

$$Q = \frac{300\ (H^2 - 50^2)}{1055 \log 3300/.75} \tag{4-4}$$

$$1000 = \frac{300\ H^2 - 750{,}000}{3{,}843.83975} \tag{4-5}$$

$$300\ H^2 = 4{,}593{,}839.75 \tag{4-6}$$

$$H = 123.7 \tag{4-7}$$

Based on the computations in (4-4) through (4-7), nearly 125 feet of saturated thickness is required to sustain a pumping capacity of 1,000 gpm. For Resource Situation 2, irrigators are assumed to pump at 1,000 gpm capacity while the saturated thickness declines from 325 feet to 125 feet. Below 125 feet of saturated thickness the water table and well yield both decline with yield declining rapidly.

Representative farm firms for both Resource Situations 1 and 2 are assumed to have one irrigation well at the beginning of all simulation runs. The adequate-water farm firms in Resource Situation 2 are assumed to have an irrigation well capable of producing 1,000 gpm over the 20-year span of each simulation run. However, firms in Resource Situation 1, with 100 feet of saturated thickness, are assumed to begin each 20-year run with a single irrigation well, pump, motor and distribution system, capable of pumping 780 gpm during the initial year of the simulation run. With the pump bowls located on the redbed underlying the Ogallala Formation, each year's pumping has several effects. First, the saturated thickness of the formation is reduced. Second, the reduction in saturated thickness leads to a reduction in pump yield. Third, the reduced capacity increases the per unit cost of delivering each acre inch of water to the plants. Fourth, the reduced capacity also alters the operator's irrigation schedule by making it more difficult to achieve timely water applications.

The relationship between declining saturated thickness and reduced well capacity is expressed in Equation (4-8).[16]

$$Q_t = \left(\frac{H_t^2}{H_{t-1}}\right) Q_{t-1} \tag{4-8}$$

where Q_t represents the well capacity in the current period t; Q_{t-1} represents the well capacity in the preceding period t-1; H_t represents the remaining feet of saturated thickness in the current period t; and

H_{t-1} represents the feet of saturated thickness in the preceding period t-1.

Equation (4-8) is used to compute current pumping capacity at the beginning of each crop year within the Production Subset of the model. Experimentation with the model reveals that at least 700-gpm well capacity is required to adequately irrigate the original production organization on the representative farm. Thus, a decision rule is built into the Production Subset which allows the irrigator to drill an additional well if pumping capacity falls below 750 gpm during a crop year. The new well is assumed drilled during the non-irrigation season and pumping capacity the following year is increased by the capacity of the existing well. For example, if the yield of irrigation well 1 declines below 750 gpm during the current season to, say, 700 gpm by the end of the crop year, the producer is assumed to drill a second well and connect it to the original distribution system which increases the system capacity to 1,400 gpm for the following crop year. Yields for both wells then decline as the saturated thickness diminishes until system capacity falls below 750 gpm again. Assume that at the end of the growing season system pumping capacity is only 700 gpm. The irrigator is assumed to drill a third well, with accompanying pump, motor and distribution system, designed to deliver 350 gpm. Once again system pumping capacity is raised above 1,000 gpm. Three irrigation wells is the maximum assumed for the one-section representative farm firm.

Detailed information regarding investment, ownership and pumping costs for irrigation wells of Resource Situation 1 and 2 are presented in Appendix D. All irrigation systems utilized in the model are furrow or surface systems suited to Richfield clay loam soils.

Development of Irrigation Strategies

It is not difficult to prescribe an optimum irrigation strategy for the farm operator under static conditions. As discussed in Chapter II, static economic theory indicates the rational operator should utilize each unit of irrigation water in its highest value use so that the marginal value product of the last unit applied just equals its marginal resource cost.

The optimal strategy prescribed under static conditions is difficult to apply under the dynamic conditions faced by the irrigator in the field. Static theory implies the ability to change water applications instantaneously from one crop to another. Theoretically, a change would occur whenever water has a higher use value on a different crop. In practice, once the operator begins to irrigate, he finds it economic to add from 1.0 to 3.0 inches of water to the soil profile of a crop before changing the irrigation set to another crop or another field. Thus, even though water is the type of resource that appears to be infinitely divisible, problems of indivisibilities exist. It is argued, however, that these indivisibilities do not invalidate the economic concepts of applying water to its highest valued uses. Each irrigation operator has an idea of which crops require water during different critical periods of the growing season. In addition, he knows which of the several crops requiring water during a specific period has the highest use value for the irrigation water available. He applies water during a specific period first to the crop which has the highest use value (marginal value product) for that unit of irrigation water. Once that crop has received an irrigation application, the crop or crop block having the highest marginal value product for the next unit of irrigation water receives the next irrigation application. At a later period of the growing season, the operator may switch crop priorities in response to changes in the value of irrigation water among crops.

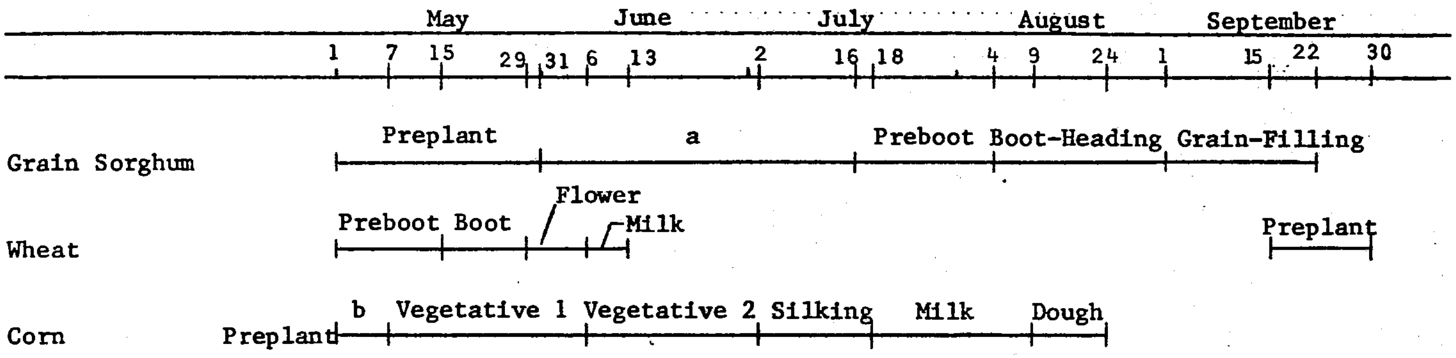
Delineation of Irrigation Periods

This line of reasoning leads to the development of a series of irrigation strategies for the growing season. Table VII presents a crop calendar covering the period May 1 through September 30. The crop calendar shows the critical stages of plant development for grain sorghum, wheat and corn. Of great importance are the periods when two or more crops are in direct competition for irrigation water. A glance at the crop calendar reveals that grain sorghum, corn and wheat all compete for water from May 1 until June 13, when wheat reaches the end of milk stage. From June 14 until September 15 both grain sorghum and corn compete for available water and from September 16 to 30, both grain sorghum and wheat compete for the available water.

The entire period covered by the crop calendar is divided into five irrigation periods. The basis for selecting the beginning point of each period is the beginning of a critical stage of plant development for a crop. Irrigation Period 1 begins on May 1, at the beginning of the growing season, and lasts until May 15, just prior to the beginning of boot stage for wheat. During this period, 14 days are assumed available for constant pumping by the irrigation system. Highest irrigation priority is for a preplant irrigation application on grain sorghum. Unless grain sorghum receives a preplant irrigation, the possibility exists of not achieving a stand. Moisture stress during the preboot stage for wheat has little effect on final yield if

TABLE VII

DELINEATION OF CRITICAL STAGES OF PLANT DEVELOPMENT, IRRIGATION PRIORITIES AND IRRIGATION STRATEGIES



Critical Periods	(1) May 1-May 15	(2) May 16-June 5	(3) June 6 - August 4	(4) August 5 - September 15	(5) Sept. 16-30
Irrigation Priorities[c]	G,W,C	W,C,G	C, G	G, C	G,W
Pumping Days	14	20	56	39	14

[a] No stage name is given to grain sorghum between preplatn irrigation applications and preboot stage. Moisture stress during this period has little effect if moisture is adequate during subsequent stages of development.

[b] Plant emergence occurs between May 1 and May 7.

[c] Irrigation priorities G, W and C represent grain sorghum, wheat and corn, respectively. All blocks of the crop listed first in a critical period are irrigated before any block of the second or third priority crops.

sufficient moisture exists during subsequent periods. Therefore, wheat is the second priority crop during Period 1. It is assured that corn receives 6.0 inches in preplant applications and is thus the lowest priority crop during Period 1.

Irrigation Period 2 begins on May 16, when wheat reaches boot stage, and lasts until June 6 when the late vegetative stage for corn begins. Irrigation water application on wheat during boot stage has a higher marginal value product than applications on grain sorghum or corn. Once wheat has received a boot-stage application, the second priority crop, corn, receives water. Then, unless soil moisture under wheat, the top priority crop, has fallen to a very low level, grain sorghum, the third priority crop, receives an irrigation application. Period 2 is assumed to have 20 days when the irrigation system can operate at full capacity.

Irrigation Period 3 begins on June 6, with initiation of the second vegetative stage of corn development, and lasts until August 5 when grain sorghum begins the boot-heading stage of development. Of the total period, 56 days are assumed available for full-time pumping. During Period 3, corn has top priority on water use. The potential yield reduction from soil moisture stress is greater for corn than for grain sorghum or wheat. The milk stage of wheat development occurs during part of Period 3, however, since wheat was the top priority crop during Period 2, it is eliminated from irrigation consideration during Period 3. Therefore, the second priority crop during Period 3 is grain sorghum. Moisture stress from June 1 to August 5 has little effect on final grain sorghum yield if sufficient water is applied during preplant, as well as during subsequent critical stages.

Irrigation Period 4 begins on August 5, with initiation of grain sorghum boot-heading stage, and concludes on September 15 when water is required to complete grain-filling applications on grain sorghum and begin preplant irrigation applications on wheat. Thirty-nine days are assumed available for full time pumping. The boot-heading stage of grain sorghum development is critical from the standpoint of soil moisture. The marginal value product of water applications on grain sorghum during this period are far greater than for corn during the dough stage of development. Grain sorghum is the top priority crop during Period 4 and corn, the only other crop competing for water, is second.

Irrigation Period 5 begins on September 16 when preplant applications for wheat must be planned. Grain sorghum remains the top priority crop during this period. The reason grain sorghum rather than wheat has top priority is that during the late August to mid-September period, operators will be irrigating grain sorghum to insure successful yields on a crop already in the ground before concentrating on preplant irrigations for wheat, which is to be planted at a later date. Fourteen days are assumed available for constant irrigation water pumping during Period 5.

The five periods encompass the irrigation season as it relates to critical stages of plant development for the major crops of the study area. In the next sections, the generalized irrigation strategies are discussed and specific strategies for each of the five periods are developed as they were programmed in the Production Subset of the model.

Irrigation Strategies by Periods

Application of irrigation water depends upon the level of soil moisture existing in the soil profile of a crop. If soil moisture in the entire profile for a crop equals or exceeds 50 percent of available soil moisture, or 12.5 inches, no irrigation water is applied. If available soil moisture falls below the 50 percent available level during a critical stage of development, significant yield reductions can occur. Thus, the model assumes that the decision to irrigate is made when the level of soil moisture falls below 12.5 inches. If sufficient water is available and actual evapotranspiration is not great, the entire crop may receive a 3.0-inch addition to the soil profile. However, if plants on the part of the field already irrigated begin to show signs of plant stress before the entire application can be completed, irrigators are assumed to reduce the application rate on the remaining acres, and return to the original portion of the crop to begin a new application. These assumptions appear reasonable based on the actions of irrigators in the area.

Varying irrigation rates on shifting numbers of acres during different stages of plant development is extremely difficult to handle from a modeling standpoint. Therefore, as indicated in Table VI, total acreage of each irrigated crop is divided into several blocks. The 170.0 acres of irrigated grain sorghum are not irrigated at one time. Instead, the 170.0 acres are divided into four blocks of 80.0 acres, 40.0 acres, 30.0 acres and 20.0 acres. Similarly, 85.0 acres of irrigated wheat are divided into two blocks--65.0 acres in the first and 20.0 in the second. Also, 60.0 acres of irrigated corn are divided into a 40.0-acre block and a 20.0-acre block. Block 1 of any crop is always irrigated first, followed by block 2, etc. If, using grain sorghum as an example, block 4 is being irrigated and block 1 begins to suffer moisture stress, the irrigation application rate is reduced on block 4 and block 1 is the next block to be irrigated. This idea is more fully developed in the following section which outlines the general irrigation strategies of the model. Then individual differences among the five periods are elaborated.

The general procedure for scheduling and executing irrigation applications is the same for every period and may be discussed in general terms. Each period has a set of crop irrigation priorities as outlined in Table VIII. The priorities determine the order in which soil moisture values are checked against the critical value (usually 50 percent available soil moisture or 12.5 inches). Assume the order of priorities is (1) grain sorghum, (2) wheat and (3) corn, as it is for Period 1. On the first day of the period, soil moisture for the first block of grain sorghum, G1, is checked against 12.5 inches of soil moisture. If soil moisture for G1 equals or exceeds 12.5 inches, no irrigation application is scheduled for G1 and soil moisture for G2 is checked against 12.5 inches, etc. If all four grain sorghum blocks have soil moisture in excess of 12.5 inches, then soil moisture for the first block of wheat (W1), the second priority crop, is checked against 12.5 inches. This process continues as long as soil moisture for each block exceeds 12.5 inches. After soil moisture for both blocks of the third priority crop, corn, have been checked against 12.5 inches, and soil moisture for all blocks is found to exceed 12.5 inches, the day is incremented to day 2 of the period and soil moisture under the first block of the first priority crop is again checked against

TABLE VIII

MOISTURE LEVELS AT WHICH IRRIGATIONS ARE SCHEDULED AND PRIORITIES ESTABLISHED BY IRRIGATION PERIODS

	Irrigation Period											
	1			2			3		4		5	
Irrigation Priority Order	GS	W	C	W	C	GS	C	GS	GS	C	GS	W
Inches of Soil Moisture at which Irrigations are Scheduled	12.50	10.98	10.98	12.50	12.50	12.50	12.50	10.98	12.50	12.50	10.98	12.50
Inches of Soil Moisture at which Priority on Water is Established	9.45	10.98	10.98	10.98	10.98	10.98	10.98	9.45	10.98	10.98	9.45	9.45

12.5 inches. In the above example, no irrigation applications would be scheduled during day 1 of Period 1.

Now consider the usual situation where an irrigation application is required. Assume that on day 1 of the period, soil moisture under G1 is less than 12.5 inches. The farm operator schedules an irrigation application for G1. Ideally, once an application has begun, he would like to add 3.0 inches of soil moisture to the G1 profile. Due to evapotranspiration and water losses from leakage and seepage, all the water pumped at the well does not find its way into the soil profile of the irrigated crop. Only about two-thirds of the water pumped from the aquifer enters the soil profile for plant use. Therefore, 4.5 inches must be drawn from the aquifer to insure a real 3.0-inch addition to the soil profile. Based on the requirement of 4.5 acre inches per acre, the irrigation water requirement is computed from (4-9):

$$WR_{ij} = 4.5\ AC_{ij} \qquad (4\text{-}9)$$

where WR_{ij} equals the water requirement, block i, crop j; and AC_{ij} equals the acres planted in block i, crop j.

Then the water requirement is compared with the pumping capacity for the period. Pumping capacity is computed based on gallons per minute delivered by the irrigation system as follows:

$$BPC_i = (GPM \times 1440.0 \times DAYS_i)/27{,}155.0 \qquad (4\text{-}10)$$

where BPC_i equals the beginning pumping capacity for period i in acre inches; GPM equals the irrigation system pumping capacity in gallons per minute; 1440.0 equals the number of minutes per day; $DAYS_i$ equals the number of days in period i; and 27,155.0 equals the gallons per acre inch.

Assuming that pumping capacity for the period equals or exceeds the water requirement for G1, the irrigation application is initiated. The number of days required to apply WR_{ij} acre inches is computed and no other crops can be irrigated until the application of G1 has been completed. The total application is divided by the number of days required to apply it, and the appropriate proportion is added to soil moisture each day. Once the application on G1 is complete, the remaining pumping capacity for the period is computed and soil moisture under the second block of the top priority crop, G2, is checked against 12.5 inches. If soil moisture exceeds 12.5 inches, soil moisture under G3 is checked, etc. If, however, G2 soil moisture is less than 12.5 inches, its water requirement is computed using (4-9) and is then compared to the remaining pumping capacity for the period. If sufficient capacity exists, the irrigation is scheduled, the number of days required computed and the appropriate amount of moisture per day added to the soil profile. No other crop may be irrigated until the application on G2 has been completed. The G2 water requirement is deducted from pumping capacity for the period, and then soil moisture for G3 is checked against 12.5 inches. This procedure continues unaltered until one of four following events occurs. (1) The water requirement for any block of a crop exceeds the remaining pumping capacity for the period. (2) The number of days remaining in the period is insufficient to allow a full irrigation. (3) A block of higher priority reaches a low soil moisture level while a low priority crop is being irrigated.

(4) The period comes to an end. These events will be considered in turn.

(1) If the water requirement for a block of a crop exceeds the remaining pumping capacity for the period, based on a 4.5-inch application per acre, the number of acre inches which can be applied per acre is computed. If that number equals or exceeds 1.5 acre inches per acre, the irrigation is scheduled and the application made. If at least 1.5 acre inches per acre cannot be applied, no irrigation application is made to the block in question.

(2) If the number of days remaining in the period is insufficient to allow a full irrigation, water is applied at the computed rate per day until the period ends.

(3) If a block of higher priority reaches a low soil moisture level while a lower priority crop or block is being scheduled for irrigation, the irrigation application on that block is reduced to 1.5 acre inches per acre. Then the higher priority crop moisture is checked, and a full 4.5-inch irrigation application is made, assuming time and pumping capacity exist to complete the application.

(4) When the period comes to an end, no further irrigations are scheduled based on crop priorities for the current period. Soil moisture under block 1 of the highest priority crop in the next period is checked against 12.5 inches of soil moisture.

The same procedure continues through all five of the irrigation periods. At the end of the crop year, crop yields on each block of each crop are computed based on soil moisture and atmospheric stress suffered during the critical stages of development and accumulated throughout the growing season.

Crop priorities and soil moisture levels at which irrigations are scheduled vary from period to period during the growing season. These differences are also highlighted in Table VIII. During Period 1, irrigation applications on the top priority crop, grain sorghum are scheduled when soil moisture falls below 50 percent available or 12.5 inches. Once a preplant application is made on all blocks of grain sorghum, wheat and corn would have priority unless available moisture under grain sorghum falls to ten percent or 9.45 inches. That is, once a preplant irrigation application has been made, a stand is insured and moisture stress will do little damage to grain sorghum, unless it is quite severe, until Period 3 is reached. Achieving a stand on grain sorghum is so important that wheat and corn irrigations are scheduled only if available soil moisture falls to the 30 percent level or 10.98 inches in the total profile.

During Periods 2 and 4, all crop irrigations are scheduled when available soil moisture falls below the 50 percent level of 12.5 inches. Once an initial irrigation has been applied, a higher priority block or crop will preempt lower priority blocks or crops only if available soil moisture falls below 30 percent or 10.98 inches.

During Period 3 corn is the top priority crop as it progresses through most of the late vegetative, silking and dough stages. Corn irrigations are scheduled when available soil moisture falls below 50 percent or 12.5 inches. Grain sorghum yields are not reduced substantially due to stress during this period if moisture is adequate during subsequent periods. Thus, grain sorghum irrigations are scheduled only if available soil moisture falls below 30 percent of 10.98 inches. The first block of corn may preempt water use from lower priority blocks and crops if available soil moisture falls below 30 percent or 10.98 inches. For grain sorghum, the first blocks may preempt water use from lower priority blocks if available soil moisture falls below ten percent or 9.45 inches.

Grain sorghum irrigations during Period 5 are scheduled whenever available soil moisture falls below 30 percent or 10.98 inches. Higher priority blocks may preempt water use from lower priority blocks when available soil moisture falls to 9.45 inches. For the second priority crop, wheat, preplant irrigation applications are scheduled if soil moisture falls below 50 percent or 12.5 inches. Block 1 preempts water use from block 2 only if available soil moisture under block 1 falls below ten percent of 9.45 inches.

The above irrigation strategies are not intended to imply that the irrigation operator is capable of distinguishing between levels of available soil moisture to two decimal places. The decision rules are merely an attempt to simulate the decisions operators make based on feel of the soil and appearance of plants. Since these actions must be computerized, the rules are quite specific in nature.

The next sections of this chapter outline procedures utilized in simulating institutional alternatives to water-use regulation. The first alternative is no regulation or restraint on water use. The second alternative is an absolute limit on the number of acre inches pumped per year. The third alternative allows irrigators to pump more than the quantity limit if they pay a graduated tax per unit of water pumped above the limit. These are considered in turn.

Simulation of Representative Farm Firms Without Institutional Restraints on Water Use

The initial institutional alternative considered is to allow unrestricted pumping from the Central Basin of the Ogallala Formation by firms in both Resource Situations 1 and 2. This alternative coincides with a continuation of current policy in accordance with present interpretations of ground water law in the study area.

For the unrestricted water use alternative, the decision rules followed by irrigators are based upon the level of available soil moisture during critical stages of plant development as outlined in previous sections. Irrigators in Resource Situation 1 have insufficient saturated thickness to irrigate the initial organization over the 20-year simulated time period. Over time, well yields decline significantly. When capacity of the irrigation system falls below 750 gpm in a given year, the irrigator is assumed to drill a new well at the end of that year. When the operator has three irrigation wells, his response to declining well yields and rising pumping costs is to reduce the number of irrigated acres. The decision rule to reduce irrigated acres is based on a comparison of net returns per acre above variable costs and opportunity cost net returns per acre for the best dryland alternative--dryland wheat. Opportunity cost net returns on dryland wheat, considered as returns to land, overhead, risk and management, are $5.24 per acre.[17] The decision to convert acreage to dryland wheat is made irrigated block by irrigated block. Every year after the third well has been added, the operator compares the net return per acre above variable costs in each block to the $5.24 opportunity cost for dryland wheat. If the opportunity cost dryland net return is greater, the block is planted to dryland wheat the following year. The operator considers net returns above variable costs on irrigated blocks as a decision criteria for two reasons. First, the machinery complement and irrigation equipment are not replaced each year. Ability to consider fixed machinery costs per acre for different irrigation levels implies a decision model of greater sophistication than is possible for the operator. Second, the irrigation system, consisting of three wells, three pumps, three motors and two distribution systems, is viewed as a fixed asset in the production process.[18] That is, the marginal value product of the irrigation equipment is greater than its salvage value, however, less than its acquisition cost. Thus, it is an economic decision to continue to irrigate crop blocks as long as net returns above variable costs exceed opportunity cost dryland net returns.

When pumping according to soil moisture levels, little attempt is made to "economize" water use. In fact, decision rules based strictly on soil moisture or a fixed length irrigation schedule may lead irrigators to maximize output per acre for each crop block rather than attempting to maximize profits. If this is true, the irrigator can increase net returns per acre by reducing water application to the point where the marginal value product of the last unit of water applied just equals the additional cost of applying that unit of water.

An additional aspect of unrestricted pumping is that irrigation wells in Resource Situation 1 decline rapidly and pumping costs rise significantly in the early years of a multiperiod run. Whether the operator is better off to deplete the water supply available to him in the early years or more slowly over a longer time horizon depends upon his time preference for income. Perhaps a rational course of action can be recommended by comparing the present values of income streams produced under alternative courses of action.

Simulation of Representative Farm Firms With a Limit on the Quantity of Irrigation Water an Operator May Pump During the Growing Season

The second institutional alternative restricts the quantity of irrigation water the individual operator is allowed to pump during the crop year. The authority of Water Resources Boards to restrict the quantity of water pumped is documented in Chapter I. It is assumed that each irrigator is restricted to pumping 1.5 acre feet of irrigation water per acre of water rights per crop year. For the representative farm firms of this study, water rights to irrigate 315 acres are assumed. At 1.5 acre feet per acre of water right, the irrigator is limited to pumping 472.5 acre feet per year or 5,670 acre inches per year.

The controlling agency is assumed to say nothing about the allocation or distribution of this water among periods of the crop year. The irrigator is free to pump his system at capacity from the beginning of the irrigation season until he has arrived at the quantity limit, or limit pumping in the early periods due to uncertainty about future moisture conditions. The rational irrigator is assumed to hedge current pumping due to uncertainty about future water needs during later stages of plant development. He is assumed to pump according to soil moisture depletion levels and crop priorities established for the unconstrained simulation runs discussed previously, however, establishes maximum amounts of water to be added to each crop during each stage of plant development. The maximum levels by crops and irrigation periods are reflected in Table IX.

TABLE IX

MAXIMUM INCHES OF WATER APPLIED PER ACRE BY CROPS AND PERIODS OF THE GROWING SEASON IN RESPONSE TO A QUANTITY LIMITATION

Period	Grain Sorghum	Wheat	Corn
April	0.0	0.0	6.0
Period 1	4.5	4.5	0.0
Period 2	4.5	9.0	4.5
Period 3	9.0	0.0	18.0
Period 4	13.5	0.0	4.5
Period 5	0.0	9.0	0.0
Total	31.5	22.5	33.0

These figures indicate, for example, that no more than 4.5 acre inches of irrigation water will be applied to each acre of grain sorghum during Irrigation Period 1. With an irrigation efficiency of two-thirds, a 3.0 inch real addition to the soil profile is implied by a 4.5 acre inch per acre water application. These self-imposed irrigation guidelines provide enough flexibility to allow sufficient water to be applied during very dry years, yet induce the irrigator to conserve water for subsequent periods to meet unexpected demands. During a year of high and timely rainfall, the irrigator will likely not pump 5,670 acre inches of water. However, during a year characterized by either untimely or low rainfall, the irrigator may easily reach the quantity limit during Irrigation Period 4 and be unable to complete grain sorghum irrigations or to prewater wheat during September.

No change in production organization is assumed. It might be argued that the rational irrigator would respond to a quantity limitation by reducing irrigated acres to the maximum number he can fully irrigate. While this course of action makes sense from an economic standpoint, it is not being followed by the operators experiencing declining well yields and water supplies. The tendency is to protect the historic production organization by applying less water per acre while maintaining the same number of acres.[19] Once it becomes unprofitable to irrigate a crop block, however, producers naturally respond by reducing irrigated acreage. The net returns per acre above total variable costs for each crop block is compared with dryland wheat opportunity cost net returns per acre. Crop blocks whose net returns per acre fail to exceed opportunity cost net returns per acre are converted to dryland wheat the following year in a multiperiod run.

Simulation of Representative Farm Firms With a Graduated Tax on Each Acre Inch of Water Pumped Above the Quantity Limitation

The third institutional alternative considered is the imposition of a graduated tax on each unit of irrigation water pumped above the quantity limitation of 1.5 acre feet per acre of water rights. It is assumed that each irrigator is restricted to pumping 1.5 acre feet per acre of water rights, or 5,670 acre inches of water per year. However, the irrigator is permitted to pump in excess of 5,670 acre inches per year if he is willing to pay a tax on each acre inch of water pumped above the quantity limitation.

It has been argued that it would not be unreasonable to use a water-rate system in which the charge per unit increases as the quantity of water increases.[20] Such a system provides an economic incentive for the irrigator to conserve water use. This economic incentive is translated into a change in decision rules by the individual irrigator. No change in decision rules is assumed until the quantity limitation has been reached. That is, decision rules for simulation of the quantity limitation, specified in the previous section, are assumed followed until the quantity limitation is reached. Thereafter, the irrigator is assumed to decide whether or not to irrigate based upon the potential loss in yield which will occur if the irrigation is not applied.

The critical decisions involve whether or not to continue irrigating grain sorghum during Irrigation Period 4 and whether or not to apply a preplant irrigation on wheat during Irrigation Period 5. The preplant irrigation on wheat is quite often of critical importance if a good stand is to be achieved. In the Production Subset of the model, failure to preplant irrigated wheat is assumed to reduce the potential yield by 15 bushels. Fifteen bushels of wheat at $1.29 per bushel returns gross revenue of $19.35. The variable cost of the additional irrigation is approximately $8.70.[21] The value of the marginal product resulting from an additional irrigation on wheat clearly exceeds the marginal resource cost. Thus, the irrigator is assumed to apply a preplant irrigation on wheat during Irrigation Period 5 every year.

The tax rate of $0.50 per acre inch is based upon tax rates which have been utilized in irrigation districts in California. At $0.50 per acre inch, the tax rate is $6.00 per acre foot. The magnitude of the graduated tax may seem excessive, however, it should be emphasized that the tax is applied to the additional or marginal unit of irrigation water. The irrigator would not find it economical to pay a $0.50 per acre inch tax on every unit pumped. However, the marginal value product of irrigation water during a critical stage of plant development, given inadequate soil moisture conditions, is quite high.

The decision whether or not to continue to irrigate grain sorghum during Irrigation Period 4 is more complex. Two critical stages of grain sorghum development overlap in Irrigation Period 4. From day 1 through day 25 of the period, grain sorghum is in the boot-heading stage of development. During this stage, the potential yield reduction per day due to soil moisture stress alone is 2.04 bushels per day. For the remaining 14 days of Irrigation Period 4, grain sorghum is in the grain-filling stage and potential yield reduction is 1.27 bushels per day.

The decision to irrigate is a function of soil moisture and days of potential yield reduction remaining in Irrigation Period 4. If soil moisture is low enough that the potential yield reduction is equal to or greater than ten bushels, the decision is to irrigate.[22] The decision rule is depicted in Figure 6. Inches of soil moisture are plotted on the vertical axis and days remaining for yield reductions are plotted on the horizontal axis. The region under the curve reflects a decision to irrigate while the region above the curve indicates a decision not to irrigate. If less than eight days remain in the period,

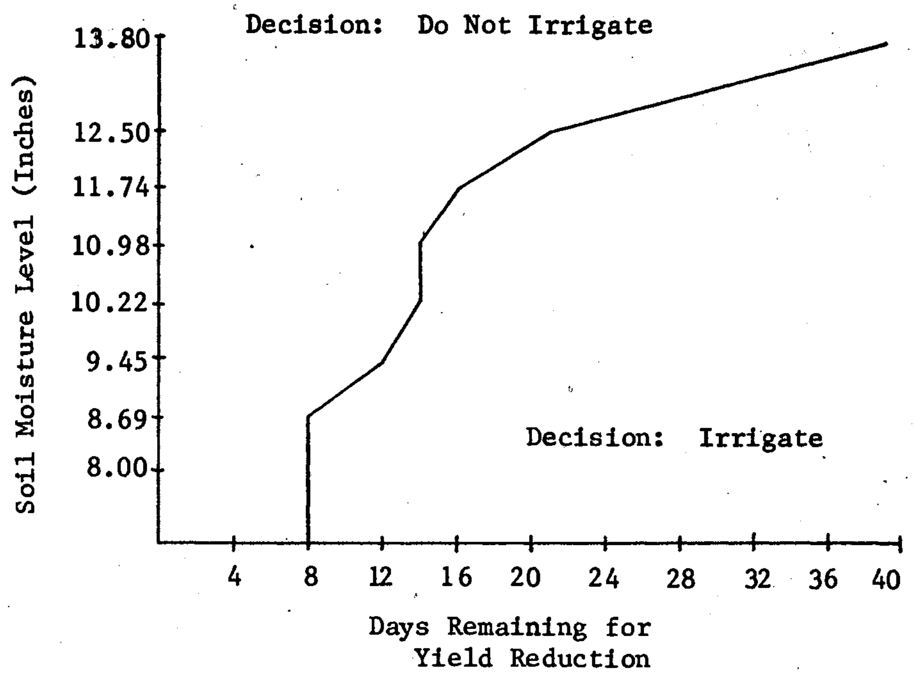


Figure 6. Decision Rule for Irrigating Grain Sorghum During Irrigation Period 4

the decision is not to irrigate. The basis of this decision is that with seven days remaining, the maximum potential yield reduction is 8.89 bushels (7 days x 1.27 bushels per day). With eight days remaining, the maximum yield reduction is 10.16 bushels and an additional irrigation will be scheduled. This discontinuity occurs when grain sorghum moves to the grain-filling stage from the boot-heading stage. The set of decision rules, in equation form, is as follows:

$$\text{If } DR \leq 8\text{, do not irrigate;} \tag{4-11}$$

$$\text{If } 8 \leq DR \leq 14\text{, then}$$

$$PYR = 1.27(SMD_i)DR; \tag{4-12}$$

$$\text{If } DR \geq 14\text{, then}$$

$$PYR = 1.27(SMD_i)14 + 2.04(SMD_i)(DR - 14); \tag{4-13}$$

$$\text{If } PYR \geq 10.0\text{, irrigate;} \tag{4-14}$$

where DR equals the days remaining in Irrigation Period 4; PYR equals the potential yield reduction, in bushels; and $SMD_i = (\frac{3.18 - SMT_i}{5.11})$ where SMT_i is soil moisture in the total profile, day i.

In making the decision whether or not to irrigate, the operator simply projects current moisture conditions to the end of the period and decides whether yield reductions will equal or exceed ten bushels per acre. As long as at least eight days remain in the period a reduction of ten bushels per acre is possible. Whenever the potential yield reduction equals ten bushels, an additional irrigation is scheduled. All wells are metered and the irrigator pays a tax of $0.50 per acre.

inch on each acre inch in excess of the 5,670 acre inches pumped during the crop year.

FOOTNOTES

[1] The volume of water in storage which may theoretically be pumped is computed using the formula

$$V_i = A_i \times M_i \times CS$$

where V_i equals acre feet of water which may be withdrawn from storage, saturated thickness interval i; A_i equals acres of surface area overlying the i^{th} saturated thickness interval; M_i equals midpoint of the i^{th} saturated thickness interval; and CS equals coefficient of storage. A coefficient of storage in common usage throughout the study of 0.15 is documented by Solomon Bekure, "An Economic Analysis of the Intertemporal Allocation of Ground Water in the Central Ogallala Formation," (unpub. Ph.D. dissertation, Oklahoma State University, 1971), p. 50.

[2] Permeability of an aquifer is the number of gallons of water which will flow through a foot-square section of the aquifer in one day, measured in gallons per day per square foot (gpd per sq. ft.).

[3] Alfred Marshall, Principles of Economics, 8th Edition, Macmillian and Company (London, 1966), pp. 264-265.

[4] Guidelines for defining typical or representative resource situations are given by James S. Plaxico, "Aggregation of Supply Concepts and Firm Supply Functions," Farm Size and Output Research, Southern Cooperative Series Bulletin 56 (June, 1958), pp. 76-91; James F. Thompson, "Defining Typical Resource Situations," Farm Size and Output Research, Southern Cooperative Series Bulletin 56 (June, 1958), pp. 32-42; Walter D. Fisher and Paul L. Kelley, Selecting Representative Firms in Linear Programming, Technical Bulletin 159, Kansas Agricultural Experiment Station (Manhattan, October, 1968); and Seamus J. Sheehy and R. H. McAlexander, "Selection of Representative Benchwork Farms for Supply Estimation," Journal of Farm Economics, Vol. 47, No. 3 (August, 1965), pp. 631-695. Problems encountered in aggregating representative farm firms and aggregation bias are discussed by Richard H. Day, "On Aggregating Linear Programming Models of Production," Journal of Farm Economics, Vol. 45, No. 4 (November, 1963), pp. 797-813; Lee M. Day, "Use of Representative Farms in Studies of Interregional Competition and Production Response," Journal of Farm Economics, Vol. 45, No. 5 (December, 1963), pp. 1438-1445; George E. Frick and Richard A. Andrews, "Aggregation Bias and Four Methods of Summing Farm Supply Functions," Journal of Farm Economics, Vol. 47, No. 3 (August, 1965), pp. 696-700; Randolph Barker and Bernard F. Stanton, "Estimation and Aggregation of Firm Supply Functions," Journal of Farm Economics, Vol. 47, No. 3 (August, 1965), pp. 701-712; and Jerry A. Sharples, "The Representative

Farm Approach to Estimation of Supply Response," American Journal of Agricultural Economics, Vol. 51, No. 2 (May, 1969), pp. 353-361.

[5] The random sample of 78 irrigated operators was a portion of a more extensive survey taken by Wyatte L. Harmon and Roy E. Hatch, Agricultural Economists, Farm Production Economics Division, Economic Research Service, U.S. Department of Agriculture, in connection with a study being undertaken by USDA in essentially the same study area.

[6] Guidelines for Application of Center-Pivot Sprinkler Irrigation Systems in Western Oklahoma, USDA Inter-Agency Ad Hoc Committee Report, Oklahoma State University Extension (Stillwater, 1970), p. 14.

[7] Interim Price Standards for Planning and Evaluating Water and Land Resources, Water Resources Council, Washington, D.C. (April, 1966).

[8] This section draws heavily upon the well hydraulics material presented in Ground Water and Wells, Edward E. Johnson, Inc. (St. Paul, 1966), pp. 99-108.

[9] As a well is pumped, the water level adjacent to the well is lowered, or drawdown occurs. Drawdown is greatest at the well and diminishes in a curvilinear manner as distance from the well increases. At some distance from the well, no drawdown occurs. The diminishing curvilinear relationship between drawdown at the well and drawdown some distance from the well forms a cone of depression. The size, shape and dimensions of each cone differ depending upon the well, pumping length and rate, and aquifer characteristics. The radius of influence is defined as the distance from the center of the well to the extreme edge of the cone of depression. The coefficient of transmissibility is the rate at which water will flow through a one-foot wide vertical strip of the aquifer, measured in gallons per day per foot (gpd per foot). The height of the vertical strip equals the height of the saturated thickness of the aquifer. The permeability of an aquifer is the number of gallons of water which will flow through a foot-square section of the aquifer in one day. Permeability is measured in gallons per day per square foot (gpd per sq. ft.).

[10] Ground Water and Wells, p. 104.

[11] Ibid., pp. 104-105.

[12] I. Wendell Marine and Stuart L. Schoff, Ground Water Beaver County, Oklahoma Geological Survey, Bulletin 97 (Norman, 1962). p. 52. Their findings indicate that permeability varies from 70 to 1,200 gpd per sq. ft. Transmissibility varies from about 5,000 to 35,000 gpd per foot, averaging about 20,000 gpd per foot.

[13] Stuart W. Fader, et. al., Geohydrology of Grant and Stanton Counties, Kansas, State Geological Survey of Kansas, Bulletin 168 (Lawrence, 1964), pp. 33-35. Aquifer tests reveal that permeability ranges from 1,250 to 2,200 gpd per sq. ft. for the Pliocene and Pleistocene deposits of the area. Coefficients of transmissibility for the Ogallala Formation range from 29,600 to 59,000 gpd per ft.

[14] Paul T. Voegeli and Lloyd A. Hershey, Geology and Ground Water Resources of Prowers County, Colorado, Geological Survey Water Supply Paper 1772 (Washington, 1965), pp. 19-21. Their tests indicate that the average coefficient of transmissibility is 20,000 gpd per ft. and the average field coefficient of permeability of the entire aquifer is 300 gpd per ft.

[15] Results of the Oklahoma aquifer tests were obtained in discussions with James Irwin, District Engineer, and George Huffman, Engineer, U.S. Geological Survey, Oklahoma City, Oklahoma, June 16, 1971.

[16] Equation (4-8) was developed in the Southern High Plains of Texas for irrigation wells pumping from the Ogallala Formation. The relation was obtained by correspondence with Mr. Frank A. Rayner, Manager of the High Plains Underground Water Conservation District, Lubbock, Texas, and Mr. Frank Hughes, ERS, USDA, Texas A & M University, College Station, Texas.

[17] This figure is based upon unpublished dryland wheat budgets for the study area.

[18] For a discussion of fixed asset theory see Clark Edwards, "Resource Fixity and Farm Organization," Journal of Farm Economics, Vol. 41, No. 4 (1959), pp. 747-759.

[19] This tendency was confirmed in discussions with James V. Howell, Irrigation Specialist, and Larry R. Peters, Area Farm Management Agent, Guymon, Oklahoma, based upon their observations of irrigators in the Central Ogallala Formation. The same tendency was confirmed by Wyatte L. Harmon, Agricultural Economist, FPED, ERS, USDA, based upon his experience with and observations of irrigation operators in the Southern High Plains of Texas.

[20] Water and Choice in the Colorado Basin, An Example of Alternatives in Water Management, Committee on Water of the National Research Council, Publication 1689, National Academy of Sciences (Washington, 1968), p. 75.

[21] Variable costs of \$8.70 include variable pumping costs of \$1.00 per acre inch for a 4.5-inch application, addition labor costs of \$0.75, added harvesting and hauling costs of \$1.20 and water taxes of \$2.25.

[22] Gross revenues from nine and ten bushels of grain sorghum at \$0.94 per bushel are \$8.46 and \$9.40, respectively. The cost of the additional irrigation, assuming variable pumping cost per acre inch is \$1.00, additional labor cost is \$0.75, tax payments are \$2.25 and added harvesting and hauling costs are either \$0.99 or \$1.10, total \$8.49 and \$8.60 for nine and ten bushels potential yield reduction, respectively. The added costs exceed added revenues for a nine bushel potential yield reduction, however, added revenues exceed added costs and an additional irrigation is justified if potential yield reduction is equal to or greater than ten bushels.

CHAPTER V

RESULTS OF SIMULATING ALTERNATIVE METHODS OF WATER-USE REGULATION

This chapter presents part of the significant results of the study. Additional results are presented in Chapter VI. Initial sections of this chapter review the assumptions of Resource Situation 1 and summarize the effects on the representative farm firm, as well as on the water supply, of unrestricted water-use, a quantity limitation on water use and a graduated tax on water use above the quantity limitation. Subsequent sections concentrate on Resource Situation 2, analyzing the effects on the representative farm firm and the water supply of the three alternative water-use regulatory methods.

Effects of Unrestricted Water Use on Resource Situation 1

Resource Situation 1 represents the poor water situation for the study area. Average saturated thickness of the underground aquifer is 100 feet. This amount of saturated thickness will support a well yield of approximately 780 gpm. Irrigation farmers are assumed to begin the 20-year simulation run with one irrigation well, pump, engine and distribution system, sufficient to irrigate 315 acres of cropland, of which 85 acres are planted to winter wheat and the remaining 230 acres are planted to grain sorghum, corn for grain and corn silage. Once the capacity of the irrigation system falls below 750 gpm, an additional well is drilled to increment system pumping capacity and maintain the organization of production. After three irrigation wells have been drilled, the irrigator is assumed to adjust the organization of production by reducing irrigated acres rather than attempting to maintain sufficient pumping capacity to fully irrigate the original organization of production.

The acreages of irrigated and dryland crops within the production organization are divided into crop blocks. The model computes the daily soil moisture balance for the average acre in each crop block. As pumping capacity declines and smaller blocks of an irrigated crop do not receive sufficient water or achieve satisfactory yields, these blocks are converted to dryland wheat production. The decision rule upon which conversion is based is an economic rule. When net returns above total variable costs per acre fall below net returns for dryland wheat, a crop block is converted to dryland wheat production.

Irrigation strategies for the unrestricted water-use analysis are based upon critical soil moisture levels and crop priorities by stage of plant development throughout the crop year, as detailed in Chapter V. These basic strategies, given the assumptions of the model are simulated over a 20-year time horizon and each simulation run is replicated 15 times. The results of the simulation analysis of three water-use regulatory alternatives are presented in subsequent sections.

Effect on Well Development and Acre Inches Pumped

The effect of unrestricted water use on the quantity of water pumped through time is shown in Table X. The table contains a summary of total acre inches pumped during each crop year for 15 replications

TABLE X

SUMMARY OF TOTAL ACRE INCHES PUMPED FOR RESOURCE SITUATION 1 WITH NO RESTRICTIONS ON WATER USE

Replication	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	5984	4225	1923	6551	8207	7607	6470	5989	6697	6009	6086	5303	4711	3799	3276	2471	2385	2331	2191	0
2	6266	5528	7692	8070	5952	6785	6737	6036	5429	6653	5524	5534	4812	4272	3642	2372	2420	2261	0	0
3	6266	5646	8208	7659	7335	6756	6459	5897	6807	6258	5632	4549	4694	4062	2708	1760	2439	903	2141	2174
4	6266	5773	7932	6921	7821	7404	6541	5856	5811	6739	5952	5236	3261	4166	3194	3495	3156	2739	1996	2015
5	2852	6039	5579	7567	4454	7335	6496	6704	5991	5117	6337	6195	4632	4949	3512	3312	2485	2297	1903	2193
6	5884	5796	7919	8451	7897	7286	6461	5767	6340	6118	5881	4692	3940	3985	3212	3265	2180	2220	2130	0
7	6254	5803	7553	6956	6532	6116	6211	5162	4981	5893	4646	6089	4717	4594	3037	3827	3419	2405	2157	1821
8	6244	5758	7854	7472	7898	6484	6286	5486	5047	4802	5270	5779	5053	4284	3887	2241	2459	2388	2235	1973
9	6191	5808	7931	5482	8229	5383	6330	5857	5608	6436	6480	5647	4749	3705	3736	2686	2450	2136	1869	2153
10	6275	5083	6188	7904	5821	6450	6661	6339	5609	6963	6236	5326	5012	2858	2698	2613	2663	2439	2361	2202
11	6064	5800	6229	4704	7470	6106	6228	6205	5861	6923	6101	5786	5161	3938	4143	3496	2321	2381	2190	0
12	4870	4672	6959	6345	7559	6083	7092	6393	5706	7492	6322	5532	4799	4212	2906	2910	2324	2351	2242	1608
13	6226	5728	8305	8285	5850	6840	6666	5249	7568	4490	5978	5468	4813	4158	3667	3350	1819	2113	1903	1886
14	6699	5779	7368	9265	7443	6775	6442	5757	7357	6568	5573	4136	3465	2938	2561	2498	2315	2274	1875	1843
15	4738	5828	6022	9142	7441	5369	5605	6325	5678	6802	6506	5148	4782	4503	3027	2582	2453	1890	2258	0
Mean	5805	5550	6911	7385	7061	6585	6446	5935	6006	6218	5898	5361	4610	4028	3280	2859	2486	2208	1963	1324
Std. Dev.	972	500	1632	1265	1094	686	323	426	754	846	503	561	539	555	472	575	377	406	565	982
Maximum	6699	6039	8305	9265	8229	7607	7092	6704	7568	7492	6506	6195	5161	4949	4143	3827	3419	2739	2361	2202
Minimum	2852	4225	1923	4704	4454	5369	5605	5167	4981	4490	4646	4136	3261	2858	2561	1760	1819	903	0	0
Range	3847	1815	6382	4561	3776	2238	1486	1542	2587	3002	1861	2059	1901	2091	1582	2066	1600	1837	2361	2202

of a 20-year simulation of the farm firm representing Resource Situation 1. The mean, standard deviation, maximum, minimum and range have been computed using the 15 replications for each year of the 20-year planning horizon.

The mean values in Table X highlight several interesting phenomenon. The second irrigation well is usually added at the end of the second or third crop year, and its effect on pumping capacity for the irrigation system is apparent. Average acre inches pumped increases from 5,550 in year 2 to 6,911 and 7,385 acre inches, respectively, during years 3 and 4. The third irrigation well is usually drilled at the end of either crop year 8 or 9. Increased pumping capacity is reflected through an increase in pumping from 5,935 acre inches in year 8 to 6,006 and 6,218 acre inches during crop years 9 and 10, respectively. After the third irrigation well is drilled, declines in acre inches pumped result from (1) declining well yields; (2) increasing pumping costs; and (3) the resulting reduction in irrigated acreage. Mean values decline steadily from 6,218 acre inches in year 10 to 1,324 acre inches in year 20.

The maximum number of acre inches pumped during any replication of any year is 9,265 during the 14th replication of crop year 4. A combination of excess pumping capacity after the addition of well 2 and extremely dry weather conditions during the year are primary causal factors. The minimum number of acre inches pumped during any replication of crop year 4 is 4,704, which occurs in replication 11.

During replications 1, 2, 6, 11 and 15, all irrigated crops are converted to dryland wheat by crop year 20 and zero pumping occurs. In replication 2, conversion to total dryland farming occurs by crop year

19. Thus one-third of the replications simulated result in a return to dryland farming by the 20th year. Variable pumping costs per acre inch during the final year in which irrigated crops are raised are $1.68, $1.42, $1.68, $1.42 and $1.42 for replications 1, 2, 6, 11 and 15, respectively.

Saturated thickness of the underground aquifer at the end of the 20-year simulation runs ranges from 33.42 to 37.53 feet and averages 35.84 feet. Transforming these figures into feet of decline in saturated thickness results in declines of from 62.74 to 66.58 feet, with an average decline of 64.16 feet over the 20-year period. This represents an average decline of 3.21 feet per year. The original 100 feet of saturated thickness underlying Resource Situation 1 contained approximately 9,600 acre feet of water which could be withdrawn for irrigation purposes.[1] The decline in saturated thickness to 35.84 acre feet leaves approximately 3,440 acre feet of water that is uneconomical to pump for irrigation purposes. Thus, of the original volume, only 35.84 percent remains at the end of the 20-year unrestricted simulation of Resource Situation 1.

Effects on Net Farm Income

Effects of water-use regulation on net farm income are of great importance to individual farm operators and to the economy of the Central Ogallala Formation. Net farm income is computed in the General Agricultural Firm Simulator as the difference between gross farm income and gross farm expense. As used in the context of the simulation model, it represents net returns to land, labor, management and risk. Net farm income is computed each year of a multiperiod simulation run. The simulation runs are sequential and firm financial changes are updated each year to reflect the current status of the firm.

Table XI contains a summary of net farm income resulting from the 15 replications of a 20-year simulation of Resource Situation 1 without water-use regulation. The mean, standard deviation, maximum, minimum and range have been computed for each year of the planning horizon.

Net farm income for farms in Resource Situation 1 increases rapidly during the initial years of irrigation system expansion. From year 1 to year 5, mean net farm income increases from \$9,019 to \$15,045, the maximum mean value for any year of the run. The rise in net farm income over a five-year period is primarily due to increased pumping capacity which increases irrigated crop yields. Increased yields result in greater government payments, which are computed on the basis of a five-year moving average of yields for wheat and feed grains. After year 5, mean net farm income declines gradually to \$10,870 in year 9, rises to \$11,324 in year 10 with additional irrigation expansion, and then follows an erratic, but declining trend through year 18. Mean net farm incomes the final two years are very low reflecting several adverse conditions. (1) Declining well yields and rising pumping costs contribute to declining profitability of the irrigated operation. (2) Conversion of an increasing number of acres to dryland production reduces the mean net farm income and increases variability of income. Effects of adverse weather conditions contribute to years of very low and even negative net farm income.

During the initial five years, mean net farm income rises while variability of income, as measured by the standard deviation, declines. The income stability contributed by government payments is obvious

TABLE XI

SUMMARY OF NET FARM INCOME FOR RESOURCE SITUATION 1 WITH NO RESTRICTIONS ON WATER USE

Replication	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	9236	22925	11262	16900	11716	13013	13842	12298	15790	14061	8923	6220	2611	11831	9828	10241	15699	8300	-4580	5794
2	5574	10390	8850	7947	16383	9456	9304	7448	6620	4917	5294	2890	3295	821	2466	7434	2521	-8407	-4915	-611
3	7796	7912	10793	11015	14230	12054	12569	10068	10055	12259	7914	12052	7163	4986	4716	4040	3251	7446	-2906	-2906
4	3397	5327	11009	15681	12934	4581	12221	4568	9453	3851	4312	3933	22581	14697	18372	10715	5067	5465	5782	1340
5	15567	3689	11846	11344	23876	18801	18868	10844	14269	19997	12507	16314	22603	5271	11388	9006	12400	8594	11113	6980
6	9266	9603	12549	8608	11545	7476	3261	7344	7986	7813	902	1007	4603	705	5224	-3668	3734	-3086	-9883	-8109
7	4340	6993	12598	15896	14554	9470	14569	19976	21111	20037	19987	9363	13132	14663	15964	11547	6567	446	9533	9127
8	4317	12105	11477	16139	9571	15018	10633	12524	16697	18871	16172	5444	5421	11245	3858	9470	9711	6813	5977	11924
9	11730	7039	13751	20930	11911	19779	17422	17674	6983	10110	5639	4173	7053	13255	8526	3487	2505	9836	6813	298
10	9640	10469	20868	14219	19813	20753	14254	13203	13789	7668	8595	11632	6622	1618	8366	8008	5210	6402	-867	2725
11	11674	2714	14890	17225	15660	22729	17473	18387	14669	12632	16007	7261	7500	11126	7908	9419	14160	-648	-4122	-4857
12	15485	20265	17611	21891	15553	16062	10120	7262	3300	5962	5183	3881	6666	1641	4876	3116	12220	10238	4180	8424
13	4655	10719	11516	9516	18687	13664	13108	12763	5817	16390	14423	8194	7484	9633	5261	1212	13192	5631	7481	4474
14	7899	8638	14239	8396	10501	11683	12650	8008	5172	2996	2645	-3534	-8629	-309	3478	-2729	571	-174	-5191	-3021
15	14710	8350	19937	11882	18745	24824	23607	9448	11345	12292	3204	7249	4427	1387	5551	4416	5735	8407	-2952	1158
Mean	9019	9809	13546	13839	15045	14624	13593	11454	10870	11324	8780	6405	7502	6838	7719	5714	7503	4351	1031	2183
Std. Dev.	4151	5470	3462	4452	3957	5840	4700	4489	5051	5775	5761	4851	7620	5666	4591	4797	4930	5453	6503	5639
Maximum	15567	22925	20868	21891	23876	24824	23607	19976	21111	20037	19987	16314	22603	14697	18372	11547	15699	10238	11113	11924
Minimum	3397	2714	8850	7947	9571	4581	3261	4568	3300	2996	902	-3534	-8629	-309	2466	-3668	571	-8407	-9883	-8109
Range	12170	20211	12018	13944	14305	20243	20346	15408	17811	17041	19085	19848	31232	15006	15906	15215	15128	18645	20996	20033
Coef.of Var.	0.46	0.56	0.26	0.32	0.26	0.40	0.35	0.39	0.46	0.51	0.66	0.76	1.02	0.83	0.59	0.84	0.66	1.25	6.31	2.58

throughout the initial and intermediate periods of the analysis. Income variability remains relatively stable across the 20-year simulation run. However, as mean net income declines in years 11 through 20, the coefficient of variation rises. The coefficient of variation is expressed as

$$cv = s/\bar{x} \qquad (5\text{-}1)$$

where cv represents the coefficient of variation; s represents standard deviation; and $\bar{x}$ represents the mean. The coefficient of variation affords a valid comparison of the variation among large values, such as income in initial periods, and variation among small values such as income in later periods.[2] The lowest coefficient of variation is 0.26 in years 3 and 5 of the 20-year simulation of net farm income. In years 18, 19 and 20, the coefficient of variation is 1.25, 6.31 and 2.58, respectively.

The maximum net farm income for any replication of any year is \$24,824 occurring in year 6, replication 15. The minimum net farm income of -\$9,883 occurs during year 19 of replication 6. The maximum range in net farm income of \$31,232 occurs during year 13. The maximum value (\$22,603) occurs during replication 5 and the minimum value (-\$8,629) occurs during replication 14. These figures emphasize the tremendous variability in net farm income that exists within the study area. The existence of irrigation water and government programs contribute definite stabilizing influences. However, as the water supply is depleted, crop yields decline and dependence on dryland production increases. As the importance of government programs continue to decline, variable weather conditions significantly affect variability of net farm income in the poor water situation.

Effects on Net Worth

The Farm Firm Simulation model computes net worth of the representative firm after each year of a multiperiod simulation run. Net worth is, of course, computed as the difference between total assets and total debts. Over time, assets and debts are constantly changing. Real estate and chattle debt payments are made each year until the beginning levels have been reduced to zero. An initial real estate debt of $42,000 and an initial chattle debt of $5,234 are assumed. Debt payments totaling $4,100, of which $2,800 is the real estate component, are made yearly. The chattle debt is paid off in five years and the real estate debt is retired during year 15. No further real estate or chattle debts are accumulated during the 20-year simulation runs. However, other short-term loans are required periodically to maintain the cash balance at $10,000. Short-term loans of this nature are paid off over a one-year period.

Over time, each capital asset is depreciated out and dropped from inventory at the end of the year concluding its useful life. The asset is replaced at the beginning of the next year and the depreciation process begins anew. Irrigation system components for wells 2 and 3 are depreciated out over 10 and 5-year periods, respectively, except for irrigation engines which must be replaced every four years. All irrigation components are replaced at the end of their useful life, regardless of the period over which their depreciation occurs.

Table XII presents a summary of net worth for representative farms in Resource Situation 1 based on 15 replications of a 20-year simulation of the firm. The mean, standard deviation, maximum, minimum and range of net worth values have been computed for each year of the simulation run. Mean values of net worth exhibit several characteristics. (1) There is a definite trend in net worth through time. (2) The trend in net worth is not linear, but, tends to follow a sigmoid pattern. (3) Net worth reaches a maximum in year 11. This maximum lags behind full irrigation development by one or two years. (4) After reaching a maximum in year 11, mean net worth for Resource Situation 1 declines steadily to year 20. Mean net worth at the end of year 1 is $120,792, increases steadily to $156,182 in year 11 and declines to $135,555 at the end of year 20. The standard deviation of net worth increases steadily from $3,334 in year 1 to $52,346 in year 20. Relative variability, as measured by the coefficient of variation, increases steadily over time from 0.03 in year 1 to 0.15 in year 11 to 0.39 in year 20. Increasing variability is again a function of several interrelated factors. (1) Declining well yields over time result in less reliance on irrigation water to stabilize crop yields. (2) The shift of crop acres from irrigated production to dryland production tends to increase variability in yields, net returns and net worth over time. (3) Despite the completely random nature of rainfall and pan evaporation events in the Production Subset, series of "wet crop years" and of "dry crop years" years appear in the simulation runs. This phenomenon has been observed and documented for a study area which encompasses a portion of the Central Ogallala Formation, but the majority part of which lies slightly to the east of the current study area.[3] The existence of

TABLE XII

SUMMARY OF NET WORTH FOR RESOURCE SITUATION 1 WITH NO RESTRICTIONS ON WATER USE

Replication	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	120981	132209	134761	141792	144693	149117	153597	156752	165779	170441	171273	170193	166031	169424	170925	172612	178723	178826	167024	164857
2	118047	119657	120000	119604	125957	127426	128151	127348	125861	126153	123633	118894	114541	107825	102681	101849	96757	80851	68436	60324
3	119824	119400	121345	123454	128118	131688	135068	136408	140863	143986	143568	146519	145507	142665	139597	135956	131562	130746	120340	120340
4	116195	113631	115735	121548	125187	122641	125732	122553	126528	122706	119324	115581	126540	131586	139433	141313	138534	136087	133912	127692
5	126009	122366	125317	127669	139548	148395	156681	158660	163480	173020	179839	186824	198840	198111	201896	203823	208574	210251	213980	214774
6	121006	122051	125413	125581	128130	127974	123589	122700	125468	124965	118326	111788	108677	101851	99206	88038	84105	73519	56136	40527
7	117026	115855	119258	125960	130889	132282	137224	146311	156177	168437	177765	179368	184103	190297	197444	201227	201251	195541	197451	199225
8	117007	120003	122495	128650	129598	135488	137299	140641	150374	158571	164753	162777	160759	163467	159786	160650	161716	160377	158364	161209
9	123015	122019	126446	136168	139003	148631	155869	163209	162351	166852	164761	161553	160760	164940	165204	161034	155927	157074	155735	148533
10	121317	123074	132747	137640	146649	157026	162131	166266	171045	173926	174514	177811	177304	172533	172958	172887	170581	168912	160545	155648
11	122969	118242	123410	130388	136184	147876	155134	162993	168321	175091	181628	181690	182008	185368	185949	187573	193079	185886	175000	163100
12	125942	135524	143124	154176	160580	167980	170263	169937	166352	167685	165276	161859	160710	155132	152197	147674	150764	152246	148732	148741
13	117289	119172	121696	122599	130699	135555	139336	142876	143910	150268	155901	154913	154227	155365	152752	146409	150259	147950	147171	143910
14	119911	120119	124791	124780	126481	129762	133208	132862	133367	128729	123755	112721	96592	88783	84606	74377	67422	59749	47056	36537
15	125342	125537	134593	137721	145873	159128	171284	172769	175885	182686	179229	179181	176959	171950	170057	166905	164773	164760	154308	147914
Mean	120792	121923	126075	130517	135829	141397	145638	148152	151717	155568	156182	154778	154237	153286	152979	150822	150268	146852	140219	135555
Std. Dev.	3334	5673	7259	9347	10140	13568	15926	17393	17780	21031	23995	27241	30219	32832	34975	38402	41421	44527	48768	52346
Maximum	126009	135524	143124	154176	160580	167980	171284	172769	175885	182686	181628	186824	198840	198111	201896	203823	208574	210251	213980	214774
Minimum	116195	113631	115735	119604	125187	122641	123589	122553	125468	122706	118326	111788	96592	88783	84606	74377	67422	59749	47056	36537
Range	9814	21893	27389	34572	35393	45339	47695	50216	50417	59980	63302	75036	102248	109328	117290	129446	141152	150502	166923	178237

series of good years contribute to a high ending net worth during replications 5 and 7 ($214,744 and $199,225, respectively). Series of dry years contribute to low ending net worth during replications 6 and 14 ($40,527 and $36,537, respectively).

The maximum and minimum net worth figures both occur during year 20. A range of $178,237 exists between the maximum of $214,774 and the minimum of $36,537.

Effects of a Quantity Restriction on Resource Situation 1

The second water-use regulatory alternative simulated is a limit on the quantity of irrigation water an individual is allowed to pump during a crop year. The irrigator is limited to pumping 1.5 acre feet per acre of water rights established for the representative farm firm. Water rights are assumed for 315 acres, resulting in a maximum allowable pumping of 472.5 acre feet or 5,670 acre inches per year.

The irrigator is free to allocate the allotted quantity of water in any manner he desires during the crop year. However, the rational irrigator is assumed to restrict pumping somewhat during early periods of the crop year (compared to the unrestricted irrigator) as a hedge against uncertain soil moisture conditions in future critical periods of crop development. The irrigator is assumed to pump according to crop priorities and soil moisture depletion levels assumed for the unrestricted irrigation operator, however, he establishes maximum quantities of water to be applied to any crop during a given irrigation period. These maximum quantities are established so that, in wet years, the 5,670 acre inch limitation is not effective while in dry years, the limitation is a significant factor in reducing final crop yields.

A quantity limitation, if imposed, could not require the irrigator to maintain constant surveillance of the well meter and cease applications the instant total pumping for the crop year reaches 5,670 acre inches. The irrigator is allowed to continue pumping until the end of the day on which his system has delivered 5,670 acre inches to the surface. Thus, there is some variation in pumping levels above 5,670 acre inches, despite the quantity limitation.

Effects on Acre Inches Pumped

Table XIII contains a summary of total acre inches pumped per year under the quantity limitation for Resource Situation 1. The situation was simulated over a 20-year period and replicated 15 times. The mean, standard deviation, maximum, minimum and range of acre inches pumped have been computed for each year of the simulation runs.

Mean values of total acre inches pumped are relatively constant from year 1 through year 12. Slightly higher values in year 3 and in years 11 and 12 reflect the increased pumping capacity created by addition of irrigation wells 2 and 3. Irrigation well 2 is added at the end of crop year 2 and well 3 is added at the end of year 10 or 11, depending on when total system pumping capacity falls below 750 gpm. Beginning with year 13, mean values of acre inches pumped decline steadily from 5,244 to 1,791 acre inches in year 20. Maximum mean acre inches pumped of 5,704 occurs during year 3 when pumping capacity of the irrigation system is greatest. Minimum pumping occurs during year 20, as expected, reflecting declining well yields and conversion of irrigated acreage to dryland wheat production. Complete conversion to

TABLE XIII

SUMMARY OF TOTAL ACRE INCHES PUMPED FOR RESOURCE SITUATION 1 WITH A QUANTITY RESTRICTION ON WATER USE

Replication	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	5703	4227	5734	5726	5711	5730	5679	5674	5674	5579	5683	5699	4781	2970	2939	2871	2829	2686	2817	1028
2	5687	5542	5732	5694	5728	5682	5686	5685	5674	5627	5686	5697	5688	5148	4358	3110	2722	2607	2406	2253
3	5687	5669	5723	5672	5682	5704	5681	5683	5687	5619	5711	5512	5683	5160	3582	1802	2592	1157	2367	2447
4	5687	5677	5741	5701	5690	5698	5680	5682	5376	5644	5670	5677	3623	5280	3930	4350	3777	3445	3064	2788
5	2852	5681	5636	5681	4188	5685	5714	5704	5693	5586	5480	5692	4925	5701	5097	4442	4000	3621	3173	2975
6	5688	5677	5696	5703	5715	5691	5680	5683	5688	5334	5671	5712	4830	5107	4344	4057	3479	3298	2272	0
7	5689	5677	5696	5719	5720	5708	5712	5394	5194	5324	4583	5678	5683	5279	3568	4351	3896	2482	2358	1901
8	5710	5708	5687	5701	5685	5702	5695	5716	4600	4024	5610	5682	5676	5387	4821	3108	3264	2507	2449	2198
9	5695	5679	5673	5543	5688	5084	5679	5678	5693	5443	5715	5700	4763	3491	3869	3535	2618	2201	2148	2458
10	5708	5067	5715	5765	5641	5708	5673	5701	5710	5669	5702	5706	5700	5135	4568	4021	3646	2437	2270	2204
11	5694	5677	5709	5257	5708	5692	5673	5707	5683	5333	5683	5691	5677	4833	4641	4135	3485	3152	2266	786
12	4870	4672	5699	5727	5727	5712	5696	5685	5713	5694	5677	5678	5689	4878	4057	3896	3501	3315	3105	1722
13	5707	5672	5718	5671	5703	5673	5681	5702	5715	4099	5717	5701	5709	5293	3592	3444	1988	2459	2219	1995
14	5687	5680	5703	5702	5685	5715	5693	5712	5681	5612	5716	5295	4703	3442	3263	3153	2345	2635	1796	2114
15	4738	5682	5714	5739	5715	5648	5676	5708	5712	5503	5709	5535	5527	5151	3213	3142	2596	2029	2628	0
Mean	5387	5466	5704	5661	5599	5656	5687	5674	5566	5339	5601	5644	5244	4817	3990	3561	3116	2669	2489	1791
Std. Dev.	768	450	26	121	391	159	13	79	305	534	288	114	615	817	638	720	624	634	393	925
Maximum	5710	5708	5741	5739	5728	5730	5714	5716	5715	5694	5717	5712	5709	5701	5097	4442	4000	3621	3173	2975
Minimum	2851	4227	5636	5257	4188	5084	5673	5394	4600	4024	4583	5295	3623	2970	2939	1802	1988	1157	1796	0
Range	2859	1481	105	482	1540	646	41	322	1115	1670	1134	417	2086	2731	2158	2640	2012	2464	1377	2975

dryland farming during the 20-year simulation occurs during 2 of 15 replications, or only about 13.3 percent of the time.

Maximum range in acre inches pumped for a single year is 2,975 acre inches in year 3. A total of 2,975 acre inches were pumped during replication 5 and a minimum of zero acre inches during replications 6 and 15.

Remaining saturated thickness of the underground aquifer at the end of the 20-year simulation run ranges from 36.08 to 41.57 feet, averaging 38.37 feet. With a beginning saturated thickness of 100 feet, an average remaining saturated thickness of 38.37 feet indicates a 61.33-foot decline in the water table. Over the 20-year period, the rate of decline averages 3.07 feet per year. Thus, even with a quantity limitation of 1.5 acre feet per acre of water rights, significant reductions in saturated thickness occur over a 20-year period. The distribution of water withdrawals differs from the unrestricted pumping situation. With the quantity limitation, less water is withdrawn in early years and more in late years of the 20-year simulation, but the resulting decline in saturated thickness is very similar in magnitude for both situations.

Effect on Net Farm Income

The effect on net farm income for representative farms in Resource Situation 1 of a limit on the quantity of irrigation water pumped per year is illustrated in Table XIV. Net farm income from the 15 replications of a 20-year simulation run are presented. The mean, standard deviation, maximum, minimum and range in net farm income are shown for each year of the multiperiod run.

TABLE XIV

SUMMARY OF NET FARM INCOME FOR RESOURCE SITUATION 1 WITH A QUANTITY RESTRICTION ON WATER USE

Replication	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	9779	22923	7347	14902	7014	7319	11522	9434	17263	14234	10182	3075	0.49	7546	5215	9830	15020	8603	-1888	7128
2	4814	10420	3186	2476	14860	7703	5676	5466	2398	2153	3663	-1356	-224	-1830	-2909	2870	-132	-11727	-6665	-2338
3	7043	7533	7803	8408	10916	8610	9800	8665	10096	12375	6635	11660	5845	3165	69	2914	2647	6382	-2816	-2903
4	2280	5151	8865	13624	9971	1056	8975	2614	9225	4245	2319	1631	20000	9246	14376	7843	4922	4619	5437	-365
5	15567	2102	11164	8746	23559	16714	17938	9035	13146	18909	13675	16739	20396	7045	12831	9441	12931	12201	13187	5002
6	9612	9656	10167	4638	6220	2228	-1160	2624	7558	7704	-3292	-534	4528	-2358	2329	-4262	3977	-3569	-10800	-10007
7	3050	8138	10223	13815	14434	9519	13260	18352	20746	22296	20585	8660	13844	12781	15133	12322	6858	507	9399	10013
8	2582	11465	6830	12477	4518	11834	7065	10804	18482	19874	15400	4207	3118	8587	3101	8305	7668	6274	5024	13910
9	12386	7205	10219	20020	7683	19521	15650	17135	5312	12274	4382	2334	4332	13841	5872	3043	3133	9252	6749	2729
10	10683	10397	21290	10719	19330	19555	14240	11423	12182	8968	8196	12961	7541	6050	7872	10589	5856	6387	-1148	3034
11	12264	2996	13752	16737	12946	22568	15543	18723	13358	12513	14381	6965	6464	13464	7723	9992	14864	1563	-3471	-4500
12	15485	20265	16736	22023	11437	15799	8457	6465	2706	6150	3754	4677	5398	3329	6221	7096	14464	12777	5542	10576
13	4563	10507	8510	5373	17166	12816	11900	12449	6365	17807	14926	8112	6336	5612	616	-2570	12310	5312	7191	5267
14	7047	8343	12807	4431	7323	11415	10532	6425	4629	4720	350	-2921	-7607	-2724	1056	-1800	2837	1753	-3952	-1559
15	14710	8622	19858	8569	16668	23952	21864	9085	10046	14270	2071	7981	3089	563	4293	4408	6353	8532	-2992	722
Mean	8791	9715	11250	11131	12270	12707	11417	9913	10234	11899	7815	5613	6204	5621	5586	5335	7581	4591	1253	2447
Std. Dev.	4703	5548	4941	5815	5412	6926	5519	5099	5650	6164	6780	5557	7314	5567	5329	5189	5056	6295	6719	6400
Maximum	15567	22923	21290	22023	23559	23952	21864	18723	20746	22296	20585	16739	20396	13841	15133	12322	15020	12777	13187	13910
Minimum	2280	2102	3186	2476	4518	1056	-1160	2614	2398	2153	-3292	-2921	-7607	-2724	-2909	-4262	-132	-11727	-10800	-10007
Range	13287	20821	18104	19547	19041	22896	23024	16109	18348	20143	23877	19660	28003	16565	18042	16584	15152	24504	23987	23917
Coef.of Var.	0.53	0.57	0.44	0.52	0.44	0.55	0.48	0.51	0.55	0.52	0.86	0.99	1.18	0.99	0.95	0.97	0.67	1.37	5.36	2.62

Mean values of net farm income generally reflect the development and expansion of irrigation facilities over time, as well as the impact of the declining water level on system pumping capacity, pumping costs per acre inch and the transition from irrigated to dryland production. Mean net farm income increases from $8,791 in year 1 to $11,250 in year 3. The impact of increased pumping capacity caused by the addition of well 2 is reflected in year 3 net farm income. The maximum value of mean net farm income is $12,270 and occurs in year 5. There are at least two plausible explanations for the maximum occurring in year 5. (1) With the quantity restriction on water pumping in effect, the excess pumping capacity created by addition of well 2 in year 3 is not depleted as rapidly as under the unrestricted alternative. Thus, adequate water may be applied with precise timing to insure good to excellent irrigated crop yields. (2) Excellent crop yields over the initial years are translated into substantial wheat and feed grain payments which, of course, contribute directly to net farm income.

Mean net farm income declines from year 5 through year 8, increases during years 9 and 10, reflecting additional irrigation expansion to a three-well system. In most years the third well is added after crop year 9 and mean net farm income in year 10 is $11,899. Mean net farm income declines dramatically to $7,815 in year 11 and to $5,613 in year 12, but stabilizes for years 13 through 16. Year 17 mean net farm income of $7,581, contradicts the trend due primarily to favorable random weather events leading to increased crop yields despite declining well yields. Mean net farm income in years 19 and 20 is $1,253 and $2,447, respectively.

Standard deviation of net farm income has a general upward trend through time. Relative variability, as measured by the coefficient of variation, is virtually stable until year 10, ranging from a low of 0.44 in year 3 to a high of 0.57 in year 2. The coefficient of variation increases from 0.52 in year 10 to 1.18 in year 13 and remains in the 0.95 to 0.97 interval before declining to 0.67 in year 17. Thereafter, the coefficient rises rapidly to 1.37 in year 18 and 5.36 in year 19 before declining to 2.62 in year 20. The large coefficient of variation in year 19 is attributable to a combination of factors including (1) continued irrigation of acres which were marginally profitable during year 18, and (2) insufficient water to offset lack of natural rainfall during the growing season. The mean net farm income for year 19 is only $1,253, while standard deviation is $6,719. The replications during which the operator continues to irrigate with insufficient pumping capacity results in negative net farm incomes and the resulting increase in magnitude of the coefficient of variation.

In general, variability of net farm income with a quantity limitation exceeds variability of net farm income under conditions of unrestricted pumping. From years 17 through 20, variability of net farm income, as measured by the coefficient of variation, were quite similar for both the unrestricted water-use alternatives.

Effects on Net Worth

Restricting water-use to 5,670 acre inches per year has a definite and significant impact on the representative firms net worth over the 20-year simulation run. Net worth of the firm follows a sigmoid pattern over the 20-year interval, first increasing at an increasing rate, then at a decreasing rate and finally decreasing absolutely.

Table XV presents a summary of net worth figures generated from 15 replications of a 20-year simulation of the quantity limitation. Mean, standard deviation, maximum, minimum and range of net worth are computed for each year. Mean net worth increases from $120,575 at the end of year 1 to $142,714 in year 11. Thereafter, net worth decreases steadily to $115,617 in year 20. It should be noted that ending mean net worth in year 20 is less than mean net worth after year 1 of the simulation sequence. If farm managers operating in the poor water resource situation react to the quantity limitation in the manner assumed in this model, indications are that depletion of the water supply coupled with gradual conversion toward dryland farming in years 11 through 20 results in absolute reductions in net worth within a 20-year period.

Standard deviation of net worth increases steadily over the 20-year simulation period. The transition is from a mean and standard deviation of $120,575 and $3,825, respectively, in year 1 to a mean and standard deviation of $115,617 and $61,094, respectively in year 20. In terms of relative variability, this transition corresponds to an increase in the coefficient of variation from 0.03 to 0.54. The maximum and minimum values of net worth generated by the General Agricultural Firm Simulator occur in years 19 and 20, respectively. Maximum net worth equals $206,441 and minimum net worth equals $2,198. It might be argued that the rational farm operator would quit farming before depleting net worth to such a low level. To the extent that this argument is valid, the net worth results may be adversely affected by replications 2 and 6 of the simulation analysis. By the same token,

TABLE XV

SUMMARY OF NET WORTH FOR RESOURCE SITUATION 1 WITH A QUANTITY RESTRICTION ON WATER USE

Replication	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	121434	132678	132071	137458	136356	135444	137974	138808	145815	150483	155044	150481	142982	142278	139674	140817	146092	146250	136862	135781
2	117421	119054	114598	109463	114607	114017	111755	109316	104107	98663	97787	88936	81208	71878	61469	56710	49079	29851	15686	5849
3	119236	118489	117972	117972	119998	120168	121286	121502	122865	126084	127781	130426	128345	123868	116437	111721	106749	105065	94749	84346
4	115128	112423	112779	116985	118244	111754	112203	107199	107858	104406	102246	96304	105409	106086	110869	110361	107462	104315	101844	93979
5	126009	120850	123190	123475	135137	141758	149257	149756	153569	161882	166510	176468	186443	186491	190856	192574	197294	201406	206441	205332
6	121294	122396	123819	120702	118898	113526	104866	99873	99156	98546	90879	82845	79670	69812	64537	52776	49074	38005	19705	2198
7	115864	115614	117084	121408	126240	127145	131052	138883	148586	159320	172019	172711	177659	182036	188128	192161	192026	185922	187316	189472
8	115417	117899	116593	119896	116680	119451	118330	120264	128200	137205	145915	142433	137911	138062	133524	133417	132763	130989	128180	132583
9	123514	122676	124143	133265	132661	141378	147166	154070	151531	154708	154519	149248	145886	150233	148172	143578	139071	139752	138360	133466
10	122165	123896	133903	136056	144620	153514	158567	161206	164587	165620	168723	172745	172644	171456	171340	173305	171549	169869	161221	156619
11	123414	118979	123290	129930	133579	144527	150241	158370	162561	166348	174443	173888	172986	177730	177757	179512	185258	179824	169282	157450
12	125942	135524	142473	153603	156761	163285	164099	162921	158480	156946	156158	153116	150668	146348	144576	143466	148321	151873	149489	151253
13	117212	118918	119004	116501	123430	126972	129798	133078	131386	138780	147103	146853	145180	142910	135999	125928	129093	126520	125492	122885
14	119240	119168	122702	119412	118511	120952	122680	121036	117904	114848	110823	100402	85295	75072	68580	59280	54491	48666	37214	28155
15	125342	125743	134736	135171	141755	153698	164465	165447	167270	172615	170755	170851	166942	160540	157141	153812	152097	152193	141700	134890
Mean	120575	121620	123890	126086	129165	132506	134916	136115	137592	140430	142714	140513	138615	136320	133937	131294	130695	127367	120903	115617
Std. Dev.	3825	6043	8455	11314	12275	16483	19805	22033	23178	25921	29252	33201	35892	39565	42733	46457	49403	53403	57903	61904
Maximum	126009	135524	142473	153603	156761	163285	164465	165447	167270	172615	174443	176468	168443	186491	190856	192574	197294	201406	206441	205332
Minimum	115128	112423	112779	109463	114607	111754	104866	99873	99156	98546	90879	82845	79670	69812	61469	52776	49074	29851	15686	2198
Range	10881	23101	29694	44140	42154	51531	59599	65574	68114	74069	83564	93623	106773	116679	129387	139798	148220	171555	190755	203134

replication 5 which results in an ending net worth of $205,332 tends to have a very favorable affect on net worth. On balance it is difficult to say definitely whether the ending mean value of net worth is shifted upward or downward. One assumption seems as plausible as the other. The overall implications of simulating a quantity restriction on pumping by individual firms appear clear. Over time profitability and net worth of the firm increase until declining water supplies and rising water costs force the conversion toward dryland farming. From that point on, profitability and net worth decline. It is not unrealistic for net worth at the end of 20 years to be less than it was at the beginning of the period. It is likely that ending net worth is significantly lower than for the irrigator who is not restricted in his pumping over time.

Effects of a Graduated Tax Per Unit of Water Pumped Above the Quantity Limitation for Resource Situation 1

The third institutional alternative considered is the imposition of a per unit tax on each acre inch of water pumped above the quantity limitation. The irrigator is assumed to follow the same set of decision rules as specified for irrigators facing a quantity restriction, with one exception. The irrigator is allowed to pump as many acre inches above the limitation as he desires so long as he pays a graduated tax of $0.50 for each acre inch pumped above the limit. An economic decision rule is followed by irrigators in deciding whether or not to apply water above the limit. The irrigator evaluates the potential yield reduction which will occur, projecting present moisture conditions, if he does not irrigate. The value of the potential loss for a given crop block is compared with the cost of an additional irrigation, plus added harvesting and hauling costs. If the value of potential yield reduction exceeds the cost of an additional irrigation, the application is made.

Examination of results of the quantity restriction simulation reveal that only Irrigation Periods 4 and 5 are of critical importance in the irrigator's decision model. During Irrigation Period 4, grain sorghum is in the boot-heading and grain-filling stages. Insufficient soil moisture leads to significant reductions in final yield. If the potential yield reduction from failing to irrigate exceeds ten bushels of grain sorghum per acre, the value of that potential loss exceeds the cost of an additional application, plus added harvesting and hauling costs and taxes, and the irrigation water is applied.

During Irrigation Period 5, wheat is involved in the decision process. The potential loss from failing to provide a preplant irrigation to wheat is at least 15 bushels per acre. Value of the potential loss exceeds the cost of an additional irrigation. Consequently, the irrigator finds it an economically rational decision to provide a preplant irrigation application for wheat each year.

Effects on Acre Inches Pumped

Table XVI summarizes the effects of a graduated tax per unit above the quantity limit on total acre inches pumped during 15 replications of each of 20 crop years. The mean, standard deviation, maximum, minimum and range of acre inches pumped have been computed for each year of the simulation analysis.

TABLE XVI

SUMMARY OF TOTAL ACRE INCHES PUMPED FOR RESOURCE SITUATION 1 WITH A GRADUATED TAX PER UNIT PUMPED ABOVE THE QUANTITY LIMIT

	Year																			
Replication	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	5787	4226	6997	6265	7108	6573	6090	6219	5270	6112	6158	5798	3966	2867	2791	2711	2665	2511	2453	0
2	5986	5531	7118	7174	5630	6365	6346	6086	5441	6114	5711	5756	5652	4483	3381	2550	2643	2427	0	0
3	5986	5502	6616	6711	6102	6416	6086	6060	5646	5867	6105	5016	5224	4662	3408	1894	2550	1087	2431	2327
4	6069	5665	6478	6168	6473	6732	6292	6138	5037	6288	6122	5755	3315	4454	3667	3935	3373	3158	5705	2529
5	2722	5842	5500	6335	4530	6128	6070	6095	6111	5359	6167	5971	4815	5300	4073	3817	3634	3271	2647	2514
6	5688	5644	6911	7187	6578	6508	6236	6070	5406	6060	6194	5407	4099	4485	3872	3614	3127	2960	2675	0
7	6072	5524	6232	6057	5790	5879	5806	5085	4838	5083	4572	6373	5205	5159	3439	4263	3790	2475	2349	1896
8	6048	5618	6666	6599	6958	6090	6135	5387	4396	4714	5172	6105	5473	3276	3158	2584	2807	2554	2462	2298
9	5830	5651	6549	4920	6700	5094	6188	5526	5901	5140	6308	6099	4452	3271	3656	3445	2637	2300	2103	2405
10	6019	4940	5535	6922	5501	5886	6292	6312	5550	6604	6044	5112	5360	4790	4177	3775	3380	2392	2300	2146
11	5785	5683	6234	4709	6329	5512	6016	5424	5988	5150	6181	6125	5583	4498	4364	3911	2797	2449	2278	0
12	4673	4673	6084	5617	6655	5655	6426	6202	5902	5422	6173	6140	5400	4427	3900	3781	3253	3067	2939	1645
13	6048	5586	6704	7199	5588	6159	6131	5366	5679	4390	5814	6004	5377	4668	3491	2899	2066	2385	2152	1910
14	6069	5665	6140	6989	6128	6160	6094	6154	5637	6140	6095	4746	3993	3236	2794	3046	2505	2512	2093	2032
15	4455	5692	5806	7216	6082	5436	5519	6055	5915	5253	6488	4481	4721	4414	2828	2888	2685	2068	2665	0
Mean	5549	5429	6371	6045	6144	6040	6115	5878	5514	5580	5954	5659	4836	4266	3533	3274	2854	2508	2483	1447
Std. Dev.	929	451	500	1408	666	463	223	397	472	639	488	573	717	741	497	673	486	522	1113	1085
Maximum	6072	5842	7118	7216	7109	6732	6426	6312	6111	6604	6488	6373	5652	5300	4364	4263	3790	3271	5705	2529
Minimum	2722	4226	5500	1799	4530	5094	5519	5085	4396	4390	4572	4481	3315	2867	2791	1894	2066	1087	0	0
Range	3350	1616	1618	5417	2579	1638	907	1227	1715	2214	1916	1892	2337	2433	1573	2369	1724	2184	5705	2529

Mean values of total acre inches pumped per year reflect the expansion and development of irrigation facilities on the farm firm representing Resource Situation 1. That is, the highest number of acre inches pumped occurs during year 3, reflecting the excess pumping capacity created by addition of a second irrigation well. Mean acre inches pumped fluctuates between 6,040 and 6,144 acre inches to year 7 and then declines until the addition of well 3, which usually occurs at the end of crop year 10. The addition of well 3 results in a pumping increase during year 11. From year 12 through year 20, mean acre inches pumped declines steadily, reaching 1,447 acre inches during year 20.

Simulation of the graduated tax results in complete conversion to dryland production during replications 1, 2, 6, 11 and 15 of the 20-year simulation run. Except for replication 2, the final transition comes in year 20. For replication 2, both years 19 and 20 are simulated with complete dryland production. This pattern of conversion to dryland production exhibits the same timing characteristics as exemplified in the unrestricted simulation analysis. The quantity of water pumped under taxation is less than under unrestricted pumping, however, the addition of a per unit tax on each unit above the quantity limit results in a similar timing of conversion to dryland production.

The maximum number of acre inches pumped during any replication is 7,216 during replication 15, year 4. The minimum, of course, is zero and occurred during both years 19 and 20. The maximum range within a single year of 5,417 acre inches occurs during year 4, when a maximum of 7,216 acre inches and a minimum of 1,799 acre inches are pumped.

The range in remaining saturated thickness at the end of the 20-year simulation period is from 34.67 to 40.97 feet, averaging 37.72 feet. Translating this into feet decline in saturated thickness results in an average foot-decline of 62.28 feet over the 20-year period, or an average of 3.11 acre feet per year. Of the total volume of water underlying the representative farm, assuming a beginning saturated thickness of 100 feet, only about 38 percent remains at the end of 20 years under the graduated tax alternative.

Effect on Net Farm Income

The effects on net farm income of a graduated tax on each acre inch of irrigation water pumped above the quantity limitation are illustrated in Table XVII. The mean, standard deviation, maximum, minimum and range of net farm income have been computed for each year of the 20-year simulation run.

Mean values of net farm income increase steadily from $9,473 in year 1 to $15,346 in year 6. This dramatic rise may be attributed to several interrelated factors. First, expansion of irrigation facilities by the addition of well 2 increases pumping capacity significantly. Second, the additional pumping capacity insures proper timing for the very profitable irrigations of grain sorghum and wheat in Irrigation Periods 4 and 5. Higher wheat and grain sorghum yields lead not only to increased net returns per acre, but to higher government payments for the farm operator. Mean net farm income declines during years 7, 8 and 9, but increases to $13,368 in year 10 with the addition of irrigation well 3. Thereafter, mean net farm income declines steadily

TABLE XVII

SUMMARY OF NET FARM INCOME FOR RESOURCE SITUATION 1 WITH A GRADUATED TAX PER UNIT ABOVE THE QUANTITY LIMIT

	Year																			
Replication	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	9955	23014	11018	16972	10651	10865	15174	14047	18757	15371	11606	4049	2229	10342	9806	12747	17195	9925	-1463	8876
2	6157	10969	7280	7179	17073	10562	9321	8625	6318	6358	7291	4256	5163	2556	3036	9481	4764	-6463	-3084	1194
3	8387	8877	11140	11333	15322	12050	12942	12826	12290	14916	10256	14241	9762	6678	7545	6879	7197	10441	1853	1476
4	3493	5823	11501	16409	13221	4556	12772	6225	13364	5560	6621	5264	23583	14734	20608	11315	7671	8664	9193	2569
5	15662	3591	12309	11274	24074	19501	20550	11687	15623	21387	14296	16670	22956	7577	14704	11174	13637	10531	11529	7797
6	9944	10297	13145	8058	10108	6183	3115	7095	11012	7625	510	2646	7452	1463	8070	-275	7064	266	-4413	-3612
7	4263	9394	12471	16511	15927	11304	15019	20673	22930	23625	21125	10178	15692	15281	15767	12898	7651	494	9411	10033
8	3846	12742	10605	16258	8610	15441	10841	14584	20328	20235	17200	6490	4422	10716	7125	11985	12323	10366	8880	17229
9	12739	7802	12620	22151	10157	20931	18136	19268	6934	13339	7101	4796	6800	16016	8356	5540	5604	12952	9317	5206
10	10404	11254	21994	13819	20235	22425	15641	13575	14827	9170	13046	14375	10203	7607	10400	9203	5316	6977	-480	3270
11	12686	3246	15038	17558	15727	24637	17437	20052	15664	14251	16302	9790	8269	13484	7518	10637	14977	453	-1748	-3920
12	16394	20357	18468	23259	13754	17367	10804	8478	4105	7174	6052	6270	7372	5331	7303	9685	16602	14356	7332	11364
13	4202	11257	11337	9623	19599	15506	14636	15762	9407	18024	17013	10409	7617	8303	5005	1219	15959	8183	10932	8578
14	8261	9331	14943	8266	11337	13786	14843	10375	9275	7398	5131	1489	-2778	1872	8056	2384	6375	5625	496	2601
15	15709	8959	20055	11956	18691	25073	23766	11653	11799	16093	3601	9344	4239	2358	5755	6104	8519	11396	-747	3176
Mean	9473	10461	13595	14042	14966	15346	14333	12995	12842	13368	10477	8018	8865	8288	9270	8065	9956	6944	3867	5056
Std. Dev.	4499	5327	3918	4953	4436	6305	4891	4553	5317	5902	5910	4583	7117	5038	4548	4257	4291	5799	5695	5667
Maximum	16394	23014	21994	23259	24074	25073	23766	20673	22930	23625	21125	16670	23583	16016	20608	12898	17195	14356	11529	17229
Minimum	3493	3246	7280	7179	8610	4556	3115	6225	4105	5560	510	1489	-2778	1463	3036	-275	4764	-6463	-4413	-3920
Range	12901	19768	14714	16080	15464	20517	20651	14448	18825	18065	20615	15181	26361	14553	17572	13173	12431	20819	15942	21149
Coef.of Var.	0.47	0.51	0.29	0.35	0.30	0.41	0.34	0.35	0.41	0.44	0.56	0.57	0.80	0.61	0.49	0.53	0.43	0.84	1.47	1.12

except for individual yearly increases due to favorable soil moisture and atmospheric stress conditions in years 15 and 17.

The maximum value of net farm income generated in any year is $25,073 in year 6, replication 15. The minimum of -$6,463 occurred in year 18, replication 2. The greatest range occurs during year 13 with the difference between the maximum of $23,583 and minimum of -$2,778 being $26,361.

Variability, as measured by the standard deviation, does not follow a definite trend. Generally, it rises when mean net farm income rises and declines as net farm income declines between years 1 and 17. The pattern is mixed the last three years of the simulation period. Relative variability, as measured by the coefficient of variation, remains low (ranging from 0.29 to 0.84) for the first 18 years of the run. Coefficients of variation for years 19 and 20 are 1.47 and 1.12, respectively. Stability of net farm income is greater under the graduated tax than under either the unrestricted or quantity restriction alternatives.

Effects on Net Worth

Table XVIII summarizes the effects on net worth for representative firms in Resource Situation 1 of a graduated tax on each acre inch of water pumped above the quantity limitation. The mean, standard deviation, maximum, minimum and range of net worth have been computed across the 15 replications of each year of the simulation run.

Net worth of the representative farm firm increases steadily from year 1 through year 13, dips slightly in year 14 and increases during years 15, 16 and 17, before declining in years 18, 19 and 20. The

TABLE XVIII

SUMMARY OF NET WORTH FOR RESOURCE SITUATION 1 WITH A GRADUATED TAX PER UNIT ABOVE THE QUANTITY LIMIT

	Year																			
Replication	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	121580	132902	135281	142391	144450	146583	152079	156594	164828	173666	176722	174016	169583	171806	173389	177170	184572	186235	178026	178902
2	118519	120590	119657	118636	125491	127243	127982	128165	126433	127905	126996	123561	120917	115859	111259	112132	109100	95138	84554	78194
3	120294	120696	122909	125282	130802	133753	137398	140948	144096	152411	153909	158582	159806	158676	157937	156647	155619	157270	151541	145451
4	116287	114135	116647	123021	126895	123708	127255	125446	129438	130262	128823	126271	137952	143028	152620	154978	154327	154536	155168	150122
5	126086	122353	125687	128011	140015	148716	158437	161235	167251	177892	186341	193850	206338	207707	214434	218592	224886	228764	233555	235767
6	121571	123195	127007	126710	128084	126246	121722	120623	122730	125214	118202	113229	112449	106347	106036	98261	97124	89890	77978	66865
7	116962	117762	121060	127517	133499	135848	141123	150767	161935	174033	187516	190075	197108	204187	211578	216969	218475	213681	216219	219573
8	116614	120137	121924	128175	128346	133963	135928	140881	150250	162668	169643	168620	165943	168326	167569	170523	173939	175528	176080	183378
9	123804	123457	126878	137498	138962	148685	156523	165140	164419	168922	171284	168841	167995	174548	174943	172932	170951	174582	175458	173202
10	121933	124348	134844	139495	148916	160004	166395	171032	176866	181241	184507	190370	193244	194226	197196	199107	198024	197850	191204	187948
11	123760	119581	124870	132117	137968	150411	157809	167111	173435	179016	189066	191367	192597	198122	198816	201943	208604	203277	195630	185696
12	126622	136305	144574	156630	161736	169614	172584	173397	170706	170534	172129	170916	170603	168746	168072	169191	175843	180694	180179	183142
13	116911	119221	121597	122589	131368	137039	142036	147915	148726	159419	166226	168208	168094	168597	166107	159772	165780	165573	167613	167755
14	120188	120971	126183	126062	128439	132778	137908	139504	140204	142506	139845	133767	123490	117778	117455	112232	110536	108222	101196	96180
15	126124	126844	136010	139257	147428	160369	172764	176163	179803	187048	187342	189220	187171	183496	182211	180974	181719	184472	176887	172958
Mean	121150	122833	127009	131559	136827	142331	147196	150995	154741	160849	163903	164060	164886	164234	166641	166762	168633	167714	164086	161676
Std. Dev.	3607	5653	7536	9847	10268	13848	16486	18075	18847	20570	24426	27310	29337	34823	33874	36645	38763	41459	44808	48017
Maximum	126622	136305	144574	156630	161736	169614	172764	176163	179803	187048	189066	193850	206338	207107	214434	218592	224886	228764	233555	235767
Minimum	116287	114135	116647	118636	125491	123708	121722	120623	122730	125214	118202	113229	112449	106347	106036	98261	97124	89890	77978	66865
Range	10335	22170	27927	37994	36245	45906	51042	55540	57073	61834	70864	80621	93889	101360	108398	120331	127762	138874	155577	168902

maximum mean value of $168,633 occurs in year 17. Variability of net worth increases steadily also from 0.03 in 1 to 0.30 in year 20. Maximum and minimum individual values of net worth both occur during year 20. The maximum net worth of $235,767 is generated during replication 5, while the minimum value of net worth of $66,865 is generated in replication 6. Mean value of ending net worth in year 20 is $161,676.

Statistical Comparisons of Unrestricted Pumping, A Quantity Limitation and a Graduated Tax on Resource Situation 1

Previous sections discussed total water pumped, remaining saturated thickness, net farm income, income variability and net worth over time for three alternative water-use regulatory alternatives. Results were presented for an unrestricted simulation, a quantity limitation on water use and a graduated tax per unit of irrigation water pumped above the quantity limitation. This section is designed to compare the three methods of water-use regulation graphically and statistically, relating the different effects each has on water use; remaining saturated thickness; net farm income; income variability, as measured by the coefficient of variation; and, net worth at the end of the 20-year simulation period. Tests are conducted to determine whether mean values of the relevant variables over the 20-year period differ significantly. Implications are drawn regarding differences in results of the three alternatives and their effects on the firm and the region.

Acre Inches Pumped

Figure 7 illustrates the effect on each water-use alternative on mean acre inches pumped through time. The effects of increasing

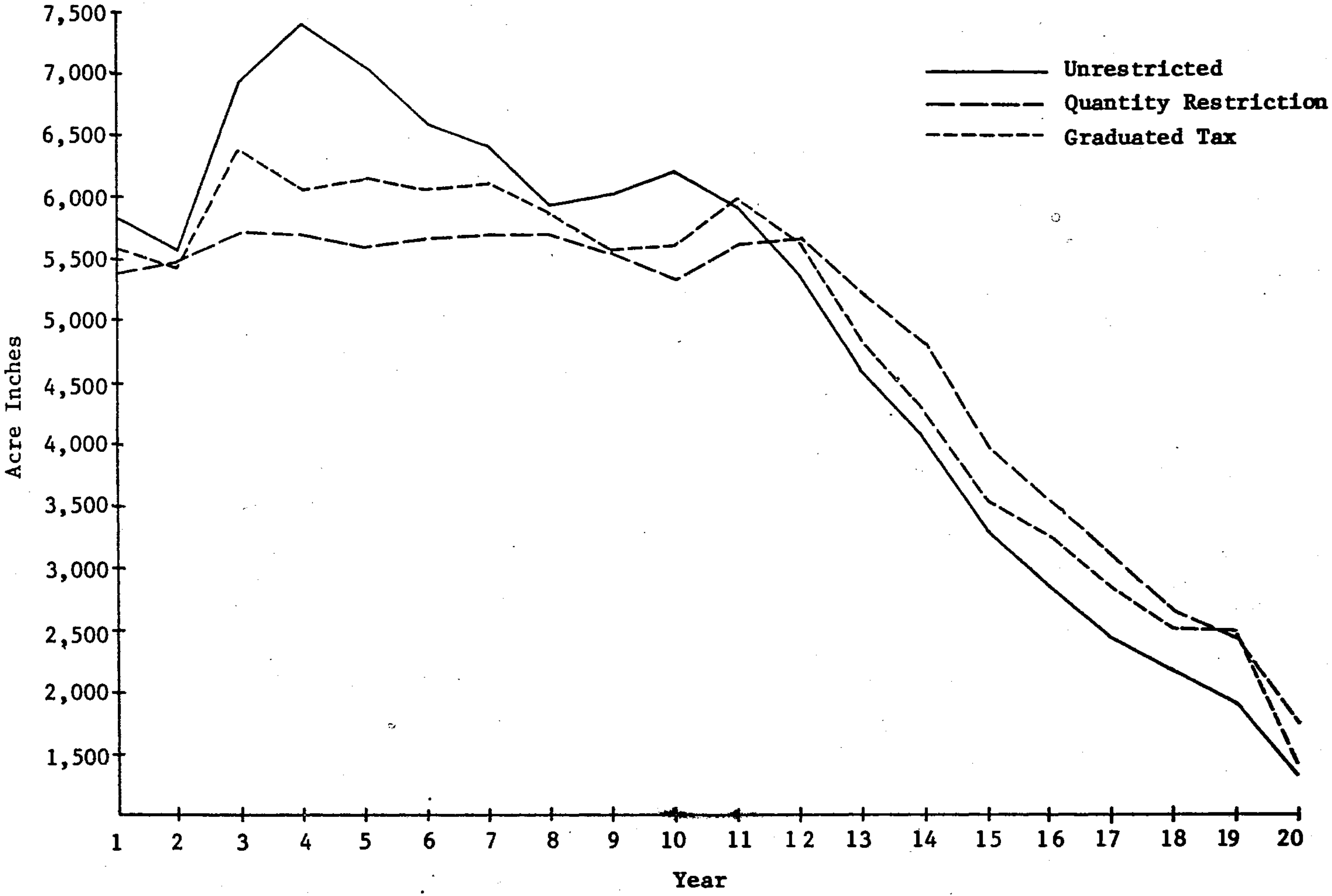


Figure 7. A Comparison of Mean Acre Inches of Irrigation Water Pumped Under Alternative Water-Use Regulation Methods for Resource Situation 1

capacity by adding irrigation wells is illustrated most dramatically by the unrestricted water-use alternative. Well 2 is usually added after year 2 and the increased capacity allows operators to pump large quantities of irrigation water during years 3, 4, 5, 6 and 7. By year 8, capacity of the system has declined significantly. Well 3 is usually added after year 9 and the increased pumping capacity leads to increased pumping in year 10.

From year 1 through year 10, mean values of total acre inches pumped under unrestricted pumping exceed acre inches pumped under the quantity limitation and graduated tax alternatives. During the same period, the irrigator paying a graduated tax for each acre inch above the quantity limit finds it profitable to pump water in excess of the quantity limitation every year except one. This exception occurred during year 2 when pumping capacity is limited. Irrigation well 3 is usually added by year 10 under the unrestricted alternative; by year 11 under the graduated tax alternative; and, by year 12 under the quantity limitation. The lag which develops reflects the different rates of pumping under each alternative in early years of the simulated time period. High early period pumping rates under the unrestricted alternative lead to lower system capacities and earlier additions of well 3. Lower pumping rates under the quantity limitation result in a slower decline in system pumping capacity and thus a lag in the requirement for well 3 until about year 12.

From year 12 to year 20, there is a complete change in the pattern of total acre inches pumped under the three water-use alternatives. Excessive pumping in early periods under the unrestricted alternative reduces irrigation system capacity to such an extent that the lowest mean total acre inches pumped from years 12 through 20 is by the unrestricted irrigator. The second largest rate of water use during the same period occurs under the graduated tax alternative. The largest rate of water use during the period occurs under the quantity limitation simply because the pumping capacity under this alternative is not depleted as rapidly in earlier years of the simulated time period as for the other two alternatives.

All three methods of water-use regulation result in approximately the same mean number of acre inches pumped during year 20. In addition, the feet of saturated thickness remaining at the end of year 20 are 35.84, 38.37 and 37.72 for unrestricted, quantity limitation and graduated tax alternatives, respectively. Thus, though the patterns of water use exhibit considerable variation, particularly during years 1 through 12, the feet of saturated thickness remaining at the end of 20 years is approximately the same for all three alternatives.

Policy makers might ask whether the mean acre inches pumped over the 20-year period under alternative methods of water-use regulation differ significantly. This question can best be answered by testing the difference in means for statistical significance, rather than by making subjective evaluation based on the graphs in Figure 6. The Wilcoxon Matched-Pairs, Signed Ranks Test is a powerful nonparametric test that may be used to test whether two related groups differ significantly.[4] A detailed discussion of the Wilcoxon Matched-Pairs, Signed Ranks Text is included in Appendix E.

To test the difference between pairs of mean values of acre inches pumped over 20 years with no restrictions and with a quantity restriction, the null hypothesis, H_0, is that the mean values are the same.

The alternative hypothesis, H_1, is that the means differ.

To conduct the test, the difference is found between mean values for each pair of years in the 20-year simulation run. Absolute values of the differences are ranked from smallest to largest. Then, the sign of each difference is assigned to the corresponding rank. Finally, the positive and negative ranks are summed. If H_0 is true, the two sums should be about equal. However, if the sum of the positive ranks is very much different for the sum of the negative ranks, the two alternatives differ, and H_0 would be rejected.[5]

The choice and an α level for testing hypotheses depends upon the objectives of the experiment and the relative importance of the Type 1 error (rejecting H_0 when H_0 is in fact true) and Type II error (accepting H_0 and H_1 is in fact true). An α level of .05 or .01 is selected for the tests conducted since they are two of the most commonly used levels.[6] An α level of .05 indicates that the probability of rejecting H_0 when it is actually true is 0.05. That is, five percent of the time a true hypothesis will be rejected.

The means of total acre inches pumped without restrictions are tested against the means of acre inches pumped under a quantity restriction using a two-tailed test of significance. The test statistic, T, is computed utilizing procedures outlined in Appendix E and is found to equal 88. Since the appropriate tabular value of 52 is less than the computed value of 88, there is no statistical basis for rejecting the null hypothesis of no difference between means.

The mean values of total acre inches pumped under the unrestricted alternative and under the graduated tax alternative are similarly tested. The computed test statistic is 82. Since the computed value of T exceeds the appropriate tabular value of 52 for the two-tailed test at $\alpha = 0.05$, there is no statistical basis for rejecting the null hypothesis of no difference between the matched-pairs of means.

The mean values of total acre inches pumped under the quantity restriction and under the graduated tax are next tested for statistical significance. The computed T value of 94 exceeds the appropriate tabular value of 52 for the two-tailed test at $\alpha = 0.05$. Thus, there is no statistical basis for rejecting the null hypothesis of no difference between the means.

Statistical tests between each set of mean values of total acre inches pumped under the three institutional alternatives reveal no significant differences among any of the distributions. Thus, even though Figure 6 indicates a seemingly large difference in acre inches pumped from year 3 through 7 under the unrestricted and quantity limitation alternatives, the means are not significantly different, from a statistical standpoint.

Since timeliness of application in relation to critical stages of plant development is more important to final yield and net returns than is the total number of acre inches applied, the possibility of significant differences among net farm income and net worth means still exists. The next sections discuss statistical tests of hypotheses concerning net farm income and net worth.

Net Farm Income

Mean values of net farm income over the 20-year period under unrestricted, quantity restriction and graduated tax alternatives are presented graphically in Figure 8. Several outstanding features merit

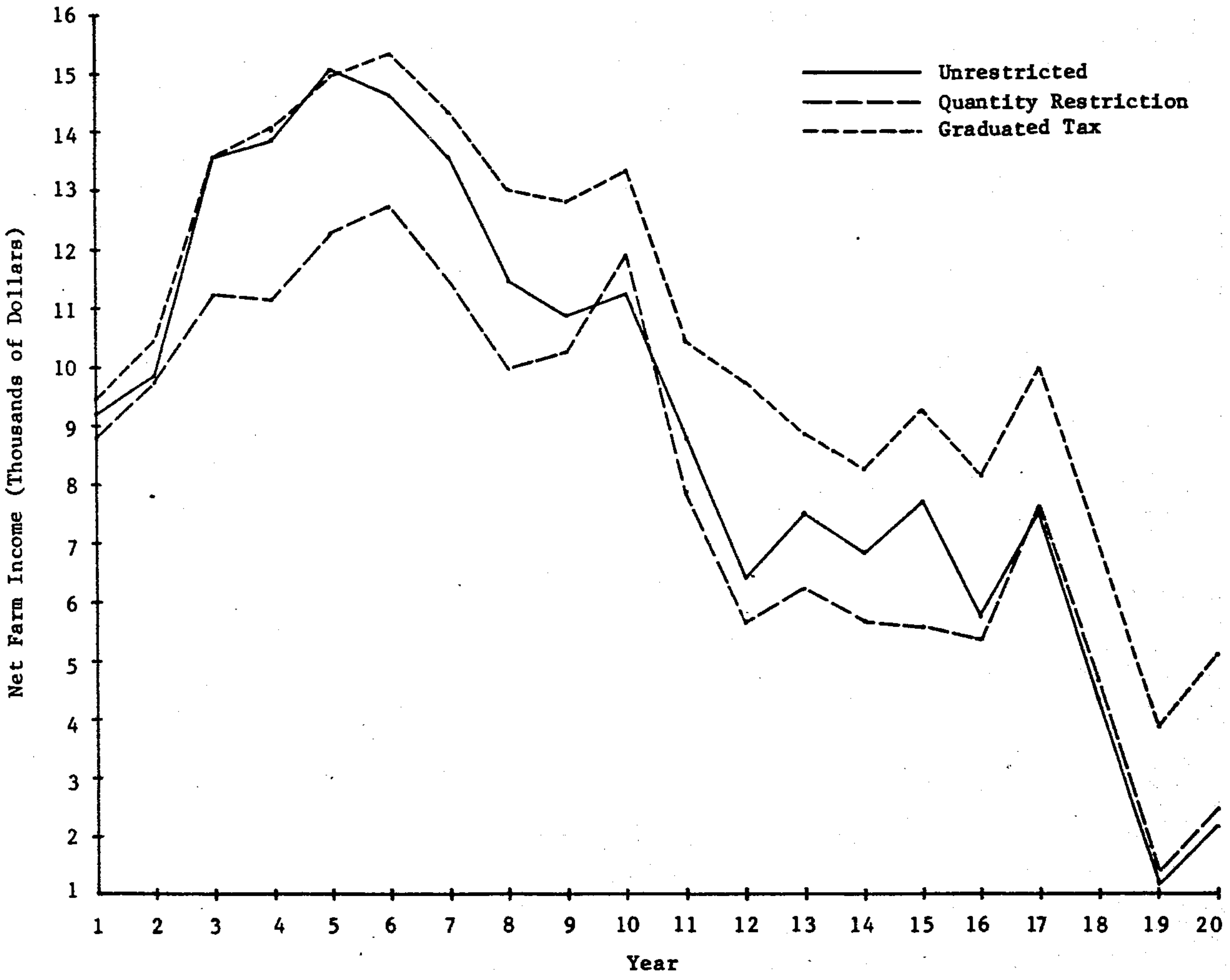


Figure 8. A Comparison of Mean Net Farm Income Under Alternative Water-Use Regulation Methods for Resource Situation 1

attention. By far the most important is that net farm income under the graduated tax alternative exceeds net farm income under the unrestricted pumping alternative during every year except year 5. From year 1 through year 5, net farm income under both alternatives increases and the level of net farm income is approximately the same for both. Beginning with year 6, net farm income under the graduated tax alternative exceeds net farm income under unrestricted pumping by a wider margin. Several interrelated factors create this phenomenon. First, the unrestricted irrigator tends to operate his irrigation system at its maximum capacity. In responding to soil moisture levels throughout the growing season, the tendency is to apply too much irrigation water. That is, by attempting to maximize yields per acre or per crop block, irrigation water is applied during certain periods of the crop year to the point where its marginal physical productivity is very low, perhaps even zero. Additional water adds very little or nothing to final crop yields. The value of output resulting from the additional water, whose marginal physical productivity is very low, is less than the cost of the added water. By reducing applications of water during some periods, applying water on grain sorghum during Irrigation Period 4 only if it is profitable and insuring a preplant irrigation on wheat every year, the irrigator operating under the graduated tax alternative is able to pay the tax and still achieve higher net farm income.

A second factor contributing to higher net farm income under the graduated tax alternative is that less water is pumped during earlier periods thus enabling the taxed irrigator to achieve more timely irrigations in relation to plant needs during later critical periods of development. More timely applications lead to higher final crop yields for the same amount of irrigation water. Since pumping costs rise more slowly, net returns per acre and net farm income are higher. A third related factor is that higher yields are reflected in higher government payments, particularly from years 11 through 20, for the irrigator under the graduated tax alternative. Higher government payments contribute directly to higher net farm income.

Net far income under the quantity restriction is of interest also. It is lower than net farm income under the graduated tax during every year and exceeds net farm income under unrestricted pumping conditions during year 10 and from year 17 through year 20. Net farm income under unrestricted and quantity restriction alternatives are almost identical from year 16 through 20, however, higher remaining pumping capacity enables the quantity restriction alternative to maintain a higher net farm income during this period.

In addition to interest in the distributions of total acre inches pumped under various water-use regulatory alternatives, policy makers may wonder whether significant differences exist among the mean values of net farm income over the 20-year period. It might be hypothesized based on analysis of Figure 7 that mean net farm income under the graduated tax alternative differs significantly from mean net farm income under a quantity restriction. This hypothesis, among others, is tested through the use of the Wilcoxon Matched-Pairs, Signed Ranks Test.

The mean values of net farm income under the graduated tax and the quantity limitation are hypothesized to be the same. The alternative hypothesis is that mean net farm income under the graduated tax is above that under the quantity restraint. The use of a directional alternative hypothesis requires use of a one-tailed test. The α level of the test is 0.01. The computed value of T is zero. All mean values under the graduated tax exceed the corresponding mean values under the quantity limitation. The appropriate tabular value of T for a one-tailed test of the null hypothesis at $\alpha = 0.01$ is 43. Since the computed value of T is less than the tabular value, there is statistical basis for rejecting the null hypothesis that the means are the same. There is statistical evidence to support the alternative hypothesis that the mean values of net farm income under the graduated tax are greater than the mean values under the quantity limitation.

The mean values of net farm income under the unrestricted alternative are tested against mean values under the quantity limitation. The null hypothesis is the same as above. The alternative hypothesis is that the mean net farm income under unrestricted pumping is above that under the quantity limitation. The computed value of T is nine. The computed value of T is less than the tabular value of 43 for a one-tailed test of H_0 at $\alpha = 0.01$. Thus, there is statistical basis for rejecting H_0 in favor of the alternative hypothesis that mean net farm income under the unrestricted alternative exceeds that under the quantity limitation.

The same hypotheses are tested for means values of net farm income under no restrictions and under the graduated tax alternative. The computed value of T, which is two, is less than the tabular value of 43 for a one-tailed test of significance at $\alpha = 0.01$. Thus, there is statistical basis for rejecting H_0 of no difference between means in favor of H_1 that mean net farm income under the graduated tax alternative is above mean net farm income under unrestricted pumping.

Thus, of the three tests conducted on mean values of net farm income, all three allow us to reject the null hypothesis of no difference between the mean values of net farm income. Mean net farm income under the graduated tax alternative is above that under either the unrestricted pumping or quantity limitation alternatives. Mean net farm income under unrestricted pumping is above that under the quantity limitation.

It is noteworthy that mean values of net farm income under the three alternatives differ significantly while no significant differences are found among mean values of acre inches pumped. Irrigators pumping under the graduated tax alternative are able to make timely applications on grain sorghum and wheat during Irrigation Periods 4 and 5. The marginal value product of these timely irrigations during critical stages of plant development are quite high. Thus, despite the tax payments required, net farm income exceeds that of the unrestricted pumper. The irrigator without restrictions tend to apply irrigation water to the point where its marginal value product is very low. This is particularly true when pumping capacity is high after the addition of irrigation well 2 early in the period. By attempting to maximize yields, the unrestricted pumper's profits are reduced. The irrigator operating under a quantity limitation is restricted by that limitation during early years of the simulation. Only during the final four years, when his pumping capacity is still adequate, does net farm income under the quantity limitation exceed that under unrestricted pumping.

Figure 9 illustrates the effects of the three water-use regulatory alternatives on variability of net farm income, as measured by the

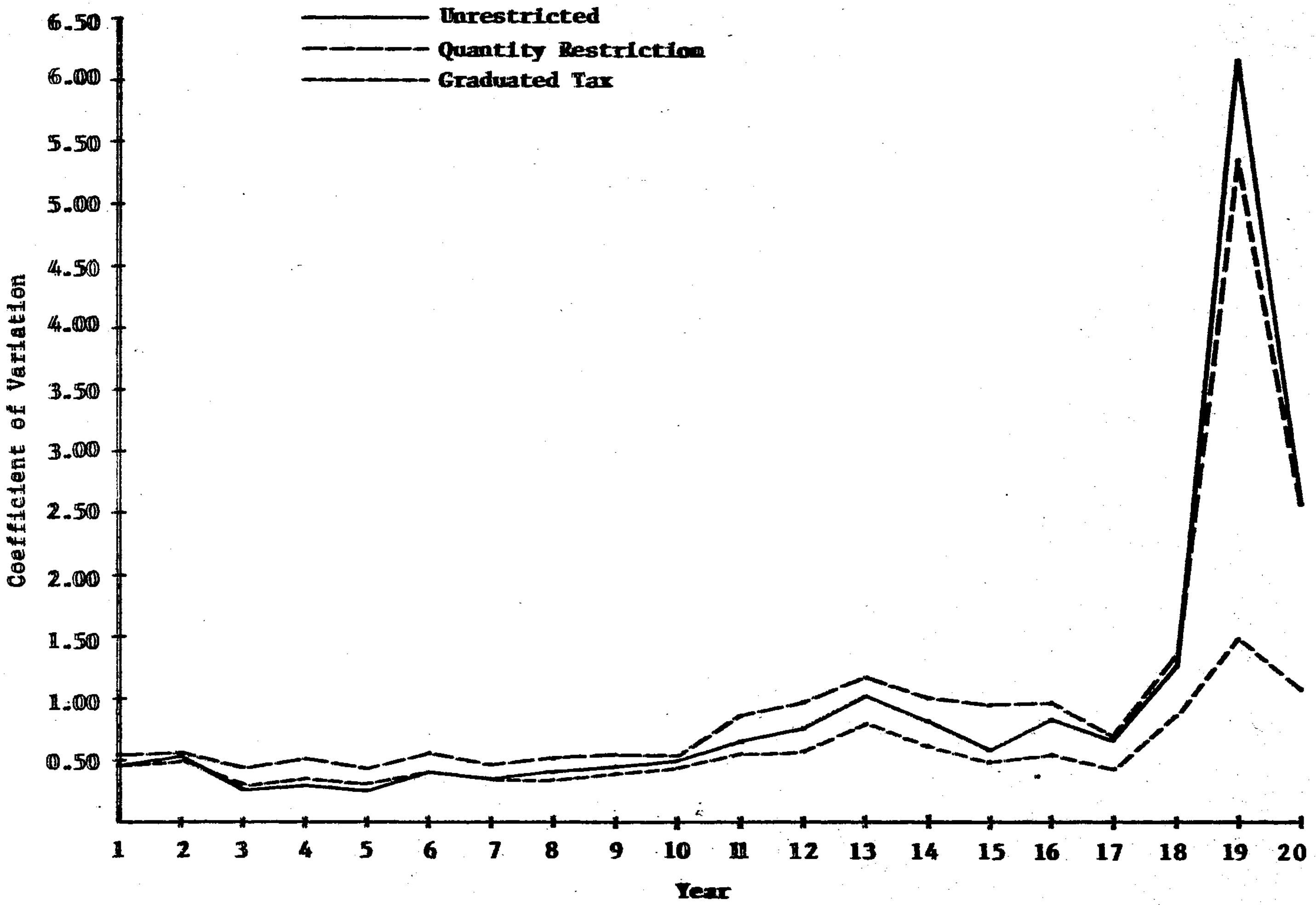


Figure 9. A Comparison of Coefficients of Variation of Net Farm Income Under Alternative Water-Use Regulation Methods for Resource Situation 1

coefficient of variation. The coefficient of variation resulting from a quantity restriction on water use is consistently higher from year 1 to year 18. This is not an unexpected result. The quantity restriction is often reached during Irrigation Period 4 when grain sorghum is in the boot-heading and grain-filling stages of plant development. Failure to apply needed moisture during this period reduces final yield unless natural rainfall is sufficient to compensate for the lack of irrigation water. In addition, when the quantity restriction is reached, preplant irrigations on irrigated wheat are eliminated. The existence of a stand on wheat is then determined by Fall soil moisture conditions. About 20 percent of the time no stand is achieved and wheat yield is assumed to be zero. Both of the above factors combine to increase variability of net farm income relative to mean net farm income under the unrestricted and graduated taxation alternatives.

Coefficients of variation of net farm income under the unrestricted and graduated tax alternatives are approximately the same for the first few years of the simulated time period. Coefficient of variation for unrestricted pumping is larger than that of the graduated tax for year 2, approximately equal during years 6 and 7, and then is larger for years 8 through 20. Thus, after year 7, the coefficient of variation for the graduated tax alternative is lower than for either the unrestricted or quantity restriction alternatives.

The marked increase in coefficients of variation during years 18, 19 and 20 reflects the declining pumping capacity, declining proportion of irrigated acres and increased variability resulting from dryland production. Extreme variability occurring in year 19 relative to years 18 and 20 results from the random occurrence of very dry years across replications of year 19. The reduced variability under the graduated tax alternative results from timely applications of irrigation water during Irrigation Periods 4 and 5. These applications stabilize wheat and grain sorghum yields, and government payments, thus reducing variability of net farm income.

Net Worth

Mean values of net worth over the 20-year simulated time period under unrestricted, quantity restriction and graduated tax alternatives are presented in Figure 10. Graphs of the three sets of means leave no doubt that net worth under the graduated tax alternative is higher throughout the period. Net worth under the unrestricted alternative is second largest over the 20-year period followed by net worth under the quantity limitation alternative. The differences appear significant, particularly after about year 10. The means were tested for statistical significance using the Wilcoxon Matched-Pairs, Signed Ranks Test.

Three null hypotheses are formulated and tested. First, it is hypothesized that mean net worth under the graduated tax and under the quantity restriction are the same. The alternative hypothesis is that mean net worth under the graduated tax alternative is above mean net worth under the quantity restriction alternative. The computed value of the test statistic T equals zero. Since the null hypothesis is directional, a one-tailed test is conducted at the $\alpha = 0.01$ level. The appropriate tabular T value is 43. The tabular value of the test statistic far exceeds the computed value. Thus, there is sufficient statistical justification for rejecting the null hypothesis that the means are the same in favor of H_1 that mean net worth under the

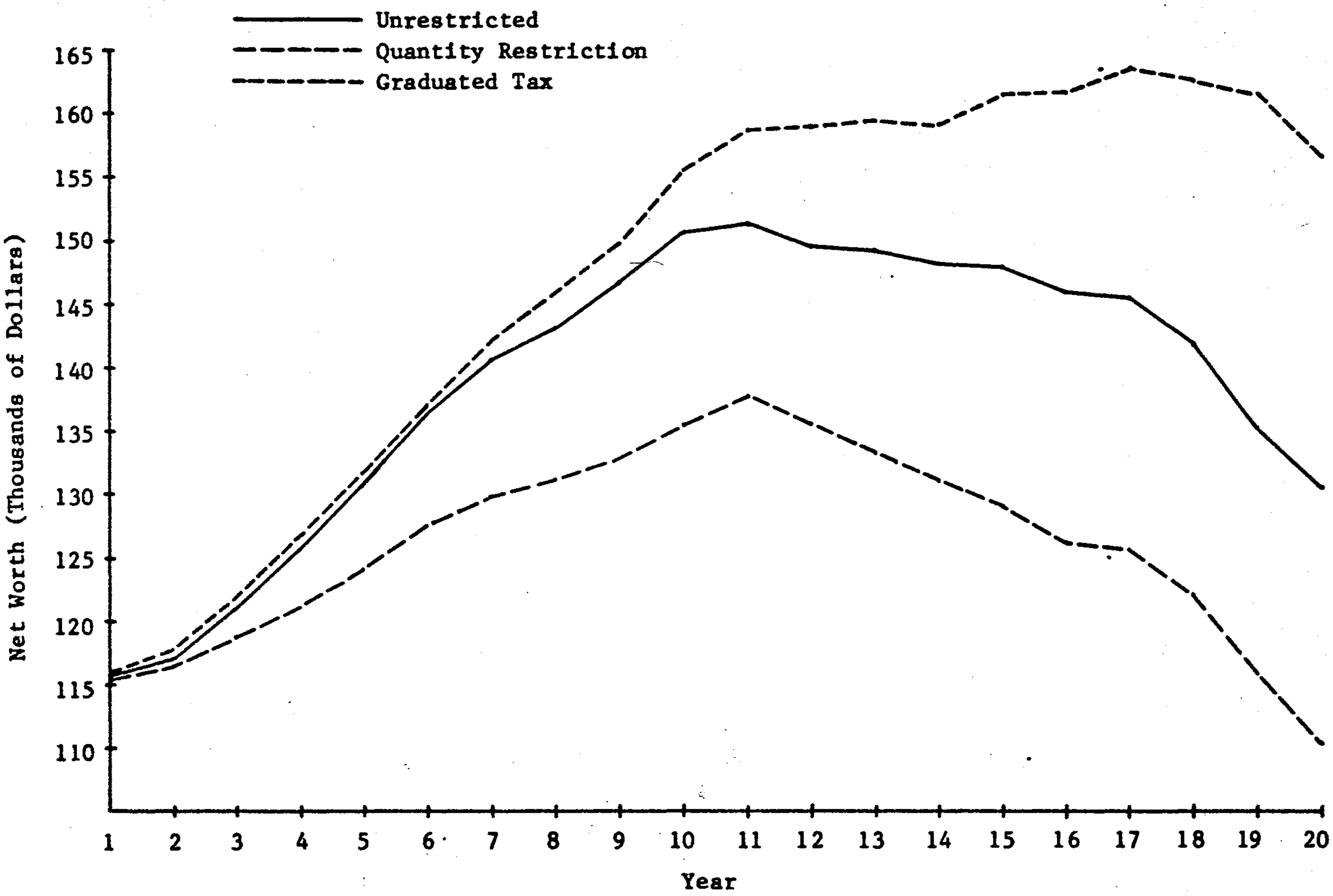


Figure 10. A Comparison of Mean Net Worth Under Alternative Water-Use Regulation Methods for Resource Situation 1

graduated tax is above that under the quantity restriction.

The second null hypothesis formulated is that mean net worth under the graduated tax and unrestricted pumping alternatives are the same. The alternative hypothesis, which is again directional, is that mean net worth under the graduated tax alternative is above mean net worth under unrestricted pumping. The computed value of T is zero. The appropriate tabular value for a one-tailed test at the $\alpha = 0.01$ level is 43. Since the computed T value is exceeded by the tabular value, there is statistical basis for rejecting the null hypothesis of no difference between means in favor of the alternative hypothesis that mean net worth under taxation is above that under unrestricted pumping.

The third null hypothesis is that there is no difference between mean net worth resulting from unrestricted pumping and the quantity limitation. The alternative hypothesis, again a directional hypothesis, is that mean net worth resulting from the unrestricted pumping alternative is above mean net worth resulting from a quantity limitation on pumping. A computed test statistic of zero is exceeded by the appropriate tabular T value of 43 for a one-tailed test of the null hypothesis at $\alpha = 0.01$. Thus, there is statistical basis for rejecting the null hypothesis of no difference in favor of the alternative hypothesis that mean net worth under the unrestricted pumping alternative is above mean net worth under the quantity limitation alternative.

Effects of Unrestricted Water Use on Resource Situation 2

Resource Situation 2 represents the adequate water situation within the study area. The weighted average saturated thickness of the underground formation is 325 feet. Only about 125 feet of saturated thickness are required to maintain an irrigation system pumping capacity of 1,000 gallons per minute. Consequently, irrigation operators represented by Resource Situation 2 may lower the static water level by approximately 200 feet before well yields begin to decline and a significant rise in pumping costs occurs.

Irrigators pumping from Resource Situation 2 are assumed to have one irrigation well, pump, engine and distribution system capable of delivering 1,000 gpm to the surface while the water table declines from 325 to 125 feet. Given the assumptions on irrigated acreage and number of wells for the representative farm, the decline in the water table is less than 200 feet during the 20-year planning horizon. Thus the well yield remains constant at 1,000 gpm for the 20-year period and no additional wells are required to maintain irrigated production of 315 acres of cropland. No expansions or contractions of irrigated cropland are assumed for representative farms in Resource Situation 2.

Acreages of individual crops are divided into crop blocks, as for Resource Situation 1, and a separate soil moisture balance system for each block maintains daily measurement of soil moisture and atmospheric stress, and the corresponding reduction in final crop yield. Irrigation strategies for the unrestricted water-use alternative are based on soil moisture levels as they relate to critical stages of plant development for individual crops throughout the growing season. The basic irrigation strategies are simulated over a 20-year time period, given the assumptions for representative firms in Resource Situation 2, and the results are replicated 15 times. The following sections outline the effects of unrestricted water use on acre inches pumped during the crop year, net farm income, variability of income and net worth of the representative farm firms in Resource Situation 2.

Effects on Acre Inches Pumped

A summary of total acre inches pumped under the unrestricted water-use alternative is presented in Table XIX. The mean, standard deviation, maximum, minimum and range of acre inches pumped has been computed for each year. Since well capacity remains at 1,000 gpm throughout the 20-year simulated time period, there are no significant changes in system capacity as there were for Resource Situation 1. Variability in quantity of water pumped results from random variation in rainfall and evapotranspiration rather than variations in pumping capacity and number of acres irrigated.

Mean values of total acre inches pumped range from 6,662 in year 10 to 7,233 in year 14. The maximum number of acre inches pumped during any of the simulation runs is 7,925 pumped during year 11, replication 12, and again during year 18, replication 2. Minimum quantity of water pumped is 3,007 acre inches in year 1, replication 5. The greatest range in acre inches pumped is 4,806 in year 1 when a maximum of 7,813 acre inches are pumped during replication 8 and 3,007 acre inches are pumped during replication 5.

Over the 20-year period, five years require pumping in excess of 7,000 acre inches. The dry years are 7, 8, 12, 14 and 16. Conversely, five years require less than 6,800 acre inches of irrigation water. These years are 1, 2, 4, 6 and 10. The considerable variability in total acre inches pumped is one indication of the weather variability

TABLE XIX

SUMMARY OF TOTAL ACRE INCHES PUMPED FOR RESOURCE SITUATION 2 WITH NO RESTRICTIONS ON WATER USE

Replication	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	6883	4297	7408	6255	7921	7921	7282	7539	6705	6593	7090	7734	7468	6951	6382	7135	6793	7312	7745	6973
2	7340	6517	7207	7701	5985	7048	7412	7288	7742	6973	6300	7764	7520	7657	7607	6868	7558	7925	7553	7198
3	7090	6795	7288	7340	7213	6919	7080	7252	6822	6525	6765	5681	7558	7865	7423	4791	7207	3352	6337	7862
4	7674	7498	7123	6480	7892	7865	7450	7865	5985	7207	7558	7597	4005	7063	5385	7140	7117	6615	6970	7519
5	3007	7348	7198	7050	3911	7063	6585	7408	7228	6695	6735	6495	4942	7524	6921	7095	6915	6892	5662	6936
6	6889	7108	7117	7862	7738	7832	7670	7595	6255	6806	7745	7243	6262	7663	6810	7468	6540	7509	7745	6365
7	7663	7232	6817	6705	6248	6309	6743	6016	5584	5993	4950	7730	6750	6879	4567	7275	7865	7825	6803	6007
8	7813	6795	7474	7185	7742	6626	6953	5878	5051	5299	5625	7490	7802	7288	7685	6210	7401	7378	7498	6695
9	6810	7607	7130	5167	7745	5325	6840	6280	7483	6718	7777	7835	7333	5998	7408	7835	7018	6540	6092	7565
10	6985	5872	5985	7311	5587	6457	7123	7498	7220	7333	6988	6105	7408	7408	7457	7430	7745	7177	7791	6885
11	6769	7745	5857	4770	6915	6097	6555	5917	7020	6999	6839	7018	7520	5947	7663	7194	6864	7685	7393	7020
12	5668	4972	6124	5872	7642	6073	7513	7475	7685	7865	7925	7348	7260	7241	6115	6815	6429	6508	7558	5227
13	7440	6750	7325	7498	5917	7243	7477	6232	7565	4740	6435	7320	7565	7435	6930	7565	4860	7162	6592	6322
14	7215	7020	6877	7228	7490	6885	7153	7655	7498	6975	7627	7326	7685	7685	7063	7618	7117	7063	5130	6206
15	5130	7108	5602	7592	6973	5475	6142	7745	7663	7213	7865	7034	7369	7895	7650	7477	7184	5707	7715	7565
Mean	6692	6711	6835	6777	6861	6743	7065	7043	6900	6662	6948	7181	6963	7233	6871	7061	6974	6843	6972	6823
Std. Dev.	1249	971	622	910	1134	806	429	739	833	795	866	635	1095	596	916	741	710	1127	846	705
Maximum	7813	7745	7474	7862	7921	7921	7670	7865	7742	7865	7925	7835	7802	7895	7685	7835	7865	7925	7791	7862
Minimum	3007	4297	5602	4770	3911	5325	6142	5878	5051	4740	4950	5681	4005	5947	4567	4791	4860	3352	5130	5227
Range	4806	3448	1872	3092	4010	2596	1528	1987	2691	3125	2975	2154	3797	1948	3118	3044	3005	4573	2661	2635

existing in the study area and of the ability of the Production Subset to simulate these variable weather conditions.

Saturated thickness at the end of the 20-year period under unrestricted pumping ranges from a minimum of 230.49 feet to a maximum of 240.62 feet, averaging 235.03 feet. In terms of feet of decline in saturated thickness, the mean decline over 15 replications at the end of 20 years is 89.89 feet for an average rate of decline of 4.50 feet per year.

Effect on Net Farm Income

The effects on net farm income of unrestricted pumping by representative farms in Resource Situation 2 are presented in Table XX. The unrestricted pumping alternative is simulated over a 20-year period and replicated 15 times. The mean, standard deviation, maximum, minimum, range and coefficient of variation of net farm income are computed for each year.

Mean values of net farm income, while fluctuating widely from year to year, have a general upward trend over the 20-year period. The rise is rapid during the first five years as the result of high crop yields per acre and a corresponding rise in government payments. Mean net farm income rises from $10,598 in year 1 to $16,754 in year 5. Over the same period, mean values of government payments (wheat certificates plus feed grain payments) rise from $8,218 to $13,625. So, of the $6,156 increase in net farm income, $5,403 results from an increase in government payments. Government payments, which are computed on the basis of a five-year moving average, stabilize after year 5 and remained in the $13,200 to $13,700 range. Mean net farm income continues its

TABLE XX

SUMMARY OF NET FARM INCOME FOR RESOURCE SITUATION 2 WITH NO RESTRICTIONS ON WATER USE

	Year																			
Replication	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	11496	24868	11989	17602	12270	14702	15977	16748	22039	20181	18404	13008	12746	20322	18598	19528	20863	18901	9324	20510
2	8173	12112	9930	11255	19198	13335	12856	12911	12184	15010	16495	13131	15146	13215	16130	20579	15829	9660	17909	19995
3	10553	12132	11804	12369	16031	14722	15558	15221	18020	20633	18030	21874	17149	14067	17189	22296	17997	26993	17974	13491
4	4330	7669	12531	17304	16366	8516	15145	10584	17191	13791	15247	15677	31737	21121	27602	21485	19595	19804	21991	18454
5	15412	4443	14808	13171	26548	20963	21435	12411	17195	23183	18734	22400	28750	13896	22077	18622	22341	20423	24284	18287
6	11600	12060	13176	10387	13747	10300	7454	10538	15895	16641	10232	14573	19817	15361	20639	14460	22732	17189	12301	21412
7	5509	10656	14331	17252	16218	12356	17056	23334	25546	26076	26156	16303	20950	22825	24379	19684	13779	12824	20384	23717
8	6481	15223	12606	16398	11030	18047	14300	17290	23805	25265	22516	12213	12923	17588	13451	22434	19924	18577	18006	21863
9	13875	9551	11773	21732	12889	22300	20299	20785	10134	17163	13519	13379	17294	23400	16664	12118	17536	23110	22307	14193
10	11285	13055	21941	14550	21454	22419	17218	15056	17518	14278	17166	22317	16273	16515	17922	18058	13455	18196	12981	17995
11	12579	4968	16270	17996	16850	24816	19202	21823	18778	18437	21830	16140	15181	21587	16457	18865	22166	12866	10616	14942
12	16403	22710	17192	22167	15117	16651	11759	9988	8612	10998	13619	13542	15932	14099	18774	15788	23296	22132	16078	25059
13	5854	14162	12444	10808	20949	17107	16760	17340	13428	24053	23178	17549	14832	16807	16016	12952	27433	20766	22568	20705
14	9826	11660	14991	7454	13251	15417	16785	12684	13332	13926	14920	13597	8665	13685	18001	14140	19824	20130	22710	21110
15	15590	11241	20406	11063	19395	26226	24518	13375	15343	18809	11256	16880	15201	10124	14319	15906	17885	22042	11036	17663
Mean	10598	12434	14413	14767	16754	17192	16421	15353	16601	18563	17420	16172	17506	16974	18548	17794	19644	18908	17364	19293
Std. Dev.	3872	5526	3340	4307	4152	5243	4112	4191	4764	4613	4545	3490	5950	4022	3774	3374	3744	4423	5045	3336
Maximum	16403	24868	21941	22167	26548	26226	24518	23334	25546	26076	26156	22400	31737	23400	27602	22434	27433	26993	24284	25059
Minimum	4330	4443	9930	7454	11030	8516	7454	9988	8612	10998	10232	12213	8665	10124	13451	12118	13455	9660	9324	13491
Range	12073	20425	12011	14713	15518	17710	17064	13346	16934	15078	15924	10187	23072	13276	14151	10316	13978	17333	14960	11568
Coef. of Var.	0.37	0.44	0.23	0.29	0.25	0.30	0.25	0.27	0.29	0.25	0.26	0.22	0.34	0.24	0.20	0.19	0.19	0.23	0.29	0.17

upward trend as chattle debts are paid off and the beginning real estate debt is retired. Cash reserves above the $10,000 minimum specified in the Farm Firm Simulation Model earn interest also. The maximum mean net farm income is $19,644 in year 17 and mean net farm income in year 20 is $19,293.

Variability of net farm income fails to follow a definite pattern over the 20-year simulated time period. Relative variability, as measured by the coefficient of variation, ranges from a high of 0.44 during year 2 to a low of 0.17 during year 20. In general, the coefficient of variation is low, and is expected to be lower in this unrestricted simulation than for either the graduated tax or quantity limitation alternatives.

The maximum yearly value of net farm income is $31,737 generated in year 13, replication 4. The minimum value of net farm income is $4,330 generated in year 1, replication 4. The greatest range in net farm income levels for a single year occurs during year 13 when $23,072 is the difference between a maximum of $31,737 and a minimum of $8,665. Although variability from year to year is significant, the unrestricted pumping alternative under adequate water conditions leads to relatively stable, increasing net farm income over time.

Effects on Net Worth

Table XXI presents the effects on net worth of unrestricted pumping for representative farms in Resource Situation 2 based on 15 replications of a 20-year simulation of the firm. The mean, standard deviation, maximum, minimum and range in net worth have been computed for each year of the simulation run.

TABLE XXI

SUMMARY OF NET WORTH FOR RESOURCE SITUATION 2 WITH NO RESTRICTIONS ON WATER USE

	Year																			
Replication	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	124014	136685	140275	148257	152036	157612	164301	171346	182543	192886	202368	208074	213851	225466	235877	247018	259554	270987	275806	289109
2	121307	124350	125799	128285	136744	140712	144286	147905	150966	156266	162899	167167	173202	177972	184804	194893	201881	204098	212925	223685
3	123250	126389	129443	132984	139109	144210	150045	155484	163157	173159	181546	193063	201596	208150	216940	229445	239329	254676	265376	273284
4	118215	117570	120917	127959	134297	134381	139758	141528	148478	152821	158331	164387	181241	192268	207764	219337	230016	241064	254151	265256
5	127076	124081	129391	133548	147360	157470	168165	171993	179666	192126	201841	214405	230909	238398	251720	262837	276946	290089	305424	318245
6	124100	127216	131392	133390	137734	139268	138461	140193	146150	152712	154236	159291	168613	174879	184973	190461	202344	210452	215230	227168
7	119190	121020	125851	133025	139303	142550	149446	160930	174207	188417	203095	211301	223249	236926	251790	263616	271667	279107	292330	307440
8	119977	125417	129051	135721	138016	145603	150504	157534	169513	183005	195019	199812	205397	214777	220985	233659	245094	255770	266538	280440
9	125890	127032	130086	140713	144690	155681	165477	175574	177898	185889	191339	196898	205699	219143	227953	233284	242955	256767	270613	279242
10	123839	127722	138522	144106	154671	166082	174002	180125	188334	194527	203079	215627	224360	233640	243908	254272	261687	272716	280395	292169
11	124865	122212	128604	136434	143305	155988	165048	175879	184932	194178	206092	214287	222144	234912	244193	255204	268973	276337	282361	292065
12	127823	139113	146822	158384	164797	172328	176280	178499	179697	182999	188412	193984	201629	208210	218147	225911	239422	252434	261736	276710
13	119476	124084	127572	129760	139498	146430	153243	160481	164803	177363	189673	198338	205325	214071	222210	227987	243439	255641	269556	282769
14	122665	125408	130921	130507	134406	140005	146683	150158	154123	158701	164184	168898	169817	174833	182991	188138	197833	207937	220392	232195
15	127220	129804	139540	142419	151475	165384	178578	183586	190288	199919	204165	212874	220690	224911	232175	240546	250780	264071	269967	281072
Mean	123260	126540	131612	137033	143829	150914	157618	163414	170317	178998	187085	194557	203181	211904	221762	231107	242128	252870	262853	274723
Std. Dev.	3087	5496	6776	8404	8697	11432	13379	14393	14915	16441	18423	20073	20889	22453	23291	24673	25219	26488	27195	27653
Maximum	127823	139113	146822	158384	164797	172328	178578	183586	190288	199919	206092	215627	230909	238398	251790	263616	276946	290089	305424	318245
Minimum	118215	117570	120917	127959	134297	134381	138461	140193	146150	152712	154236	159291	168613	174833	182991	188138	197833	204098	212925	223685
Range	9608	21543	25905	30425	30500	37947	40117	43393	44138	47207	51856	56336	62296	63565	68799	75478	79113	85991	97499	94560

Mean values of net worth increase steadily from year 1 through year 20 of the simulated time period. The minimum mean net worth is $123,260 in year 1. Maximum mean net worth is the ending net worth of $274,723. Ending net worth has a range of $94,560. This figure is the difference between the maximum ending net worth of $318,245 in replication 5 and the minimum ending net worth of $223,685 in replication 2. Two factors contribute to rising net worth over the 20-year period. The first is gradual retirement of chattle and real estate debt, which reduces liabilities. The second is gradual accumulation of cash, in excess of the $10,000 minimum, which adds to the value of assets.

Effects of a Quantity Restriction on Resource Situation 2

This section elaborates the effects of restricting the quantity of irrigation water an individual irrigator is allowed to pump each crop year on representative farm firms in Resource Situation 2. The quantity restriction limits the individual irrigator to pumping 1.5 acre feet per acre of water rights. For the representative farm firm with 315 irrigated acres, the limitation is 5,670 acre inches per crop year. Rather than pump water with abandon in every critical irrigation period, the irrigator is assumed to pump only a specified quantity per acre per crop during each critical stage of the irrigation season. The effect of this action is to reduce the maximum pumping possible in early periods of the crop year to insure that some irrigation water remains for later periods of the year. The 5,670 acre inch limit is not absolute. That is, irrigators are allowed to complete a daily application on the day the system has delivered 5,670 acre inches to the surface.

Thus, there is a mean and variance associated with the quantity limitation even though, with constant pumping capacity, the standard deviation is generally quite low.

Effect on Total Acre Inches Pumped

The effect of a quantity restriction on acre inches pumped per crop year is reflected in Table XXII. The table presents total acre inches pumped per crop year over the 20-year simulated time period, with the results of each run replicated 15 times. The mean, standard deviation, maximum, minimum, and range of total acre inches pumped are shown for each year.

Mean values showed very little variability, as expected, ranging from a minimum of 5,472 acre inches in year 1 to a maximum of 5,699 acre inches in year 7. Individual yearly observations show considerably more variation. The maximum number of acre inches pumped during any year is 5,730 in year 1, replication 11. The minimum number of acre inches pumped, 3,008, also occurs during year 1, but in replication 5. Since both the maximum and minimum number of acre inches pumped occur in year 1, the maximum range of 2,722 acre inches occurs during year 1.

Saturated thickness remaining at the end of the 20-year simulation runs varies from a minimum of 250.82 feet to a maximum of 254.26 feet. Mean saturated thickness after 20 years under the quantity restriction is 251.81 feet. Assuming a beginning saturated thickness of 325 feet, this represents an average decline in saturated thickness of 73.19 feet or 3.66 feet per year. This rate of decline under the quantity restriction compares to the 4.50 feet per year decline for the

TABLE XXII

SUMMARY OF TOTAL ACRE INCHES PUMPED FOR RESOURCE SITUATION 2 WITH A QUANTITY RESTRICTION ON WATER USE

	Year																			
Replication	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	5680	4297	5677	5707	5716	5707	5682	5722	5692	5677	5692	5677	5686	5677	5677	5692	5677	5707	5677	5712
2	5692	5677	5692	5712	5681	5677	5673	5722	5677	5692	5704	5677	5712	5677	5677	5677	5686	5677	5692	5705
3	5692	5707	5692	5692	5707	5677	5692	5718	5692	5680	5671	5681	5707	5677	5692	4791	5692	3352	5715	5703
4	5673	5712	5682	5692	5707	5616	5707	5690	5681	5707	5707	5677	4005	5673	5385	5705	5722	5692	5723	5692
5	3008	5677	5692	5677	3911	5692	5722	5677	5677	5685	5722	5722	4943	5690	5692	5677	5707	5692	5662	5722
6	5722	5692	5692	5677	5692	5712	5677	5677	5707	5718	5686	5692	5692	5692	5692	5677	5722	5707	5677	5722
7	5686	5692	5677	5722	5693	5713	5686	5712	5583	5690	4950	5699	5686	5692	4567	5677	5703	5707	5707	5679
8	5707	5692	5707	5677	5677	5671	5692	5671	5051	5299	5625	5686	5716	5677	5686	5673	5677	5722	5692	5685
9	5680	5712	5707	5168	5677	5130	5718	5702	5677	5707	5677	5712	5707	5694	5677	5677	5677	5692	5691	5712
10	5692	5715	5681	5699	5539	5722	5692	5712	5673	5722	5677	5704	5707	5671	5692	5692	5677	5692	5692	5710
11	5730	5705	5490	4770	5692	5696	5722	5674	5722	5707	5697	5672	5703	5490	5677	5692	5674	5677	5707	5692
12	5595	4972	5674	5715	5677	5672	5692	5712	5716	5716	5692	5677	5712	5707	5672	5715	5687	5721	5707	5160
13	5703	5722	5707	5716	5681	5692	5722	5685	5692	4545	5692	5707	5712	5692	5692	5677	4860	5722	5707	5696
14	5692	5722	5722	5677	5692	5692	5692	5677	5707	5722	5692	5692	5677	5716	5673	5703	5692	5705	5130	5681
15	5130	5712	5689	5677	5692	5475	5711	5692	5677	5692	5690	5692	5692	5677	5692	5677	5707	5707	5707	5712
Mean	5472	5560	5679	5599	5636	5643	5699	5696	5642	5597	5638	5691	5537	5673	5590	5627	5637	5545	5659	5665
Std. Dev.	697	397	54	267	536	154	17	19	166	309	192	15	467	52	293	232	216	607	147	141
Maximum	5730	5722	5722	5722	6639	5722	5722	5722	5722	5722	5722	5722	5716	5716	5692	5715	5722	5722	5723	5722
Minimum	3008	4297	5490	4770	3911	5130	5673	5672	5051	4545	4950	5677	4005	5490	4567	4791	4860	3352	5130	5160
Range	2722	1425	232	952	2728	592	49	50	671	1177	772	45	1711	226	1125	924	462	2370	593	562

unrestricted pumping alternative. The implications of various water-use rates for different regulatory alternatives is discussed in detail in a subsequent section.

Effect on Net Farm Income

Table XXIII summarizes the effects on net farm income of a quantity restriction on water use for representative farm firms in Resource Situation 2. The quantity restriction is simulated for a 20-year period and replicated 15 times. The mean, standard deviation, coefficient of variation, maximum, minimum and range of net farm income have been computed for each crop year.

Net farm income under quantity restriction follows essentially the same pattern as under the unrestricted water-use alternative except that the level of income is considerably lower under the quantity restriction. Mean values of net farm income increase from the minimum level of \$9,576 for year 1 to \$15,632 in year 20, however, the highest mean net farm income is \$15,762 in year 17. A major proportion of the increase results during the first five years and is attributable to increased yields leading to increased government payments. From year 1 to year 5, net farm income increases from \$9,576 to \$13,440, or by \$3,864. During the same period, government payments, composed of wheat certificate and feed grain payments, increase from \$7,610 to \$11,406, or \$3,796. After year 5, total government payments, which are computed on the basis of five-year moving averages for the individual crops concerned, stabilize in the \$10,700 to \$11,500 range. Net farm income continues to rise, in general, but with considerable variability.

TABLE XXIII

SUMMARY OF NET FARM INCOME FOR RESOURCE SITUATION 2 WITH A QUANTITY RESTRICTION ON WATER USE

	Year																			
Replication	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	10665	24380	9639	16935	9346	8985	14018	12764	18664	16867	15161	8802	8986	17277	14685	16765	18133	14964	4779	17532
2	6774	9235	5955	6074	15424	8781	8301	7589	6365	9678	12205	7922	8696	7525	8898	13603	8768	757	11158	13759
3	9661	10789	8917	9916	12509	10349	10752	10876	13248	16691	14523	19771	13188	9383	13432	20475	15091	25061	17524	10572
4	2950	4374	9199	13999	11570	2323	9594	3046	12024	6979	8239	8469	26891	16548	23891	17049	16220	16097	19257	14242
5	15412	3394	13697	10605	24923	18676	19008	9303	14547	20340	16062	19390	26803	10096	19738	15924	19669	17674	22218	15918
6	10471	10803	11653	5531	8052	3453	952	4377	11768	10250	4019	7988	13558	7938	13527	6207	15415	9455	3955	14380
7	3595	8321	11758	14509	13678	10231	13289	20824	23940	25220	25314	14240	19169	20889	22725	16214	10246	8373	17635	21325
8	4068	13738	8970	13392	6450	13154	9990	13233	20490	23515	21926	10201	10008	14935	8919	18416	16339	15747	14465	18738
9	12990	7243	10172	19954	8372	19898	17788	19706	7065	15051	9530	8190	12938	20768	13405	7404	14871	20566	20312	10950
10	10695	12296	21365	12212	20234	20545	15113	10768	14491	10563	14242	20194	13296	13417	14745	15054	9648	14731	7088	13158
11	11736	2056	14781	16626	14826	23469	16213	20881	16439	16399	19018	13913	10240	19806	13208	15973	19225	9337	6906	11742
12	16468	22710	17250	22255	13148	16799	9463	7464	5108	7772	8248	9857	10537	9932	16459	13055	20365	19108	11961	22632
13	4031	12426	9546	7333	17728	13697	13949	14886	8732	21360	20604	14230	11534	12473	12762	7657	24905	19804	19722	19349
14	8530	9972	12610	4676	8492	11858	12760	8345	7738	8725	7183	8210	2797	7729	11450	6486	13359	13164	17574	17648
15	15590	10123	19997	8979	16854	24587	23574	9351	12650	16780	6182	13281	11633	4388	8921	11118	14179	19407	6938	12529
Mean	9576	10791	12367	12200	13440	13787	12984	11561	12885	15079	13497	12311	13352	12874	14451	13427	15762	14816	13429	15632
Std. Dev.	4528	6180	4362	5303	5094	6768	5299	5558	5439	5879	6316	4536	6467	5293	4614	4608	4347	5963	6252	3761
Maximum	16468	24380	21365	22255	24923	24587	23574	20881	23940	25220	25314	20194	26891	20889	23891	20475	24905	25061	22218	22632
Minimum	2950	2056	5955	4676	6450	2323	952	3046	5108	6979	4019	7922	2797	4388	8898	6207	8768	757	3955	10572
Range	13518	22324	15410	17579	18473	22264	22622	17835	18832	18241	21295	12272	24094	16501	14993	14268	16137	24304	18263	12060
Coef. of Var.	0.47	0.57	0.35	0.43	0.38	0.49	0.41	0.48	0.42	0.39	0.47	0.37	0.48	0.41	0.32	0.34	0.28	0.40	0.47	0.24

The standard deviation of net farm income follows no definite pattern. Relative variability, as measured by the coefficient of variation, fluctuates from year to year. The maximum value is 0.57 in year 2 and the minimum value is 0.24 in year 20. Variability of net farm income is related to yield variability. The quantity restriction results in failure to fully irrigate grain sorghum during boot-heading and grain-filling stages of crop development and failure to preplant irrigate all irrigated wheat acreages. During years in which full irrigation applications cannot be completed, final crop yield is more dependent upon highly variable natural rainfall. Thus, restricting the quantity pumped to 5,670 acre inches per year reduces crop yield, increases yield variability and, as a result, increases variability of net farm income.

The maximum value of net farm income of $16,891 occurs during year 13, replication 4. The minimum value of $757 occurs during year 18, replication 2. The maximum range of $24,304 also occurs in year 18 with a maximum net farm income of $25,061 in replication 3 and the previously mentioned minimum of $757 in replication 18.

<u>Effect</u> <u>on</u> <u>Net</u> <u>Worth</u>

Table XXIV summarizes the effects of a quantity restriction on net worth for representative farms in Resource Situation 2. The relevant decision rules are simulated over a 20-year period and replicated 15 times. The mean, standard deviation, maximum, minimum and range of net worth have been computed for each year.

Net worth increases continuously from year 1 through year 20. Beginning net worth at the end of year 1 is $122,422. Ending net worth

TABLE XXIV

SUMMARY OF NET WORTH FOR RESOURCE SITUATION 2 WITH A QUANTITY RESTRICTION ON WATER USE

Replication	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	123342	135704	137384	144767	146056	146840	151561	155102	163276	170494	176622	177954	179547	187688	193799	201370	210370	217063	216134	225261
2	120212	120879	118925	116986	122590	122903	122800	122104	120406	121445	124524	124096	124331	123583	123967	128155	128457	121680	123908	128225
3	122528	124542	125176	126542	129872	131447	133358	135351	139248	145850	150754	159670	163905	165241	169517	179043	184878	198048	206325	209710
4	116961	113611	114248	118724	121293	116013	116981	112391	115319	114120	113963	114006	127918	134405	146265	153101	159322	165442	173948	178937
5	127076	123156	127555	129575	142145	150342	159015	159987	165169	175019	182004	191713	206940	210573	221296	229296	240426	250272	263798	273540
6	123182	125234	128115	126014	125696	121494	114903	111556	114290	115782	112121	111747	115898	115480	119606	117778	123374	124226	120504	125291
7	117578	117491	120217	125110	129360	130837	134767	144405	156304	169343	182812	188695	198545	210004	222820	231064	235138	237667	247495	260426
8	117997	122296	122880	126951	125324	129144	130419	134304	143802	155429	166024	168058	170070	176049	177137	185315	192329	198982	204991	214637
9	125203	124435	126090	135342	135464	144489	151999	160864	160087	165791	167276	167727	172050	182436	187356	187308	193270	203539	214066	218040
10	123368	126648	137018	140701	150359	160256	166351	168806	174302	177038	182716	193090	198705	204614	211402	218358	221457	228410	229771	236084
11	124213	118872	123987	130636	135753	147344	153808	163520	170296	177420	186774	192582	195786	206349	212049	219716	230120	233221	234638	240029
12	127874	139167	146925	158560	163443	171039	173098	173151	171301	171629	172309	174318	177030	179349	186502	190939	201174	210726	215236	227930
13	117965	121226	122248	121372	128756	133022	137457	142623	142894	152956	162601	167717	170963	175072	179201	179009	192042	200231	210229	220441
14	121606	122921	126456	123574	123637	126428	129965	129900	129312	129579	128546	128364	123536	122940	125410	123803	127791	131618	138830	146149
15	127221	128895	138395	139531	146531	159161	171495	172984	177219	184875	184451	189650	193839	192394	194142	197380	203220	212965	213584	218757
Mean	122422	124338	127707	130959	135085	139384	143197	145803	149548	155118	159566	163292	167938	172412	178031	184999	189558	195606	200897	208230
Std. Dev.	3645	6531	8685	11109	12248	16215	19241	21047	21922	24186	26861	29457	30820	33197	34851	37023	38707	41322	43073	44598
Maximum	127874	139167	146925	158560	163443	171039	173098	173151	177219	184875	186774	193090	206940	210573	222820	231064	240426	250272	263798	273540
Minimum	116961	113611	114248	116986	121293	116013	114903	111556	114290	114120	112121	111747	115898	115480	119606	117778	123374	121680	120504	125291
Range	10913	25556	32677	41574	42150	55026	58195	61595	62929	70755	74653	81343	91042	95093	103214	113286	117052	128592	143294	148249

is $208,230. Between the two points, mean values of net worth increase approximately linearly. The maximum value of net worth generated during any simulated year occurs as expected, during year 20. The maximum value of $273,540 is generated in replication 5. The minimum net worth value for any year ($113,611) is generated in year 2, replication 4.

Effects of a Graduated Tax Per Unit of Water Pumped Above the Quantity Limitation for Resource Situation 2

The third water-use regulatory alternative considered is the imposition of a graduated tax on each unit of irrigation water pumped above the quantity limitation. The irrigator is allowed to pump as much water as he desires, however, a tax of $0.50 per acre inch is charged for each acre inch pumped above the 5,670 acre inch limit. Decision rules are the same as for the quantity limitation. That is, each irrigator is assumed to restrict pumping during early periods of the growing season (as contrasted against the unrestricted pumpers actions) as a hedge against uncertain weather conditions during Irrigation Periods 4 and 5. Once the quantity limitation is reached, irrigators are assumed to pump additional water only if the value of the yield reduction saved by irrigating exceeds the additional costs of irrigating, plus harvesting, hauling and tax payments, per acre. This decision rule is applied at the margin for each crop block requiring an irrigation after the quantity limitation has been reached. The estimation of potential yield reduction by the irrigator is explained explicitly in Chapter IV.

The primary decisions faced by the irrigator, once the quantity limitation has been reached, are (1) whether to irrigate grain sorghum during Irrigation Period 4 and (2) whether to preplant irrigate wheat during Irrigation Period 5. Since the preplant wheat irrigation nets a minimum 15-bushel-per-acre-yield increase, it always pays to apply the additional water. The additional irrigation on each block of grain sorghum is made only if the value of additional production exceeds the cost of the irrigation, including the tax payment.

Effect on Acre Inches Pumped

Table XXV presents a summary of total acre inches pumped under the graduated tax alternative for 15 replications of a 20-year simulation of Resource Situation 2. The mean, standard deviation, maximum, minimum and range of acre inches pumped have been computed for each of the 20 years.

Mean values of total acre inches pumped range from a low of 5,875 in year 1 to a high of 6,274 in year 12. Fluctuations between these extremes follow no definite pattern. Variation in acre inches pumped per year exceed that of the quantity restriction, but are not as great as under unrestricted pumping. The maximum number of acre inches pumped is 6,795 and occurs during three different years--year 1, replication 4; year 12, replication 7; and year 19, replication 12. The minimum number of acre inches pumped is 2,722 in year 1, replication 5. Maximum range in acre inches pumped occurs in year 1 also. The 4,073 acre inches pumped is the difference between the maximum of 6,795 and minimum of 2,722 acre inches.

TABLE XXV

SUMMARY OF TOTAL ACRE INCHES PUMPED FOR RESOURCE SITUATION 2 WITH A GRADUATED TAX PER UNIT PUMPED ABOVE THE QUANTITY LIMIT

	Year																			
Replication	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	6255	4297	6420	5895	6735	6570	6270	6300	6120	6105	6210	6525	6525	6180	6195	6280	6210	6525	6645	6300
2	6075	6105	6165	6525	5535	6060	6435	6390	6465	6120	5940	6525	6525	6645	6420	6195	6525	6645	6120	6435
3	6120	6120	6300	6300	6135	6420	6300	6165	6165	6165	6195	5535	6570	6645	6480	4791	6165	3352	5910	6645
4	6795	6525	6495	5850	6195	6735	6270	6735	5625	6435	6570	6255	3915	6210	5265	6345	6165	6255	6165	6165
5	2722	6585	6075	6105	3911	6165	6075	6465	6285	6157	6105	6030	4993	6735	6191	6195	6150	6075	5310	6165
6	6225	6120	6075	6780	6285	6525	6645	6525	5895	6255	6525	6255	6075	6480	6120	6345	6075	6375	6525	6030
7	6525	6165	6165	6075	5513	5893	5963	5402	5074	5544	4950	6795	6120	6075	4477	6150	6645	6570	6135	5445
8	6510	6075	6375	6330	6645	6105	6338	5518	4699	4714	5445	6525	6735	6345	6525	6210	6195	6255	6255	6157
9	6075	6525	6270	4695	6465	5130	6075	5717	6525	5820	6465	6525	6225	5370	6645	6645	6300	6030	5458	6525
10	6075	5242	5355	6615	5310	5985	6360	6525	6300	6570	6180	5685	6555	6195	6075	6075	6525	6075	6165	6510
11	6220	6750	5490	4770	6075	5467	6165	5535	6255	6180	6285	6120	6645	5310	6345	6135	6236	6285	6435	6120
12	4905	4972	5721	5452	6120	5499	6660	6525	6735	6555	6300	6525	6525	6375	5689	6187	5850	6216	6795	5160
13	6645	6075	6240	6735	5625	6165	6165	5654	6300	4320	5895	6510	6525	6165	6075	6645	4860	6075	6120	5760
14	6300	6300	6120	6465	6165	6075	6165	6800	6735	6345	6165	6165	6645	6735	6300	6645	6165	6435	4950	6015
15	4680	6300	5265	6465	6255	5205	5850	6300	6420	6120	6735	6135	6075	6526	6300	6285	6345	5310	6445	6525
Mean	5875	6010	6035	6070	5931	6000	6249	6157	6107	5960	6131	6274	6173	6209	6073	6209	6161	6032	6099	6130
Std. Dev.	1046	668	391	651	696	488	225	458	576	645	451	343	765	460	559	436	410	806	511	416
Maximum	6795	6750	6495	6780	6735	6735	6660	6735	6735	6570	6735	6795	6735	6735	6645	6645	6645	6645	6795	6645
Minimum	2722	4297	5265	4695	3911	5130	5850	5402	4699	4320	4950	5535	3915	5310	4477	4791	4860	3352	4950	5160
Range	4073	2453	1230	2085	2824	1605	810	1333	2036	2250	1785	1260	2820	1425	2168	1854	1785	3293	1845	1485

Saturated thickness at the end of the 20-year simulation runs ranges from 242.88 to 249.19 feet, averaging 245.61 feet. Assuming a beginning saturated thickness of 325 feet, the average decline in saturated thickness is 79.39 feet, or about 3.97 feet per year. This rate of decline compares with 4.50 feet per year for the unrestricted alternative and 3.66 feet per year for the quantity limitation alternative.

Effect on Net Farm Income

Table XXVI contains a summary of net farm income under the graduated tax alternative for Resource Situation 2. The 20-year simulation runs have been replicated 15 times and the mean, standard deviation, maximum, minimum, range and coefficient of variation computed for each year of the analysis.

Mean values of net farm income under the graduated tax alternative increase generally over the 20-year period, though not without yearly fluctuations. The lowest mean net farm income is $10,866 in year 1 and the highest is $19,572 in year 17. Mean net farm income in year 20 is $19,020. A rapid rise in mean net farm income occurs from year 1 ($10,866) to year 6 ($16,790). This increase corresponds to, and results largely from, a rapid increase in total dollar value of government payments from $8,217 in year 1 to $13,296 in year 5. After year 5, government payments are relatively stable between $12,900 and $13,300 per year. Mean values of net farm income continue to rise after government payments stabilize, however, relative variability, as measured by the coefficients of variation, remains in the 0.20 to 0.37 range after

TABLE XXVI

SUMMARY OF NET FARM INCOME FOR RESOURCE SITUATION 2 WITH A GRADUATED TAX PER UNIT PUMPED ABOVE THE QUANTITY LIMIT

	Year																			
Replication	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	11917	24866	11368	17882	12135	11724	16701	15920	22286	20011	18386	11875	12228	20623	18113	19886	21387	18712	7869	21418
2	8301	10976	8132	9067	18587	12335	11961	11893	10867	14720	16225	12888	13602	12619	14659	20282	15062	7567	18234	20296
3	10959	12546	11134	12461	16161	14378	14613	15995	17906	20672	18418	22063	16370	12471	16760	22035	17901	26596	18583	12329
4	4629	6444	12039	17630	16055	6705	14255	8493	16549	12439	14368	14673	31541	21359	27520	21448	19583	19747	22266	17399
5	15782	4428	15503	12909	26549	21373	21854	12322	17207	23922	19257	22849	28738	13596	22621	18851	22693	20909	24582	18610
6	11824	12593	13852	8343	11965	7704	5236	9106	15536	15077	9148	13466	19326	14372	20264	13434	22608	16880	10441	21445
7	4928	10241	14339	17433	16802	12944	16730	23944	26176	26617	25974	16109	21046	23287	24253	19122	13094	11733	20315	23935
8	5775	15588	11610	16477	10173	17260	14223	17246	24169	25720	22718	11622	11916	17326	11608	21538	19767	19120	17677	22213
9	14652	8927	12390	22326	11154	21612	20406	21071	9312	17786	12489	11093	16230	23656	16398	10126	17838	23402	22924	14012
10	11927	13962	22849	14467	21574	22709	17186	13808	17369	13706	17557	22591	16061	16301	17537	17844	12841	17909	10258	16284
11	13271	4566	15811	17647	17158	25389	17992	21984	18870	18703	21792	16663	13816	21909	16136	18701	22130	12047	9998	14974
12	17467	22710	17870	23613	14733	18210	12032	10170	8161	11051	11636	13142	14032	13487	18839	16034	23883	22176	15712	24621
13	5394	14378	11736	10488	20877	17299	17482	18324	11971	23727	23285	16982	14582	15209	15968	11317	26908	20625	22578	21004
14	9858	11897	15062	7479	12179	15856	16934	12763	13150	13602	12212	13211	7636	13616	17729	13247	20042	20136	22697	21077
15	16304	11579	21022	10838	19637	26348	24667	11813	14940	19080	9604	16860	14858	7678	12155	14381	17850	21902	9677	15681
Mean	10866	12380	14314	14604	16383	16790	16151	14990	16298	18456	16871	15739	16798	16501	18037	17216	19572	18631	16921	19020
Std. Dev.	4294	5722	3917	4933	4557	5966	4582	4761	5225	4984	5215	3985	6265	4698	4269	3871	3945	4923	5827	3730
Maximum	17467	24866	22849	23613	26549	26348	24667	23944	26176	26617	25974	22849	31541	23656	27520	22035	26908	26596	24582	24621
Minimum	4629	4428	8132	7479	10173	6705	5236	8493	8161	11051	9148	11093	7631	7678	11608	10126	12841	7567	7869	12329
Range	12838	20438	14717	16134	16376	19643	19431	15451	18015	15566	16826	11756	23910	15978	15912	11909	14067	19029	16713	12292
Coef. of Var.	0.40	0.46	0.27	0.34	0.28	0.36	0.28	0.32	0.32	0.27	0.31	0.25	0.37	0.28	0.24	0.22	0.20	0.26	0.34	0.20

year 5. Years 1 and 2, with coefficients of variation of 0.40 and 0.46, respectively, have the highest relative variability.

The maximum value of net farm income generated is $31,541 in year 13, replication 4. The minimum value is $4,428 in year 2, replication 5. The maximum range in net farm income occurs in year 13. The range of $23,910 is the difference between the maximum of $31,541 and minimum of $7,631.

Effect on Net Worth

Table XXVII presents a summary of net worth resulting from 15 replications of a 20-year simulation of Resource Situation 2 under the graduated tax alternative. The mean, standard deviation, maximum, minimum and range of net worth have been computed for each of 20 years.

Mean values of net worth increase steadily from $123,468 in year 1 to $268,714 in year 20. The increase is very nearly linear. The combination of increased government payments during the initial five years, retirement of chattle and real estate debts over the next ten years and accumulation of excess cash reserves above $10,000 all combine to push net worth constantly upward.

The maximum value of net worth generated is $323,366 in year 20, replication 5. The minimum value of $116,832 occurs in year 2, replication 4. The maximum range in net worth occurs in year 20. The range of $117,763 is the difference between a maximum of $323,366 and minimum of $205,603.

TABLE XXVII

SUMMARY OF NET WORTH FOR RESOURCE SITUATION 2 WITH A GRADUATED TAX PER UNIT PUMPED ABOVE THE QUANTITY LIMIT

Replication	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	124363	137046	140179	148332	152002	155252	162373	168726	180014	190190	199550	204251	209451	221130	231054	242287	255046	266155	269661	283528
2	121414	123537	123485	124094	132114	135300	138176	140997	142982	148048	154272	157985	162453	166331	171583	181036	186929	186838	195235	205603
3	123586	127083	129627	133210	139449	144201	149302	155340	162915	172938	181627	193295	201264	206537	214919	227141	236858	251830	262898	269824
4	118464	116832	119772	127076	133163	131737	136422	136485	142972	146244	151021	156048	172461	183330	198546	209729	220089	230701	243600	253589
5	127376	124382	130271	134248	148088	158482	169548	173360	181098	194092	204173	217176	233771	241188	255038	266398	280915	294494	310202	323366
6	124285	127849	132568	132950	135888	135272	132641	133200	138895	144216	144810	148885	157447	162519	171950	176140	187425	194739	197436	208662
7	118713	120198	125001	132287	138953	142628	149264	161166	174938	189508	204088	212229	224288	238272	253092	264589	272129	278763	292012	307267
8	119411	125148	127990	134624	136179	143185	147925	154919	167080	180830	192917	197178	201869	210899	215513	227370	238437	249278	259599	273503
9	126489	127157	130727	141847	144498	154939	164790	175087	176727	185119	189730	193426	201286	214757	223179	226754	236406	250191	264170	272397
10	124370	128982	140479	146075	156812	168534	176527	181769	189924	195748	204660	217482	226120	235300	245329	255648	262677	273519	279165	289613
11	125396	122430	128459	136003	143106	156225	164371	175303	184405	193843	205715	214313	221125	234104	243096	253934	267626	274276	279744	289368
12	128627	139948	148184	160773	166971	175788	180106	182635	183652	187162	191195	196556	202880	209016	219035	227032	240951	254057	263131	278805
13	119094	123879	126773	128682	138363	145404	152759	160568	163775	176039	188382	196542	203224	210688	218653	222984	238853	250766	264589	277840
14	122692	125614	131194	130812	133868	139793	146536	150076	153892	158232	161592	165872	165872	170671	178443	182746	192401	202294	214519	226126
15	127743	130611	140867	143614	152912	166969	180248	184081	190531	200388	203333	211994	219498	221714	227182	234230	244188	257207	261751	271221
Mean	123468	126713	131705	136975	143491	150247	156733	162247	168920	177506	185138	191906	200203	208430	217774	226535	237395	247674	257181	268714
Std. Dev.	3416	5913	7635	9573	10055	13322	15712	16875	17470	19297	21553	24467	24636	26286	27381	28991	29756	31502	32494	33184
Maximum	128627	139948	148184	160773	166971	175788	180248	184081	190531	200388	205715	217482	233771	241188	255038	266398	280915	294494	310202	323366
Minimum	118464	116832	119772	124094	132114	131737	132641	133200	138895	144216	144810	148885	157447	162519	171583	176140	186929	186838	195235	205603
Range	10163	23116	23412	36679	34857	44051	47607	50881	51636	56172	60905	68597	76324	78669	83455	90258	93986	107656	114967	117763

Statistical Comparisons of Unrestricted Pumping, A Quantity Limitation and a Graduated Tax on Resource Situation 2

The preceding sections have discussed each water-use regulatory alternative separately. Tabular presentation was made of the effects of unrestricted pumping, a quantity restriction and a graduated tax above the quantity restriction on variables relevant to the analysis. Included among these variables were the total acre inches pumped, feet decline in saturated thickness, net farm income, variability of net farm income and net worth for the representative farm.

The following sections are designed to compare the three water-use regulatory alternatives in more specific terms. First, the relative effect of each alternative on total number of acre inches pumped is compared graphically. Then, statistical tests are conducted to determine whether effects of the regulatory alternatives on total acre inches pumped are significantly different, from a statistical standpoint. Similar techniques are utilized to compare the effects of the three water-use regulatory alternatives on mean values of net farm income and net worth for representative farm firms in Resource Situation 2.

Acre Inches Pumped

Figure 11 illustrates the effect on total acre inches pumped for each water-use regulatory alternative. Several features are obvious at first glance. First, the number of acre inches pumped under the unrestricted alternative exceed total acre inches pumped under the graduated tax alternative by a wide margin. Second, acre inches pumped under the graduated tax alternative likewise exceed acre inches pumped under the quantity restriction by a wide margin. Third, there is

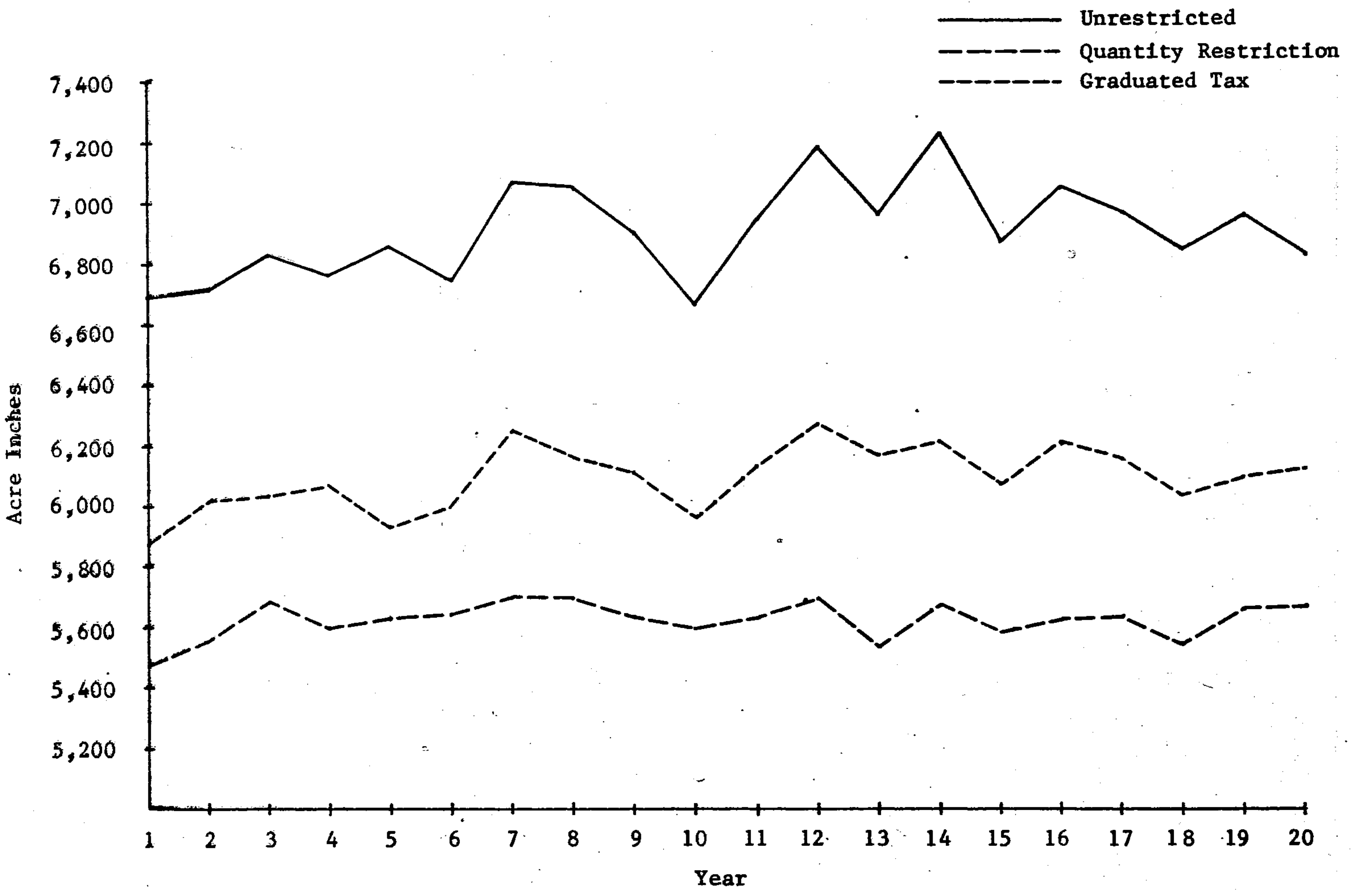


Figure 11. A Comparison of Mean Acre Inches of Irrigation Water Pumped Under Alternative Water-Use Regulation Methods for Resource Situation 2

considerably more variability associated with the unrestricted alternative. Of the three alternatives, the quantity restriction has the smallest variation in total acre inches pumped, as expected.

The patterns of variability in weather conditions are apparent in the graph of mean values of acre inches pumped under the unrestricted pumping alternative. Dry years, requiring pumping of more than 7,000 acre inches per year, are apparent in years 7, 8, 12, 14 and 16. Years requiring less than 6,800 acre inches of irrigation water, occur in years 1, 2, 4, 6 and 10.

Of critical importance to policy makers is whether the three water-use regulatory alternatives differ with respect to total acre inches pumped from a statistical standpoint. To answer this question, mean values of total acre inches pumped over the 20-year period are tested for significant differences using the Wilcoxon Matched-Pairs, Signed Ranks Test.

To test for a significant difference between mean total acre inches pumped over the 20-year period under the unrestricted alternative and mean acre inches pumped under the quantity limitation, the null hypothesis, H_0, is that there is no difference between the matched-pairs of means. The alternative hypothesis, H_1, is that the mean under unrestricted pumping is above the mean under the quantity restriction. To reject the null hypothesis of no difference between means, the computed test statistic T must be less than the tabular value of T at the α level of the test, where $\alpha = 0.01$. The computed value of T for this test is zero. Thus, for any α level chosen for the test, the computed value of T is less than the tabular value which, for example, is 43 for a one-tailed test at $\alpha = 0.01$. Thus, the null hypothesis of no difference between means is rejected in favor of the alternative that mean acre inches pumped under unrestricted pumping is above that under the quantity restriction.

Next, mean acre inches pumped under unrestricted pumping is tested against mean acre inches pumped under the graduated tax alternative. The null hypothesis is that of no difference between the means. The alternative hypothesis is that the mean under unrestricted pumping is above the mean under the graduated tax alternative. The computed value of T is zero for this test. Since the computed value of T is less than the tabular value of 43 at $\alpha = 0.01$ the null hypothesis may be rejected in favor of the alternative hypothesis that the mean of total acre inches pumped over the 20-year period under unrestricted pumping is greater than that under graduated taxation.

Finally, mean values acre inches pumped under the graduated tax alternative are tested against mean values under the quantity limitation. The null hypothesis for the test is that the means are the same. The alternative hypothesis, which is again directional and necessitates use of a one-tailed test, is that mean acre inches pumped under the graduated tax is above that under the quantity limitation. The computed value of the test statistic T is again zero. Thus, the null hypothesis of no difference between means is rejected at the $\alpha = 0.01$ level.

Statistical tests reveal a significant difference between mean values of acre inches pumped for the unrestricted pumping versus quantity limitation alternatives, unrestricted pumping versus graduated tax alternatives and graduated tax versus quantity limitation alternatives. Referring to Figure 11, statistical tests reveal that each set of means of total acre inches pumped is above the set or sets of means underlying it.

Net Farm Income

A graphic presentation of mean net farm income over a 20-year period under unrestricted, quantity restriction and graduated taxation alternatives appears in Figure 12. The graph illustrates the effect on net farm income of increased yields and increasing government payments over the initial five years of the simulated time period. From year 5 through year 20, the increase in net farm income is moderate, reflecting gradual retirement of chattle and real estate debts and accumulation of cash in excess of the $10,000 minimum specified at the beginning of the simulation analysis.

The level of farm income under the graduated tax alternative is only slightly less than under unrestricted pumping. Both unrestricted pumping and the graduated tax alternative have levels of net farm income which greatly exceed the level under the quantity restriction. Based on the graphic analysis, three statistical tests are conducted to test three hypotheses.

The first test conducted is to determine whether or not significant differences exist between mean net farm income under unrestricted pumping and the quantity restriction. The null hypothesis is that no significant differences exist between the two matched-pairs of means. The alternative hypothesis is that mean net farm income under unrestricted pumping is above mean net farm income under a quantity restriction on water use. This directional hypothesis requires the use of a one-tailed test at the $\alpha = 0.01$ level. The computed value of the

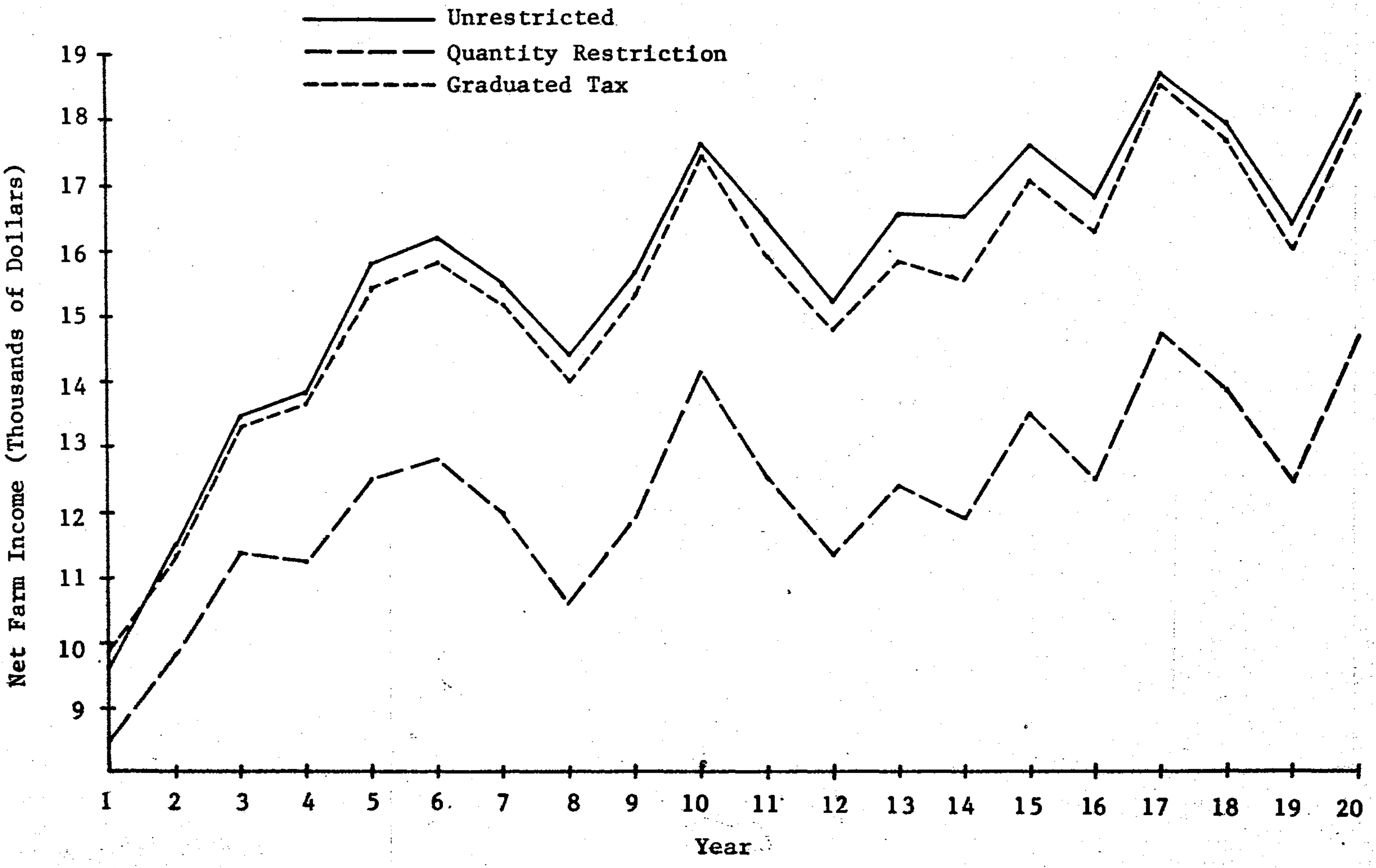


Figure 12. A Comparison of Mean Net Farm Income Under Alternative Water-Use Regulation Methods for Resource Situation 2

test statistic T is zero. Since the computed value of T is less than the tabular value of 43 for one-tailed test at $\alpha = 0.01$, the null hypothesis may be rejected in favor of the alternative hypothesis that mean net farm income under unrestricted pumping is above that under the quantity restriction.

The second test conducted is to determine whether or not a significant difference exists between mean net farm income under the graduated tax alternative and a quantity restriction on pumping. The null hypothesis is that no difference exists between the matched-pairs of means. The alternative hypothesis is that mean net farm income under the graduated tax alternative is above mean net farm income under the quantity limitation. Computations reveal that the test statistic T has a value of zero. Since the computed T value is less than the tabular value for a one-tailed test at $\alpha = 0.01$ the null hypothesis may be rejected in favor of the alternative hypothesis that mean net farm income under graduated taxation is above that under a quantity restriction.

The final statistical test concerning net farm income tests the null hypothesis of no difference between the mean under unrestricted pumping and the mean under graduated taxation. The alternative hypothesis is that mean net farm income under unrestricted pumping is above that under graduated taxation. The computed value of the test statistic is six. The tabular value for a one-tailed test at $\alpha = 0.01$ is 43. Since the computed T value is less than the tabular value at the $\alpha = 0.01$ level of significance, we may reject the null hypothesis of no difference between means in favor of the alternative that the mean under unrestricted pumping is greater.

For Resource Situation 2, statistical tests reveal that mean acre inches pumped without restrictions is above mean acre inches pumped under the graduated tax or quantity limitation alternatives. In addition, the mean under the graduated tax alternative is above the mean under the quantity restriction. Statistical tests of mean net farm income under the three water-use alternatives lead to similar conclusions. Mean net farm income under unrestricted pumping exceeds that under either the graduated tax alternative or the quantity limitation. The mean under a graduated tax is significantly larger than under the quantity limitation.

A comparison of Figures 11 and 12 reveals that the difference between mean acre inches pumped over the 20-year period for unrestricted pumping versus graduated taxation is greater than the difference between corresponding means of net farm income. That is, irrigators pumping without restrictions tend to apply irrigation water to the point where its marginal value product is very low. Thus, the irrigator operating under graduated taxation is able to apply significantly less water, pay the tax on additional water pumped above the quantity limitation and achieve a level of net farm income which appears reasonably close to that achieved under unrestricted pumping. From a policy maker's standpoint, the graduated tax might appear preferable to unrestricted pumping since it reduces pumping significantly while maintaining net farm income at a reasonable level. The farmer would prefer to pump without restrictions, not only because of the additional freedom afforded by that alternative, but because net farm income is larger.

The quantity restriction results in significantly lower total acre inches pumped and lower net farm income than the other two alternatives.

Variability of net farm income is much greater than under the other two alternatives. The quantity restriction is likely to be the least preferred alternative by irrigators in the area. Policy makers wishing to pursue this alternative must build their case by evaluating two important factors. (1) The quantity limitation lengthens the life of the aquifer and provides a longer, though lower stream of net income. (2) Unrestricted pumping shortens the economic life of the aquifer and thus provide a shorter, higher stream of net farm income for individual irrigators. By discounting the streams of net returns over the life of the aquifer under alternative policies, a rational economic decision can be made. The life of the aquifer is not projected in this analysis. However, a discounting model is utilized in a subsequent section to compare net income streams under alternative policies over the 20-year span of this analysis.

Figure 13 compares relative variability of net farm income in terms of the coefficient of variation. As expected, coefficients of variation hold the exact opposite relationships of levels of net farm income. That is, the quantity restriction on water use results in the greatest relative variability of net farm income. The unrestricted water-use alternative results in the lowest relative variability in net farm income, with the graduated tax alternative falling between the two.

Net Worth

Figure 14 presents a graphic view of mean values of net worth over the 20-year simulation period. Net worth increases almost linearly, but at a slightly increasing rate, for all three water-use alternatives.

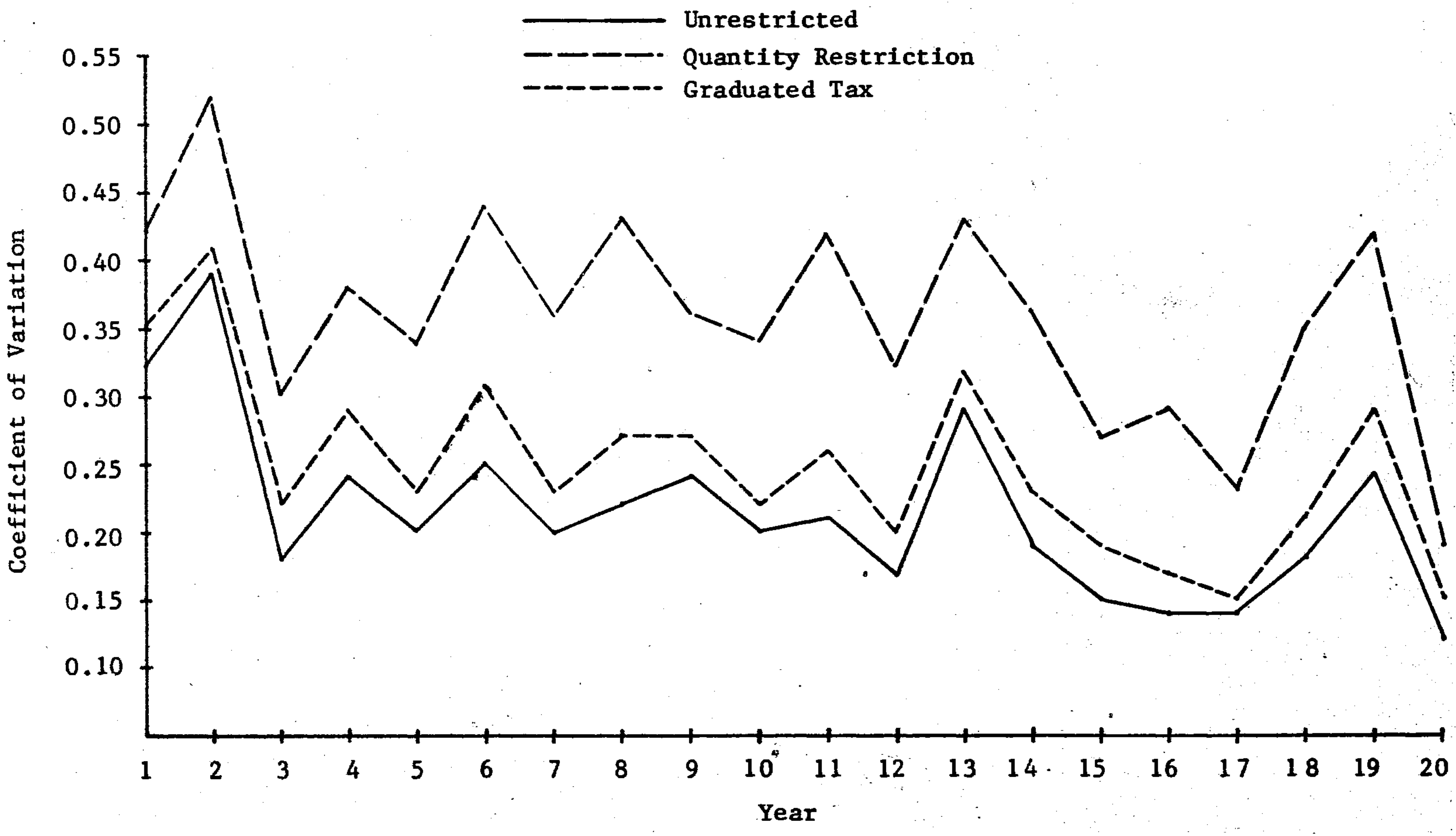


Figure 13. A Comparison of Coefficients of Variation of Mean Net Farm Income Under Alternative Water-Use Regulation Methods for Resource Situation 2

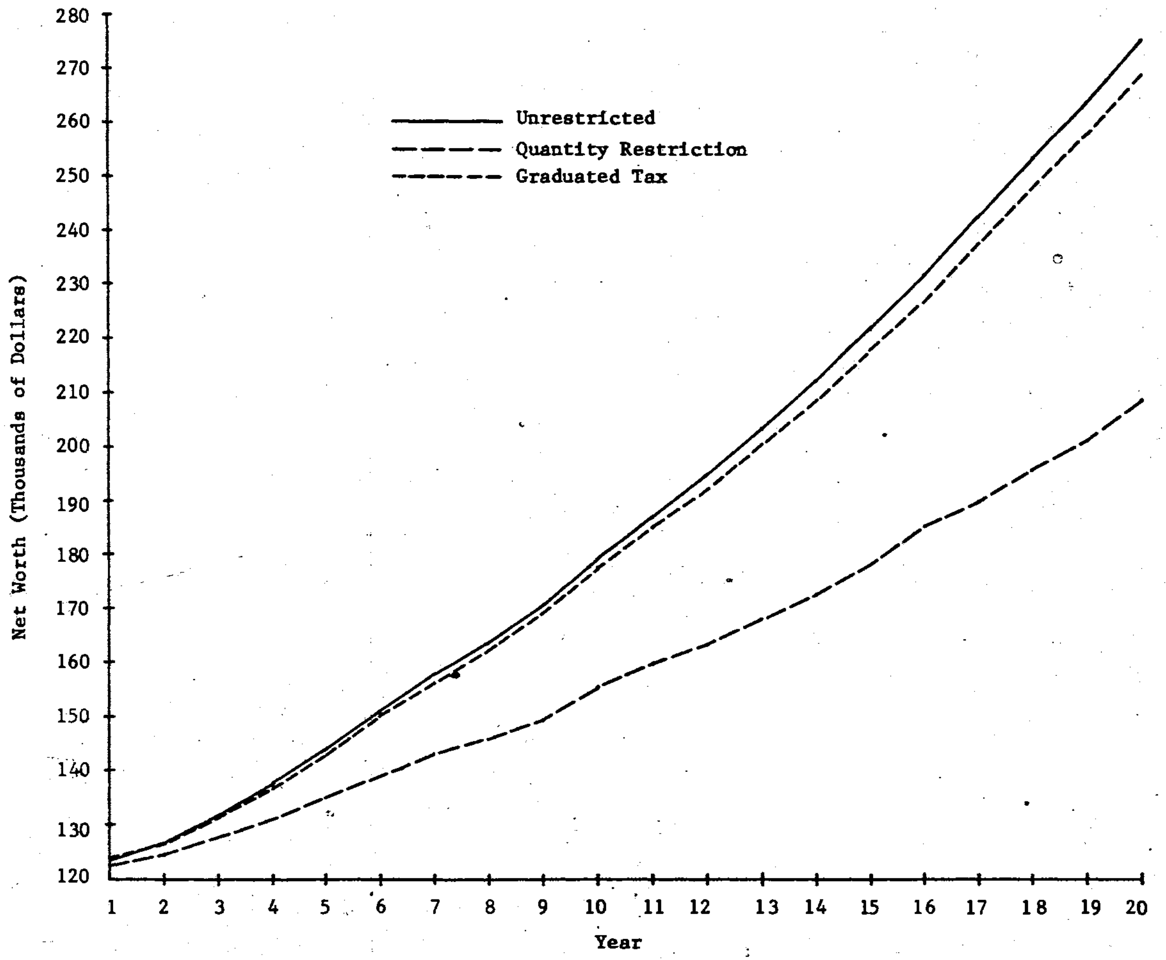


Figure 14. A Comparison of Mean Net Worth Under Alternative Water-Use Regulation Methods for Resource Situation 2

Net worth levels under unrestricted pumping and graduated taxation are nearly identical and both exceed net worth under the quantity restriction by a large margin. Based on the graphic analysis, three statistical tests are conducted on mean values of net worth.

The first test conducted is to determine whether a significant difference exists between mean net worth under no restrictions and under a quantity restriction. The null hypothesis is that no difference exists between the matched pairs of means. The alternative hypothesis is that mean net worth under unrestricted pumping is above mean net worth under a quantity restriction. The computed value of the test statistic T is zero. The tabular value for a one-tailed Wilcoxon Matched-Pairs, Singed Ranks Test at the $\alpha = 0.01$ level is 43. Since the computed value is less than the tabular value, there is sufficient statistical basis to reject the null hypothesis of no difference at the $\alpha = 0.01$ level. Thus, the null hypothesis is rejected in favor of the alternative hypothesis that mean net worth under unrestricted pumping is above that under a quantity limitation.

The second null hypothesis tested is that of no difference in mean net worth resulting from a graduated tax and that resulting from a quantity limitation. The alternative hypothesis is that mean net worth under the graduated tax alternative is above that existing under a quantity limitation. The computed value of the test statistic is zero. The tabular value for a one-tailed test at $\alpha = 0.01$ is 43. Thus, the null hypothesis of no difference between matched-pairs of means is rejected in favor of the alternative hypothesis that mean net worth under a graduated tax is above that under a quantity limitation.

The third test is conducted to determine whether a statistically significant difference exists between mean net worth resulting from unrestricted versus graduated taxation alternatives. The null hypothesis is that no difference exists. The alternative hypothesis is that mean net worth under unrestricted pumping is above that under the graduated tax alternative. The computed value of T is ten. The tabular value for a one-tailed test at $\alpha = 0.01$ is 43. Since the computed value is less than the tabular value, there is statistical basis for rejecting the null hypothesis of no difference in mean net worth in favor of H_1 that mean net worth under unrestricted pumping is above mean net worth under the graduated tax alternative.

Thus, mean net worth for both unrestricted pumping and the graduated tax differ significantly from mean net worth under a quantity limitation. Also the two former means differ significantly from one another.

This chapter has summarized the effects of unrestricted pumping, a quantity restriction and a graduated tax per unit above the quantity restriction on acre inches of water pumped per year, net farm income, variability of net farm income and net worth for Resource Situations 1 and 2. The next chapter concentrates on the implications of these results for the farm firm, policy makers and the water supply. In addition, the importance of government payments is emphasized and the effects of each water-use alternative on aggregate or regional net farm income are analyzed.

FOOTNOTES

[1] The figure 9,600 acre feet is computed assuming 640 acres overlie the 100 feet of saturated thickness and that the specific yield of the Ogallala Formation is 0.15. Then 640 acres x 100 feet x 0.15 = 9,600 acre feet.

[2] Bernard Ostle, *Statistics in Research* (Ames, 1963), p. 64.

[3] R. W. Greve, J. S. Plaxico, and W. F. Lagrone, *Production and Income Variability of Alternative Farm Enterprises in Northwest Oklahoma*, Oklahoma Agricultural Experiment Station, Bulletin B-563 (Stillwater, 1960), pp. 20-24.

[4] Sidney Siegel, *Nonparametric Statistics* (New York, 1956), pp. 75-83.

[5] Ibid., p. 76.

[6] Ibid., p. 8; and P. G. Hoel, *Introduction to Mathematical Statistics* (New York, 1962), pp. 48-49.

CHAPTER VI

IMPLICATIONS OF ALTERNATIVE METHODS OF WATER-USE REGULATION

Additional results are discussed in this chapter. First, the importance of government payments as a component of net farm income is emphasized for each Resource Situation. Second, the implications of relative rates of water withdrawal for each regulatory alternative are discussed. Third, streams of net farm income resulting from each water-use alternative are discounted to their present value at four different interest rates and the findings discussed. Finally, aggregate implications of alternative water-use policies are drawn for each Resource Situation and the region.

Comparison of Net Farm Income and Government Payments

The importance of government payments as a component of net farm income is mentioned in previous chapters. This section presents direct comparisons of net farm income and government payments under three water-use alternatives for the two Resource Situations.

Comparisons between mean values of net farm income under unrestricted pumping, a quantity restriction and graduated taxation for Resource Situation 1 are presented in Table XXVIII. Government payments are a significant portion of net farm under all three water-use alternatives. Under unrestricted pumping, net farm income exceeds

TABLE XXVIII

COMPARISON OF NET FARM INCOME AND GOVERNMENT PAYMENTS UNDER THREE WATER-USE ALTERNATIVES FOR RESOURCE SITUATION 1

Year	No Restrictions		Quantity Restriction		Graduated Tax	
	Net Farm Income	Government Payments	Net Farm Income	Government Payments	Net Farm Income	Government Payments
1	9,019	8,048	8,791	7,838	9,473	8,084
2	9,809	9,043	9,715	8,808	10,461	9,144
3	13,546	10,565	11,250	9,876	13,595	10,647
4	13,839	12,107	11,131	11,001	14,042	12,189
5	15,045	13,615	12,270	12,086	14,966	13,624
6	14,624	13,761	12,707	12,073	15,346	13,699
7	13,593	13,827	11,417	11,778	14,333	13,737
8	11,454	13,331	9,913	11,534	12,995	13,384
9	10,870	13,048	10,234	11,367	12,842	13,084
10	11,324	13,035	11,899	11,545	13,368	13,105
11	8,780	12,789	7,815	11,393	10,477	12,968
12	6,406	12,477	5,613	11,366	8,018	12,995
13	7,502	12,270	6,204	11,449	8,865	12,638
14	6,838	11,822	5,621	11,512	8,288	12,450
15	7,719	11,051	5,586	11,205	9,270	11,972
16	5,714	10,405	5,335	11,045	8,065	11,639
17	7,503	10,152	7,581	11,112	9,956	11,446
18	4,351	9,792	4,591	10,655	6,944	10,920
19	1,031	9,315	1,253	10,072	3,867	10,370
20	2,183	8,911	2,447	9,634	5,056	9,952

government payments from year 1 through year 6. Beginning in year 7, government payments exceed net farm income. That is, without government payments, net farm income would be negative from year 7 through year 20 for the unrestricted alternative.

Comparisons of net farm income and government payments under both the quantity limitation and graduated taxation lead to the same conclusion. The impact of government payments is the difference between positive and negative net farm income. Under the quantity restriction, government payments exceed net farm income beginning in year 7. Under the graduated tax alternative, net farm income exceeds government payments for the first seven years of the simulation run. However, from year 8 through year 20, with the exception of year 10, government payments exceed net farm income.

The irrigation operator is not afforded the opportunity to expand his operation in this analysis. However, it appears that irrigators in Resource Situation 1 are faced with the alternative of expanding the size of operation, or going out of business. Even with substantial government payments, net farm income is quite low by the time the water supply reaches economic exhaustion. These implications hold for Resource Situation 1, regardless of the water-use alternative followed.

Government payments are important to the irrigation operator represented by the adequate water position in Resource Situation 2. A comparison of mean values of net farm income and government payments under the three water-use regulatory alternatives is presented in Table XXIX.

Under unrestricted pumping, government payments increase from $8,218 in year 1 to $13,648 in year 6 and remain stable for the

TABLE XXIX

COMPARISON OF NET FARM INCOME AND GOVERNMENT PAYMENTS UNDER THREE WATER-USE ALTERNATIVES FOR RESOURCE SITUATION 2

	No Restrictions		Quantity Restriction		Graduated Tax	
Year	Net Farm Income	Government Payments	Net Farm Income	Government Payments	Net Farm Income	Government Payments
1	10,598	8,218	9,576	7,610	10,866	8,127
2	12,434	9,431	10,791	8,512	12,380	9,305
3	14,413	10,776	12,367	9,407	14,314	10,571
4	14,767	12,166	12,200	10,382	14,604	11,924
5	16,754	13,621	13,440	11,406	16,383	13,196
6	17,192	13,648	13,787	11,451	16,790	13,293
7	16,421	13,554	12,984	11,332	16,151	13,237
8	15,353	13,456	11,561	11,256	14,990	13,150
9	16,601	13,438	12,885	11,238	16,298	13,129
10	18,563	13,534	15,079	11,320	18,456	13,260
11	17,420	13,446	13,497	11,253	16,871	13,160
12	16,172	13,381	12,311	11,126	15,739	13,094
13	17,506	13,431	13,352	11,075	16,798	13,115
14	16,974	13,400	12,874	10,937	16,501	13,041
15	18,548	13,320	14,451	10,816	18,037	12,925
16	17,794	13,296	13,427	10,737	17,216	12,904
17	19,644	13,449	15,762	10,882	19,572	13,069
18	18,908	13,407	14,816	10,866	18,631	13,047
19	17,364	13,356	13,429	10,907	16,921	13,022
20	19,293	13,395	15,632	10,980	19,020	13,070

remainder of the simulated time period. Net farm income exceeds government payments every year. Thus, positive net farm income is possible under unrestricted pumping for irrigators in Resource Situation 2. However, without government payments net farm income would range from less than $2,000 to about $6,000.

Under the quantity restriction, both the level of net farm income and government payments are lower than under unrestricted pumping. Net farm income exceeds government payments during every year of the simulation run. However, the difference between the two is smaller than for the unrestricted alternative. Net farm income exceeds government payments by a minimum of about $300 and a maximum of just under $5,000.

The relationship between net farm income and government payments under the graduated tax alternative compares favorably with the relationship under unrestricted pumping. Net farm income exceeds government payments during every year of the 20-year simulation run. The difference between the two ranges from about $1,800 to over $6,000.

The impact of government payments is of great significance to irrigators in both the poor and adequate water situations for the representative farm defined in this study. Irrigators in Resource Situation 2 are able to maintain positive net farm incomes over time without government payments. However, the level of net farm income is low regardless of the water-use alternative selected. Without government payments, many individual operators would be forced to either reduce current consumption or borrow heavily to maintain that consumption level. Irrigators in Resource Situation 1 who are under the pressure of declining well yields, rising pumping costs, declining crop yields and declining net farm income may find government payments of critical importance if they are to survive. The existence of low levels of net farm income while government payments are still in the $8,000 to $10,000 range indicates that negative net farm incomes (net returns to land, labor, management and risk) are likely without government payments. Their alternatives are to expand or migrate from the farm.

The implications drawn here are based upon the simulation of 640-acre representative farms defined for this study. Assumptions regarding prices (Chapter IV, p. 94), irrigation strategies (Chapter IV, pp. 102-104) and expansion of irrigation facilities (Chapter IV, pp. 115-117) are quite specific. Extrapolation from these resource situations to others in the study area must be made with caution.

Relative Rates of Water Withdrawal for Each Water-Use Alternative

Table XXX presents a summary of feet of saturated thickness remaining at the end of each of 15 replications of the 20-year simulation run. For Resource Situation 1, the mean values of feet of remaining saturated thickness are 35.84, 38.37 and 37.72 for unrestricted pumping, quantity restriction and graduated tax alternatives, respectively. Water is used at different rates for each alternative. That is, unrestricted pumping results in more rapid pumping in early periods and slower withdrawals, due to declining pump capacity, in later periods. The quantity restriction results in lower rates of withdrawal in early periods as capacity presses against the quantity limitation, but lower rates in later periods because greater pumping capacity remains for the irrigation system. Pumping or withdrawal rates for the graduated tax alternative remain between those for the unrestricted and taxed

TABLE XXX

REMAINING SATURATED THICKNESS OF OGALLALA FORMATION AT THE END OF 20-YEAR SIMULATION RUNS

	Resource Situation 1			Resource Situation 2		
Replication	Number Restrictions	Quantity Limitation	Graduated Tax	Number Restrictions	Quantity Limitation	Graduated Tax
1	35.74	41.57	39.73	233.60	251.80	243.90
2	36.51	37.23	39.13	230.49	250.92	243.07
3	35.97	39.57	37.70	237.00	252.97	246.56
4	33.42	36.08	34.67	233.85	252.11	244.94
5	37.53	36.51	36.91	240.62	254.26	249.19
6	35.27	37.94	35.73	231.10	250.82	242.88
7	36.09	37.75	37.57	239.07	252.13	248.38
8	35.61	38.20	38.48	235.23	251.64	245.60
9	35.63	39.88	38.69	234.82	251.56	245.91
10	36.39	36.42	35.52	234.01	250.93	245.33
11	36.28	37.19	38.14	236.59	251.69	246.34
12	35.95	37.04	36.18	236.90	251.70	246.38
13	34.66	39.16	37.75	236.21	252.07	246.52
14	35.59	40.54	38.65	232.21	251.20	243.30
15	36.93	40.52	40.97	233.78	251.36	245.84
Mean	35.84	38.37	37.72	235.03	251.81	245.61
Std. Dev.	0.96	1.72	1.70	7.78	0.88	1.82
Maximum	37.53	41.57	40.97	240.62	254.26	249.19
Minimum	33.42	36.08	34.67	230.49	250.82	242.88
Range	4.11	5.49	6.30	10.13	3.44	6.31
Feet Decline	64.16	61.33	62.28	89.97	73.19	79.39
Decline/Year	3.21	3.07	3.11	4.50	3.66	3.97

alternatives. Regardless of the alternative utilized, the ending position is approximately the same. The individual either completely returns to dryland farming or is maintaining about 80 acres of irrigated grain sorghum and attempting to spread fixed costs of the irrigation system over 40 to 65 acres of irrigated wheat during portions of the crop year not devoted to intensive irrigation of summer crops. The decline in saturated thickness is 64.16, 61.33 and 62.28 feet for the unrestricted, quantity restriction and graduated tax alternatives, respectively. The average decline is 3.21, 3.07 and 3.11 feet per year for the three alternatives. From the standpoint of the underground water supply, all alternatives will lead to economic exhaustion within Resource Situation 1 in about 20 years, given the assumptions of the model.

Based on water-use rates in Resource Situation 1, there is little reason for policy makers to restrict water use with a quantity limitation. It results in lower levels of net farm income while depleting the water supply at approximately the same point in time as for the other two alternatives. The policy maker might lean toward a graduated tax if water-use regulation is deemed desirable. Higher levels of net farm income are due primarily to individual action to restrict water use in earlier periods of the crop year, and to utilize economic decision rules in allocating water once the quantity limitation has been reached. One might argue against any type of water restriction in the poor water situation on the grounds that rational irrigators merely need to be informed that applying economic decision rules in the allocation of water can lead to higher levels of net farm income. An educational program to encourage voluntary application of rational economic decision rules to allocating the existing water supply would be more palatable to individual operators as well as to policy makers within the study area. The model developed in this study is capable of providing information regarding various irrigation strategies and their impact on net farm income.

Table XXX also presents feet of remaining saturated thickness for each water-use alternative for Resource Situation 2. Mean levels of saturated thickness are 235.08, 251.81 and 245.61 for the unrestricted, quantity restriction and graduated tax alternatives. The feet decline in saturated thickness are 89.97, 73.19 and 79.39 for the three water-use alternatives, respectively.

An 89.97-foot decline in saturated thickness for the unrestricted alternative is an average of about 4.50 feet per year. With approximately 110 feet of saturated thickness before well yields begin to decline, the unrestricted irrigator in Resource Situation 2 may be able to pump for an additional 24 years (a total of 44 years) before encountering significant changes in pumping capacity, and for perhaps an additional 35 years (a total of 55) before facing a reduction in irrigated acres.

The graduated tax alternative results in a 79.39-foot decline in saturated thickness, averaging 3.97 feet per year. At the end of 20 years, approximately 121 feet of saturated thickness remain before well reductions begin to occur. If the water table continues to decline at 3.97 feet per year, an irrigator in Resource Situation 2, operating under the graduated tax alternative, may be able to pump an additional 30 years (a total of 50 years) before well yield declines commence, and for perhaps an additional 41 years (a total of 61 years) before facing a reduction in irrigated acreage.

Pumping under a quantity restriction results in a decline of 73.19 feet in saturated thickness for an average of 3.66 feet per year. Almost 127 feet of saturated thickness remain before yield reductions begin. If the water table continues to decline at a rate of 3.66 feet per year, perhaps 35 years (a total of 55 years) of pumping remain before the irrigator in Resource Situation 2, pumping under a quantity restriction, is faced with declining well yields and rising pumping costs. Perhaps an additional 46 years (a total of 66 years) pumping exists before any reduction in irrigated acreage is necessary.

These statements apply strictly to the individual irrigator with a beginning saturated thickness of 325 feet, depth to water of 125 feet, well depth of 450 feet and pump depth of 400 feet. They also assume the irrigator is pumping from a closed basin one section in size with a given 1,000 gpm well and constant production organization. One must exercise great care when extrapolating from the assumed situation to all irrigators who are classified in Resource Situation 2. Some individuals in Resource Situation 2 have just above 200 feet of saturated thickness and experience an impact on well yield and pumping cost before 20 years have expired, assuming a decline of 4.5 feet per year in saturated thickness. Other individuals in Resource Situation 2 have perhaps 500 feet of saturated thickness and a seemingly endless water supply. At least, barring extraordinary and unforeseen circumstances, their water supply is sufficient for this generation. Thus, statements regarding the water situation for Resource Situation 2 must be viewed as applying to the modal representatives farm firm defined for this study. Considerable variation exists among individual operators. Unfortunately, only a limited number of situations may be simulated in a project approaching the magnitude of this one.

Based on the simplified analysis above, the maximum difference between the time unrestricted irrigators and irrigators operating under a quantity restriction begin to experience reductions in irrigated acreage is approximately 11 years. Eleven years is not an insignificant time period. Much can happen in that span of time as the present analysis indicates. However, this 11 years is the difference between 55 and 66 years of pumping for irrigators in Resource Situation 2 prior to significant reductions in irrigated acreage. Individual operators and policy makers would find it difficult to justify current restrictive actions based upon an uncertain event either 55 or 66 years in the future. Individual irrigators, under the circumstances, are sure to prefer unrestricted pumping to water-use restriction. Policy makers may find it difficult to make a convincing case for water-use regulation, even though it may prolong the economic life of the aquifer at least 11 years. The appropriate economic decision model in this instance is one that discounts future income streams over the life of the aquifer, under alternative water-use policies, to their present values. The income streams, discounted and summed, provide a common basis upon which policy makers can evaluate the alternatives. The projected life of the aquifer under alternative policies has not been determined in this study. However, a discounting model, presented in the next section, allows us to look at the present value of different income streams resulting from alternative water-use regulatory policies over the 20-year simulated time period of this study.

Discounting Net Income Streams to Their Present Value

The streams of net farm income resulting under the unrestricted, quantity restriction and graduated tax alternatives are discounted to their present value at several interest rates. Present values of net farm income for each regulatory alternative at four different interest rates for Resource Situations 1 and 2 are presented in Table XXXI.

The discounting model is appropriate because income in the current time period is worth more than income in future time periods due to uncertainty about the future and a preference by most individuals for current rather than future income. Through time, the discounting factor, $\frac{1}{(i+1)^n}$, increases. Thus, the value of future net income is reduced relative to the value of current net income. The magnitude of present values increases as interest rates decline because the discounting factor declines with the interest rate. Thus, the value of net income, when discounted, is larger.

Implications to be drawn from the analysis do not vary with interest rates. For Resource Situation 1, present value of net income is greatest for the graduated tax alternative. This finding is not surprising since net farm income under the graduated tax alternative exceeds net farm income under the unrestricted pumping alternative during every year but one. Present value of net farm income under unrestricted pumping exceeds that under the quantity limitation. Net farm income under unrestricted pumping greatly exceeds net farm income under a quantity restriction during early years of the simulated time period. During early years, the discounted factor is small, and discounted values of net farm income large. It is only during year 10 and

TABLE XXXI

PRESENT VALUE OF NET FARM INCOME FOR THREE WATER-USE REGULATION ALTERNATIVES AT FOUR INTEREST RATES

	Resource Situation 1			Resource Situation 2		
	Water-Use Regulation Alternative			Water-Use Regulation Alternative		
Interest Rate	No Regulation	Quantity Limitation	Graduated Tax	No Regulation	Quantity Limitation	Graduated Tax
.08	101,264	89,695	112,843	155,056	124,868	151,760
.05	123,421	109,469	139,711	200,776	160,733	196,366
.03	142,643	126,696	163,444	242,817	193,728	236,743
.01	166,761	148,392	193,694	298,321	237,257	291,736

years 17, 18, 19 and 20 that net farm income under a quantity restriction slightly exceeds net farm income under unrestricted pumping. In late periods, the discount factor is large, and contributions to the present value of net farm income by these excesses of income under a quantity restriction over income under unrestricted pumping are small.

For Resource Situation 2, the present value of net farm income under unrestricted pumping exceeds present values under both graduated taxation and a quantity limitation. This result is expected since the level of net farm income under unrestricted pumping exceeds that under the graduated tax every year except year 1. Since the levels of net farm income remain homologous over time, the present values are nearly the same. Present values of net farm income under both unrestricted pumping and graduated taxation exceed present value of net farm income under the quantity limitation. This finding is consistent with the significant differences found between distributions of net farm income under unrestricted pumping and graduated taxation when tested against the distribution under the quantity restriction.

Based on computation of present values of net farm income over the 20-year simulated time period, one can conclude that the timing aspects of the streams of net farm income do not differ enough for the implications of this analysis to be changed. A more valid basis of comparison would be to compute the present value of the longer, smaller stream of net farm income under the quantity restriction and compare it with a shorter, larger stream resulting under unrestricted pumping. Unfortunately, this study does not lend itself to that type of analysis.

Aggregate Implications

Aggregation of figures presented in previous sections to make meaningful statements about the water supply or net farm income of the region is difficult. Part of the difficulty stems from the fact that little is known regarding the intensity of irrigation development as it relates to specific saturated thickness conditions of the underground aquifer. However, there is data available relating the potential for irrigation development to specific saturated thickness intervals. Of the 5,193,968 acres within Resource Situation 1, a total of 3,536,224 acres, or 68.08 percent of the acres in the interval, are irrigable. For Resource Situation 2, 4,504,631 of 5,955,370 acres, or 75.64 percent of the total, are irrigable.[1] Development of irrigation facilities depends upon a great many factors including age of the operator, years of farming experience, years of irrigation experience, financial condition, managerial ability, borrowing capacity, labor availability and others, in addition to the existence of a water supply sufficient for current needs. Thus, it may be argued that irrigators in the less than 200-foot saturated thickness interval are as likely to develop or expand irrigation facilities as irrigators in the greater than 200-foot saturated thickness interval, as long as saturated thickness is sufficient to irrigate the production organization. If this is the case, those portions of the study area represented by Resource Situation 1 may be expected to continue to develop as rapidly as the adequate water situations.

It is assumed, based upon the above argument, that irrigation development in each of the Resource Situations is proportional to the number of irrigated acres. Thus, of the 1,528,789 irrigated acres in the study area, 712,263 are assumed to lie in the zero to 200-foot saturated thickness interval.[2] In addition, constant returns to size are assumed. Thus, if each one-section representative farm in Resource Situation 1 has 315 irrigated acres, a total of 2,261 such sections is required to represent the Situation. This does not imply that 2,261 representative farms are required to represent Resource Situation 1. Farms may vary in size. However, when aggregated, each section is assumed to have 315 irrigated acres. Aggregate computations of net farm income within the region under alternative water-use alternatives appear in Table XXXII.

Aggregate net farm income under the unrestricted alternative increased from $20,391,959 in year 1 to a maximum of $34,016,745 in year 5. Thereafter, income declines, except for a few years, reaching $4,935,763 in year 20. Similar patterns exist for the quantity restriction and graduated tax alternatives, although the magnitude of aggregate net farm income varies between the two alternatives. Under the quantity restriction, a maximum aggregate net farm income of $28,730,527 is reached in year 6, with income declining to $5,532,667 by year 20. Under the graduated tax alternatives, aggregate net farm income reaches a maximum of $34,697,306 in year 6 and declines only to $11,431,616 by year 20. Thus, aggregate net farm income resulting from irrigation operations in Resource Situation 1 is greatest under the graduated tax alternative of water-use regulation.

The remaining 816,526 irrigated acres are assumed to lie in Resource Situation 2. Again assuming constant returns to size and a one-section farm with 315 irrigated acres, the Resource Situation may be represented by 2,593 sections of land. This does not imply that

TABLE XXXII

AGGREGATE NET FARM INCOME UNDER THREE WATER-USE ALTERNATIVES FOR RESOURCE SITUATION 1

Year	No Restrictions	Quantity Restriction	Graduated Tax
1	20,391,959	19,876,451	21,418,453
2	22,178,149	21,965,615	23,652,321
3	30,617,506	25,436,250	30,738,295
4	31,289,979	25,167,191	31,748,962
5	34,016,745	27,742,470	33,838,126
6	33,064,864	28,730,527	34,697,306
7	30,733,773	25,813,837	32,406,913
8	25,897,494	22,413,293	39,381,695
9	24,577,070	23,139,074	29,035,762
10	25,603,564	26,903,639	30,225,048
11	19,851,580	17,669,715	23,688,497
12	14,481,705	12,690,993	18,128,698
13	16,962,022	14,027,244	20,043,765
14	15,460,718	12,709,081	18,739,168
15	17,452,659	12,629,946	20,959,470
16	12,919,354	12,062,435	18,234,965
17	16,964,283	17,140,641	22,510,516
18	9,837,611	10,380,251	15,700,384
19	2,331,091	2,833,033	8,743,287
20	4,935,763	5,532,667	11,431,616

2,593 farms are required to represent Resource Situation 2. Farm size may vary considerably. However, each section in the aggregated analysis is assumed to have 315 irrigated acres. Aggregate net farm income for that portion of the study area in Resource Situation 2 for each of three water-use alternatives is presented in Table XXXIII. With the exception of year 1, aggregate net farm income under the unrestricted pumping alternative is greater than under either the quantity restriction of graduated taxation alternatives. Aggregate income reaches $50,936,892 during year 17 for the unrestricted alternative. Minimum level of aggregate income is $24,830,568 during year 1 under the quantity restriction.

The two Resource Situations are combined for the study area aggregate income analysis in Table XXXIV. Under the unrestricted alternative, aggregate net farm income for the study area increases from $47,872,573 in year 1 to a maximum of $77,643,720 in year 6. Thereafter, aggregate income is variable, but declines gradually to $54,962,512 in year 20. Aggregate income is less under the quantity restriction alternative. It increases from $44,707,019 in year 1 to $64,480,218 in year 6, declines slightly before reaching a maximum of $66,003,486 in year 10, and is then variable, reaching $46,066,443 in year 20. Aggregate income under the graduated tax alternative exceeds income under either of the other two alternatives. Income increases from $49,593,991 in year 1 to a maximum of $78,233,776 in year 6, dips before rising to $78,081,456 in year 10 and generally declines to $60,750,476 in year 20.

In addition to producing the highest level of aggregate regional net farm income, the graduated tax alternative reduces water use

TABLE XXXIII

AGGREGATE NET FARM INCOME UNDER THREE WATER-USE ALTERNATIVES FOR RESOURCE SITUATION 2

Year	No Restrictions	Quantity Restriction	Graduated Tax
1	27,480,614	24,830,568	28,175,538
2	32,241,362	27,981,063	32,101,340
3	37,372,909	32,067,631	37,116,202
4	38,290,831	31,634,600	37,868,172
5	43,443,122	34,849,920	42,481,119
6	44,578,856	35,749,691	43,536,470
7	42,579,653	33,667,512	41,879,543
8	39,810,329	29,977,673	38,869,070
9	43,046,393	33,410,805	42,260,714
10	48,133,859	39,099,847	47,856,408
11	45,170,060	34,997,721	43,746,503
12	41,933,996	31,922,423	40,811,227
13	45,393,058	34,621,736	43,557,214
14	44,013,582	33,382,282	42,787,093
15	48,094,964	37,471,443	46,769,941
16	46,139,842	34,816,211	44,641,088
17	50,936,892	40,870,866	50,750,196
18	49,028,444	38,417,888	48,310,183
19	45,024,852	34,821,397	43,876,153
20	50,026,749	40,533,776	49,318,860

TABLE XXXIV

AGGREGATE NET FARM INCOME UNDER THREE WATER-USE ALTERNATIVES FOR THE STUDY AREA

Year	No Restrictions	Quantity Restriction	Graduated Tax
1	47,872,573	44,707,019	49,593,991
2	54,419,511	49,946,678	55,753,661
3	68,000,415	57,493,881	67,854,497
4	69,580,810	56,801,791	69,617,134
5	77,459,867	62,592,390	76,319,245
6	77,643,720	64,480,218	78,233,776
7	73,313,426	59,431,349	74,286,456
8	65,707,823	52,390,966	68,250,765
9	67,623,463	56,549,879	71,296,476
10	73,737,423	66,003,486	78,081,456
11	65,021,640	52,667,436	67,435,000
12	56,415,701	44,613,416	58,939,925
13	62,355,080	48,648,980	63,600,979
14	59,474,300	46,091,363	61,526,261
15	65,547,623	50,101,389	67,729,411
16	59,059,196	46,878,646	62,876,053
17	67,901,175	58,011,507	73,260,712
18	58,866,055	58,798,139	64,010,567
19	47,355,943	37,654,430	52,619,440
20	54,962,512	46,066,443	60,750,476

significantly below unrestricted pumping and generates tax revenues for the region. The magnitude of tax revenues generated from individual farms in the two Resource Situations, and aggregated by Resource Situations and the study area, are presented in Table XXXV. Tax revenue or payments by individual farms with each Resource Situation are derived by finding the difference between mean total acre inches pumped per year under the graduated tax and the quantity restriction of 5,670 acre inches. When acre inches pumped under the graduated tax are greater, the tax is computed at the rate of $0.50 per acre inch on the difference between the two. Revenues are aggregated by Resource Situations and for the region utilizing the same assumptions employed in the initial portion of this section.

The pattern of tax revenues generated under the graduated tax alternative point to several interesting relationships. First, individual farms in Resource Situation 1 pay the tax only during seven of the 20 years. During years 1, 2, 9, 10 and 12 through 20, no tax payments are made because pumping capacity was not great enough to apply 5,670 acre inches of irrigation water. The largest single tax payment per farm is made during year 3 in Resource Situation 1 ($353 for 706 acre inches pumped above the quantity limitation). Second, tax payments are made every year by irrigators in Resource Situation 2. The amount of tax payments varies from $103 to $302. Tax payments by irrigators in Resource Situation 2 exceed tax payments in Resource Situation 1 by a wide margin over the 20-year period. The tax is not as regressive as it might appear at first glance because irrigators in the poor water situation pay no tax almost one-third of the time. Third, tax revenue generated each year is substantial. It ranges from $267,079 in year 1

TABLE XXXV

REVENUE GENERATED FROM THE GRADUATED TAX BY RESOURCE SITUATION FOR THE STUDY AREA

	Resource Situation 1		Resource Situation 2		Study Area
Year	Individual Farm Taxes	Aggregate Tax Revenue	Individual Farm Taxes	Aggregate Tax Revenue	Tax Revenue
1			103	267,079	267,079
2			170	440,810	440,810
3	351	793,611	182	471,926	1,265,537
4	187	422,807	200	518,600	941,407
5	237	535,857	131	339,683	875,540
6	185	418,285	165	427,845	846,130
7	223	504,203	290	751,970	1,256,173
8	104	235,144	244	632,692	867,836
9			218	565,274	565,274
10			145	375,985	375,985
11	142	321,062	231	598,983	920,045
12			302	783,086	783,086
13			251	650,843	650,843
14			270	700,110	700,110
15			201	521,193	521,193
16			269	697,517	697,517
17			246	637,878	637,878
18			181	469,333	469,333
19			215	557,495	557,495
20			230	596,390	596,390

to $1,265,537 in year 3 and is seldom less than half a million dollars. Revenues appear sufficient to administer the tax and fund research efforts to study ways of conserving water, utilizing the existing stock more efficiently or importing water from areas with a surplus supply.

It should be emphasized that the aggregate implications are based upon the existence of approximately 1.5 million irrigated acres in the study area. Irrigated acreage is expected to continue to expand over the next decade.[3] As this expansion occurs, both aggregate net farm income and the level of tax revenues generated are expected to rise accordingly. The present analysis does not include future expansion in the 20-year simulated time period.

FOOTNOTES

[1] Solomon Bekure, "An Economic Analysis of the Intertemporal Allocation of Ground Water in the Central Ogallala Formation" (unpub. Ph.D. dissertation, Oklahoma State University, Stillwater, 1971), pp. 48-49.

[2] Ibid., p. 8.

[3] Bekure, p. 77 and p. 100, presents projections of irrigated acreage within the study area utilizing two different growth models.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Growth of irrigation within the Central Basin of the Ogallala Formation has progressed rapidly during the past decade. Future development is expected to continue at a rapid rate. The Central Basin is essentially a closed container of water. Additions to the water supply occur only as a result of percolation of rainfall and irrigation water into the aquifer. Average annual recharge is negligible relative to current withdrawals. Thus, over time, the quantity of water within the Central Basin is being depleted by the actions of individual irrigators.

The Ogallala Formation is not a uniform aquifer. Depth to water and saturated thickness are quite variable within the Central Basin. As the water table declines, the effects of declining well yields and rising pumping costs on profitability of irrigated crop production are expected to vary widely from area to area within the aquifer. Estimates of the impact of continued depletion of water supplies on individual farm firms in different resource situations are not available.

The finite quantity of water in the Central Basin of the Ogallala Formation is a stock resource possessing many of the characteristics of commonality. It is a stock resource because its total quantity does not increase with time. Commonality problems arise because all irrigators pump from a common source and each has his own self interests in mind. Individuals act to maximize returns to the scarce water resource from year to year without reference to future years. The collective actions of all irrigators increase future pumping costs and reduce the availability of future water supplies. Current water laws do little or nothing to discourage water use. Since the increased cost of pumping must be borne partly by all irrigators pumping from the basin, there is a divergence of private and social costs.

Several courses of action are available in the light of divergent social and private costs. One is to ignore the divergence of costs, allow current rates of water application to continue and deplete the water supply at a rapid rate. A second course of action is to more closely align social and private costs by restricting the quantity of water each irrigator is allowed to pump during a crop year. A third course of action to more closely align private and social costs is to levy a graduated tax per unit above the quantity limitation. Other courses of action are available, but this study is limited to consideration of the above three.

Objectives and Procedures

The specific objectives are: (1) to construct a model of a representative farm firm capable of simulating the effects of soil moisture and atmospheric stress during critical stages of plant development on final yields of the major irrigated and dryland crops of the study area; (2) to simulate, for poor and adequate water resource situations, over a 20-year period, several alternative methods of regulating water use, including (a) continued pumping at the present rate with no restrictions on water use, (b) restricting the quantity of water pumped per crop year to 1.5 acre feet per acre of water rights, and

(c) restricting the quantity of water pumped per crop year to 1.5 acre feet per acre of water rights, but allowing the irrigator to apply additional irrigation water if it is economically feasible to pay a graduated per unit tax of $0.50 per acre inch for each acre inch pumped above the quantity limitation; (3) to compare the effects of the three methods of water-use regulation on net farm income, variability of net farm income, net worth, variability of net worth, quantity of water pumped and availability of water for future periods; (4) to evaluate the alternative methods of restricting water use by discounting the streams of net returns and comparing present values of those net income streams.

The basic model utilized in accomplishing the objectives of this study is composed of two parts. The first is the General Agricultural Firm Simulator. This Simulator provides a general structure within which many problems may be solved by varying the situation being simulated. For this study, a representative farm firm is constructed to fit the input data requirements of the Simulator based on a random sample of irrigated farms in the study area. The Simulator, given a set of input data for the representative farm, performs capital management operations, determines the quantities of inputs required to operate the activities at levels specified in the data, computes the output of products, computes the quantity of input services available from capital inventory, makes appropriate inventory adjustments, applies prices and costs to outputs and inputs and prepares a financial summary of the firm's operation each year of a multiperiod simulation run. This portion of the model is utilized to acquire a sequential analysis of the financial status of the representative firm during each 20-year simulation of a water-use regulatory alternative.

The second portion of the model utilized is a new Production Subset for the General Agricultural Firm Simulator. The Production Subset circumvents the restrictive assumption of the Simulator that all crop yields are normally and independently distributed with known mean and standard deviation. The Production Subset determines final crop yields as a function of the length and severity of soil moisture and atmospheric stress in relation to critical stages of plant development for each dryland and irrigated crop included in the analysis. Components of the model include discrete probability distributions for rainfall, lognormally distributed pan evaporation distributions, a set of relationships between pan evaporation and evapotranspiration for each crop, a series of equations composing a soil moisture balance system and coefficients relating soil moisture and atmospheric stress to yield reductions for each crop. Daily values of rainfall and pan evaporation are generated probabilistically. Daily soil moisture values are maintained for each crop. Daily yield reductions are a function of severity of soil moisture and atmposheric stress for each crop. Daily yield reductions are summed across three critical stages of grain sorghum development, four critical stages of wheat development and five critical stages of corn development. Final yield for each crop is determined by subtracting yield reduction from a potential yield which may be reached under adequate soil moisture conditions throughout the growing season.

The Production Subset provides input data for the General Agricultural Firm Simulator. In addition to final crop yield for each crop or crop block, the Production Subset also specifies the number of hours of machine use by implement and crop enterprise, hours of crop and irrigation labor required by periods, acre inches of irrigation water pumped per acre by crops and periods of the crop year, cash costs per acre by crops, hours of annual use of each component of irrigation equipment and government payments per acre for wheat, grain sorghum and corn. This output data is punched on cards for use by the Simulator as input data. Thus, over time, the output from the Production Subset serves as input data for the Simulator which provides an economic analysis of the consequences of water-use regulatory alternatives.

Three water-use alternatives are simulated. The first alternative is continued development and pumping without restrictions. Irrigators are assumed to base irrigation decisions on the level of available soil moisture specified as critical for each crop during each of the irrigation periods. This alternative provides no incentive to conserve water use in the current period for future use.

The second alternative simulated requires irrigators to restrict pumping to 1.5 acre feet per acre of water rights. Rather than pumping strictly on the basis of available soil moisture, the irrigator is assumed to reduce pumping in early periods of the crop year to a specified maximum number of acre inches per crop per period. This reduction in pumping during irrigation periods early in the year acts as a hedge against the uncertainty of weather conditions during later periods of the crop year.

The third water-use regulatory alternative simulated allows the irrigator to pump as much irrigation water as desired, however, once the previously mentioned quantity limitation is reached, additional acre inches may be pumped only if the irrigator is willing to pay $0.50

per acre inch for each acre inch pumped above the quantity limitation. The irrigator is assumed to follow the rules specified under the quantity limitation alternative until that limit is reached. Then additional applications are made if the value of yield reductions which will occur, projecting current moisture conditions, exceeds the cost of the additional irrigation, including added harvesting and hauling, pumping, labor and tax costs.

Each alternative is simulated over a 20-year period and replicated 15 times.

Results and Conclusions

Resource Situation 1

Resource Situation 1 represents the "poor water" situation within the study area. The weighted average saturated thickness of 100 feet will support a well yield of approximately 780 gpm. Over time, well yields decline rapidly. Irrigators are assumed to add an additional well when pumping capacity for the system falls below 750 gpm. Once three wells are in use, no further expansion occurs. Instead, when water requirements outstrip pumping capacity, irrigators are assumed to reduce the number of acres devoted to irrigated crop production. The decision rule is that whenever net returns above variable costs for a block of irrigated crop fall below opportunity cost net returns on dryland wheat, the irrigated crop block is converted to dryland wheat production.

Of interest to irrigators and policy makers are the effects of unrestricted pumping, a quantity limitation and graduated taxation on total acre inches pumped, net farm income and net worth for irrigators in Resource Situation 1. The differences in mean values of acre inches pumped under the three water-use alternatives are tested for statistical significance using the Wilcoxon Matched-Pairs, Signed Ranks Test. It is designed to test the null hypothesis that two related groups do not differ significantly. The alternative hypothesis may be that they do differ significantly (for a two-tailed test) or that one group is "greater" than the other (a one-tailed test). Two-tailed tests are conducted at the $\alpha = 0.05$ level of significance and one-tailed tests at the $\alpha = 0.01$ level of significance.

Statistical tests between each set of means of total acre inches pumped over the 20-year period under the three institutional alternatives reveal no significant differences. Thus, mean acre inches pumped are the same whether water use is unrestricted, subject to a quantity limitation, or taxed $0.50 per acre inch for each acre inch pumped above the quantity limitation. The unrestricted irrigator pumps more water during early years of the 20-year period, depletes his pumping capacity rapidly and pumps the smallest number of acre inches from year 12 through 20. The quantity limitation results in fewer acre inches pumped during early years, but leaves the irrigator capacity to pump the greatest number of acre inches per year from year 12 through 20. Water use under the graduated tax alternative is between the two extremes. The three water-use alternatives, though differing somewhat in timing of applications result in essentially the same saturated thickness and decline in the water table at the end of the 20-year period. The feet of saturated thickness remaining are 35.84, 38.37 and 37.72 for the unrestricted, quantity restriction and graduated tax alternatives, respectively.

Mean values of net farm income over the 20-year period under the three water-use alternatives are tested for statistical significance, using the Wilcoxon Matched-Pairs, Signed Ranks Test. The tests reveal that mean net farm income under the graduated tax alternative is significantly above mean net farm income under unrestricted pumping and a quantity limitation. Also, the mean under unrestricted pumping is significantly larger than the mean under a quantity restriction on water-use.

Perhaps most surprising is the conclsuion that mean net farm income under the graduated tax alternative is greater than under unrestricted pumping. Several interrelated factors contribute to this condition. The unrestricted irrigator tends to operate his irrigation system at maximum capacity, attempting to achieve maximum yields. By attempting to maximize yields per acre, irrigation water is applied during certain periods to the point where its marginal value productivity is very low. That is, additional water adds little or nothing to final crop yield and the value of the additional yield is less than the cost of the added water. Under the graduated tax alternative, less water is applied during early periods. Thus, the taxed irrigator is able to achieve more timely irrigations in relation to plant needs during later critical periods of development. More timely applications lead to higher final crop yields for the same amount of water. Since pumping costs rise more slowly, net returns per acre and net farm income are higher, despite the tax payments.

Variability of net farm income, as measured by the coefficient of variation, is greater under the quantity restriction than under either of the other alternatives. Net farm income under a graduated tax possesses the lowest relative variability.

Mean values of net worth are also tested for significant differences using the Wilcoxon Matched-Pairs, Signed Ranks Test. These tests reveal that mean net worth under graduated taxation is above mean net worth under unrestricted pumping or the quantity limitation. Also, mean net worth under unrestricted pumping is above that under a quantity limitation.

Resource Situation 2

Resource Situation 2 represents the "adequate water" situation within the study area. The weighted average saturated thickness of the Ogallala Formation is 325 feet. Since only 125 feet of saturated thickness are required to maintain pumping capacity at 1,000 gpm, irrigation operators may lower the water table approximately 200 feet before well yields begin to decline and a significant rise in pumping costs occurs. Given the assumptions on irrigated acreage, the static water table does not decline 200 feet within the 20-year time span of this analysis. Thus, the irrigator in Resource Situation 2 is assumed to require only one well which delivers 1,000 gpm during each year of the analysis. No additional wells are required to maintain irrigated production of 315 acres of cropland.

Policy makers and irrigators are interested in the effects of water-use regulatory alternatives on representative farm firms in the adequate water situation. The effects of unrestricted pumping, a quantity limitation and graduated tax alternatives on total acre inches pumped, net farm income and net worth for the representative firm are simulated over a 20-year period. The differences in mean values of acre inches pumped, net farm income and net worth are tested for statistical significance using the Wilcoxon Matched-Pairs, Signed Ranks Test.

For the first test, the null hypothesis is that the mean values of total acre inches pumped under unrestricted pumping do not differ from the mean values under the quantity limitation. The alternative hypothesis is that mean acre inches pumped under unrestricted pumping is greater than under the quantity limitation. The null hypothesis is rejected at the $\alpha = 0.01$ level. Additional tests reveal that mean acre inches pumped under the unrestricted alternative is above that under graduated taxation and that mean acre inches pumped under graduated taxation is above that under the quantity limitation.

The unrestricted alternative allows the irrigator to pump at the capacity of the system for the entire growing season. Both the graduated tax and quantity limitation restrict water-use to levels significantly lower than under unrestricted pumping. Since capacity does not decline over time, the unrestricted irrigator is capable of applying more irrigation water than irrigators who are restricted. Variability of acre inches pumped is greatest under the unrestricted pumping alternative. The least relative variability is observed under a quantity limitation because the irrigator is prohibited from pumping more than the upper limit, even during very dry years.

The three water-use policies result in different water-use rates and feet of saturated thickness remaining at the end of the 20-year period. Remaining saturated thickness is 235.03, 251.81 and 245.61 feet under unrestricted pumping, a quantity limitation and graduated taxation, respectively. The corresponding feet of decline in saturated thickness are 89.97, 73.19 and 79.39, respectively. The three policies result in declines of 4.50, 3.66 and 3.97 feet per year, respectively. Projecting these rates of decline linearly, the irrigator pumping without restrictions should have an additional 24 years (a total of 44) before encountering significant declines in pumping capacity. The graduated tax alternative should provide an additional 30 years pumping (a total of 50 years) before significant reductions in well yields occur. The quantity limitation should provide an additional 35 years pumping (a total of 55) before significant reductions in well yields occur. The difference between the maximum and minimum number of years prior to encountering well yield reductions is 11 years (the difference between 55 years under the quantity limitation and 44 years under unrestricted pumping). Policy makers and irrigators must weigh the value of production from 11 years additional life under the quantity limitation against the value of current income foregone if unrestricted pumping is prohibited. This analysis is limited to a 20-year time horizon rather than projecting the length of life of the aquifer under alternative policies.

Mean values of net farm income resulting under the three water-use alternatives over the 20-year period are tested for statistical significance. Two sets of matched-pairs are compared in each test. The tests reveal that mean net farm income under unrestricted pumping is above mean net farm income under either the graduated tax or the quantity limitation. Also, mean net farm income under the graduated tax is above that under the quantity limitation. Thus, the unrestricted irrigation in Resource Situation 2 is able to maintain the highest level of net farm income while pumping the greatest quantity of water. Mean net farm income under graduated taxation, while significantly lower from a statistical standpoint, remains at a reasonable level, as indicated in Figure 12, Chapter V. The unrestricted irrigator tends to apply water to the point where its marginal value product is very low. Thus, the irrigator operating under a graduated tax is able to apply less water and achieve net returns comparable to those of the unrestricted irrigator.

Variability of net farm income, as measured by the coefficient of variation, is greatest under the quantity limitation. Irrigators have less flexibility under the quantity limitation than under the other two alternatives. Once the quantity limitation is reached, no additional water can be applied. Thus, moisture stress during dry years results in significant yield reductions, corresponding reductions in net farm income and an increase in variability of net farm income. Lowest relative variability results from the unrestricted pumping alternative. With no reductions in pumping capacity or levels, timely irrigations can be applied as required. Thus, variability of net farm income is reduced. Relative variability of the graduated tax alternative is between that of unrestricted pumping and the quantity limitation.

Mean values of net worth generated under the unrestricted pumping, quantity limitation and graduated tax alternatives are tested for statistical significance using the Wilcoxon Matched-Pairs, Signed Ranks Test. The results of these tests indicated that mean net worth under unrestricted pumping exceeds that of both the graduated tax and quantity limitation alternatives. Mean net worth under the graduated tax exceeds that under the quantity limitation. These results are expected based upon the differences in net farm income for each alternative.

Present Values of Streams of Net Returns

Streams of net farm income resulting under the unrestricted, quantity restriction and graduated tax alternatives are discounted to their present value at several interest rates. The income streams are discounted for uncertainty and time preference of income over the 20-year period of the analysis.

Discounting the streams to their present values at one, three, five and eight percent does not change the implications of the analysis. That is, for Resource Situation 1, present value of net farm income is greatest under graduated taxation, followed by unrestricted pumping and the quantity limitation, regardless of the interest rate used. For Resource Situation 2, present value of net farm income under restricted pumping exceeds present values under both graduated taxation and a quantity limitation. Likewise, present value of net farm income under graduated taxation exceeds that under the quantity limitation.

Thus, the difference in timing of net farm income resulting from the different water-use alternatives is not great enough over the 20-year time span to alter the implications of the analysis.

Government Payments

Comparisons of net farm income and government payments are made for each Resource Situation and method of water-use regulation. For Resource Situation 1, government payments exceed net farm income after year 6 or 7, regardless of the water-use policy adopted. That is, net farm income would be negative from year 7 or 8 to year 20, except for the existence of government programs. Irrigators in Resource Situation 1 must either expand their operations or migrate from the farm.

Government payments are a significant portion of net farm income for irrigators in Resource Situation 2, regardless of the method of water-use regulation employed. Net returns are positive every year under all three alternatives, but exceed government payments by amounts ranging from only $300 to about $6,000. Irrigators in Resource Situation 2 are heavily dependent upon government payments for both size and stability of net farm income.

Aggregate Net Farm Income

Net farm income is aggregated by Resource Situation and for the study area using assumption of constant returns to size. For Resource Situation 1, aggregate income is greatest under graduated taxation, while for Resource Situation 2, aggregate net farm income is largest under unrestricted pumping. For the study area as a whole, aggregate income is greatest under graduated taxation.

In addition to generating the highest level of aggregate income, the graduated tax generates tax revenues ranging from $267,079 to $1,256,173 with the total revenue seldom falling below $500,000. This revenue is seen as sufficient to administer the tax and finance research on means of conserving water-use in the region.

Policy Implications

Policy implications differ somewhat for the two Resource Situations. In Resource Situation 1, the poor water situation, economic exhaustion appears likely in about 20 years regardless of the water-use policy adopted. Policy makers interested in conserving water may be indifferent as to whether pumping continues unrestricted or is reduced in initial periods by applying a graduated tax or quantity limitation. However, policy makers are also interested in the level of income that may be maintained if water-use is restricted. This analysis indicates that the level of net farm income and net worth are significantly greater under the graduated taxation alternative than under either unrestricted pumping or a quantity limitation. For this reason, the policy maker might prefer imposition of a graduated tax on water-use. A complicating factor is that the current legal framework within the study area does not lend itself to imposition of taxes on water-use. Laws would have to be changed. Restriction of water-use through taxation requires a significant change from a strict interpretation of the Doctrine of Prior Appropriation.

Individual irrigators are likely to prefer unrestricted pumping despite some evidence that the graduated tax alternative may lead to higher net farm income. One factor should be emphasized. The primary reason the graduated tax results in greater net farm income, while utilizing essentially the same quantity of water, is that it provides an incentive for irrigators to reduce excessive pumping in early periods of the crop year and apply an economic decision rule in allocating water during Irrigation Periods 4 and 5. It may be argued that no water restrictions are needed for irrigators in Resource Situation 1. Perhaps irrigators merely need to be informed that application of economic decision rules in allocating water to maximize net returns, rather than crop yields, can lead to higher levels of net farm income. An educational program of this nature would be more palatable to individual operators as well as policy makers within the study area. The Production Subset utilized in this analysis is capable of providing information regarding the impact of various strategies on net farm income.

Restriction of water-use for Resource Situation 2 has a different impact and somewhat different policy implications. Unrestricted pumping results in the greatest water use, highest level of net farm income and net worth and lowest relative variability of net farm income of any alternative studied. For the individual irrigator, unrestricted pumping provides the most favorable set of conditions. However, unrestricted pumping does deplete the water supply more rapidly than either the graduated tax or quantity limitation alternatives.

Policy makers may argue that the graduated tax alternative reduces water use significantly while maintaining a level of net farm income comparable to that under unrestricted pumping. Imposition of the graduated tax requires significant changes in the legal and institutional framework and may prove difficult to enact and administer. However, significant revenue may be generated from this alternative.

Policy makers have an additional alternative. The quantity limitation provides the lowest level of net farm income with the greatest relative variability. However, water-use rates are reduced by the largest amount also. Policy makers wishing to pursue this alternative have the legal basis already in existence. However, the economic feasibility rests upon answers to several important questions. First, how much will the quantity limitation lengthen the life of the aquifer? Second, what is the present value of the longer but lower stream of net farm income? Third, what will the length of the economic life of the aquifer be under unrestricted pumping? Fourth, what is the present value of the shorter, higher stream of net farm income under unrestricted pumping? This analysis does not project the life of the aquifer under alternative policies. However, based upon some linear projections of water use rates under the three policies, the maximum difference between the time of significant well yield reductions under the policy of most rapid depletion (unrestricted pumping) and the policy of slowest depletion (a quantity limitation) is only about 11 years. This 11 years is the difference between a total of 55 years under the quantity restriction and 44 years under unrestricted pumping. Policy makers may find it difficult to convince individual farmers in the area to forego almost certain income in the current period for the prospect of uncertain income from 44 to 55 years in the future. Thus, policy makers may find it difficult to make a convincing case for water-use regulation in Resource Situation 2.

A final policy implication is that government payments provide a substantial portion of net farm income for both Resource Situations 1 and 2. Without government payments, irrigators in Resource Situation 1 are likely to experience negative net farm income over a large part of the 20-year period. Irrigators in Resource Situation 2 are able to maintain positive net farm income without government payments, but the level of income is relatively low.

Limitations

Mathematical formulations of models designed to represent any situation with a degree of sophistication approaching reality tend to be extremely complex. The trade off between reality and managability requires simplifying assumptions. Simplifying assumptions may reduce the rigor or extent of the analysis, but leave the implications unchanged. Hopefully, this is the case in the current analysis.

The compromise between reality and managability necessitated definition of only two resource situations to represent six saturated thickness intervals. Rather than drawing implications for each of six resource situations, these are aggregated into the two resource situations. Implications with respect to net farm income and water supply within six individual resource situations are not expected to differ significantly. While the magnitude of net farm income and decline in the water table may differ, the direction of change should be the same. Resource situations with less than 100 feet of saturated thickness are likely to experience a return to dryland farming in less than 20 years. Irrigators with more than 325 feet of saturated thickness simply have a greater number of years before experiencing economic exhaustion of the water supply.

An additional limitation is the definition of one model representative farm to represent all farm sizes in the study area. While water-use rates may not be affected significantly, net farm incomes and net worth figures would likely differ with farm size. The assumption of constant prices may affect the results over time. If prices of the products produced rise significantly, estimates of net farm income may be too low. However, if prices paid for inputs rise more rapidly than output prices, the estimates of net farm income may be too high. During the past decade, prices paid for production inputs have risen faster than prices received for agricultural outputs. If this trend continues, estimates of net farm income may be too high.

The study is limited by lack of sufficient data on the relationships between soil moisture and atmospheric stress and crop yield reduction during critical stages of plant development. Coefficients for grain sorghum, wheat and corn are synthesized with the assistance of experts in several fields of study. Mathematical derivation of the relationships is impossible due to insufficient data. Lack of data prevents use of additional crops besides grain sorghum, wheat and corn. Data on small grain grazing, native pasture and other crop yield-stress relationships would increase the applicability of the model immeasurably.

The hydrologic assumptions of the study are subject to limitations also. Saturated thickness varies widely within any interval and the well yields from that saturated thickness vary due to the characteristics of the aquifer at the point of well discharge. Assumptions of constant permeability and coefficient of storage may introduce errors in well yield, and volume of water in storage. Thus, individuals within one of the Resource Situations defined may experience quite different well yields, rates of decline, pumping costs and net farm income levels than those revealed by this study.

Suggestions for Further Research

Additional studies designed specifically to isolate critical stages of development for additional crops in the study area would be quite beneficial. Then, the effect of moisture stress and atmospheric stress during each stage of plant development requires specific study. Such information is needed to expand the usefulness and applicability of the Production Subset of the model. Given sufficient data, the

Production Subset could be utilized to evaluate irrigation strategies for farm operators and to isolate optimum strategies.

Once the data is available to expand the model to include all relevant crops for the study area, several interesting economic analyses appear possible. By incorporating the Production Subset and a linear programming subroutine into the General Agricultural Firm Simulator, the combination of enterprises to maximize profits subject to constraints could be specified for each year of a multiperiod run. Given the production organization at the beginning of the crop year, based on expected yields and net returns per acre, actual yields could be determined in the Production Subset as a function of soil moisture and atmospheric stress. Alternative water use policies could be evaluated through simulated time with an optimal organization of production.

Another economic application might be to simulate crop yields within the Production Subset under a large number of irrigation policies for each period or stage of the crop year. The state variable might be soil moisture level. Probabilities of moving from state to state under different policies and the resulting net returns must be established. Then a dynamic programming procedure may be applied to determine the optimal irrigation strategy over the one year planning horizon.

The development of a dynamic input-output model for the study would make possible more explicit statements about impacts of policy alternatives on various sections of the regional economy. The effects on output, income and employment may be evaluated within the framework of traditional multiplier analysis. A dynamic model lends itself to projecting future changes in income, output and employment based upon alternative policies within the region. The primary and secondary impacts of irrigation development may be isolated and future impacts predicted based on alternative rates of development.

Additional hydrologic refinements are possible. The existence of a digital computer model of the aquifer would permit accurate representation of effects of intensive irrigation development on the static water level. Such a model would provide a valuable input into any economic analysis involving the water supply or hydrologic characteristics of the aquifer.

The possibilities for additional research appear promising. Each new project could expand the frontier of knowledge. However, the use of more sophisticated models must be undertaken with discretion. The results are likely to be only as good as the weakest link in the chain of input data required for successful completion of the project.

A SELECTED BIBLIOGRAPHY

Allen, R. R., et. al. *Grain Sorghum Yield Response to Row Spacing in Relation to Seeding Date, Days to Maturity and Irrigation Level in the Texas Panhandle.* Texas Agricultural Experiment Station, PR-2697, June, 1969.

Aitchinson, J. and J. A. C. Brown. *The Lognormal Distribution.* New York: Cambridge University Press, 1957.

Barker, Randolph and B. F. Stanton. "Estimation and Aggregation of Firm Supply Functions." *Journal of Farm Economics*, Vol. 47, No. 3 (1965).

Bekure, Solomon. "An Economic Analysis of the Intertemporal Allocation of Ground Water in the Central Ogallala Formation." (unpub. Ph.D. dissertation, Oklahoma State University, 1971).

Castle, E. N. and K. H. Lindeborg. "The Economics of Ground-Water Allocation: A Case Study." *Journal of Farm Economics*, Vol. 42, No. 1 (1960).

Clements, A. M., H. P. Mapp, Jr. and V. R. Eidman. *A Procedure for Correlating Events in Farm Firm Simulation Models.* Agricultural Experiment Station, Oklahoma State University, Technical Bulletin T-131, 1971.

Covey, Winton and M. E. Bloodworth. *Mathematical Study of the Flow of Water to Plant Roots.* Texas Agricultural Experiment Station, College Station, MP-599, 1962.

Dale, R. F. and R. H. Shaw. "Effect on Corn Yields of Moisture Stress and Stand at Two Fertility Levels." *Agronomy Journal*, Vol. 57 (1965).

Dawson, J. A. "The Productivity of Water in Agriculture." *Journal of Farm Economics*, Vol. 39, No. 5 (1957).

Day, L. M. "Use of Representative Farms in Studies of Interregional Comptetition and Production Response." *Journal of Farm Economics*, Vol. 45, No. 5 (1963).

Day, R. H. "On Aggregating Linear Programming Models of Production." *Journal of Farm Economics*, Vol. 45, No. 4 (1963).

Denmead, O. T. and R. H. Shaw. "Availability of Soil Water to Plants as Affected by Soil Moisture Conditions and Meterological Conditions." *Agronomy Journal*, Vol. 54 (1962).

__________. "The Effects of Soil Moisture Stress at Different Stages of Growth on the Development and Yield of Corn." *Agronomy Journal*, Vol. 52 (1960).

__________. "Evapotranspiration in Relation to the Development of the Corn Crop." *Agronomy Journal*, Vol. 51 (1959).

Doll, J. P., et. al. *Economics of Agricultural Production, Markets, and Policy*. Illinois: 1968.

Edwards, Clark. "Resource Fixity and Farm Organization." *Journal of Farm Economics*, Vol. 41, No. 4 (1959).

Eidman, V. R. "Framework for Analysis of Irrigation Development." *Irrigation as a Factor in the Growth, Operation, and Survival of Great Plains Farms*. Great Plains Agricultural Council, Publication No. 30, Washington, D.C., 1967.

__________. "Optimum Production Plans for California Turkey Growers with Chance-Constrained Programming." (unpub. Ph.D. dissertation, University of California, Berkeley, 1965).

Fader, S. W., et. al. *Geohydrology of Grant and Stanton Counties, Kansas*. State Geological Survey of Kansas, Bulletin 168, 1964.

Fisher, W. D. and P. L. Kelley. *Selecting Representative Firms in Linear Programming*. Agricultural Experiment Station, Kansas State University, Technical Bulletin 159, 1968.

Frick, G. E. and R. A. Andrews. "Aggregation Bias and Four Methods of Summing Farm Supply Functions." *Journal of Farm Economics*, Vol. 47, No. 3 (1965).

Geology and Ground-Water Resources of the North Plains Ground Water Conservation District No. 2. North Plains Water District, Progress Report No. 2, Dumas, Texas, 1968.

Gordon, H. S. "The Economic Theory of a Common-Property Resource: The Fishery." *The Journal of Political Economy*, Vol. 42 No. 2 (1954).

Green, J. W., V. R. Eidman and L. R. Peters. *Alternative Irrigated Crop Enterprises on Clay and Sandy Loam Soils of the Oklahoma Panhandle: Resource Requirements, Costs and Returns*. Agricultural Experiment Station, Oklahoma State University, Processed Series P-554, 1967.

Greve, R. W., J. S. Plaxico and W. F. Lagrone. *Production and Income Variability of Alternative Farm Enterprises in Northwest Oklahoma*. Agricultural Experiment Station, Oklahoma State University, Bulletin B-563, 1960.

Ground Water and Wells. St. Paul, Minnesota: Edward E. Johnson, Inc., 1966.

Guidelines for Application of Center-Pivot Sprinkler Irrigation Systems in Western Oklahoma. U.S. Department of Agriculture Inter-Agency Ad Hoc Committee Report, Oklahoma State University Extension, Stillwater, 1970.

Hirshleifer, J., et. al. *Water Supply: Economics, Technology and Policy*. Chicago: University of Chicago Press, 1960.

Hoel, P. G. *Introduction to Mathematical Statistics*. New York: John Wiley and Sons, 1962.

Holmes, R. M. and G. W. Robertson. "Application of the Relationships Between Actual and Potential Evapotranspiration in Dryland Agriculture." *Trans. Am. Soc. Agr. Engrs.*, *6* (1963).

__________. "A Modulated Soil Moisture Budget." *Monthly Weather Review*, *87* (1959).

Holt, R. F., D. R. Timmons, W. B. Voorhees and C. A. Van Doren. "Importance of Stored Soil Moisture to the Growth of Corn in Dry to Moist Subhumid Climatic Zone." *Agronomy Journal*, Vol. 55 (1963).

Huffman, R. E. *Irrigation Development and Public Water Policy*. New York: The Ronald Press, Company, 1953.

Hughes, W. F. and A. C. Magee. *Some Economic Effects of Adjusting to a Changing Water Supply*. Agricultural Experiment Station, Texas A & M University, Bulletin 966, 1960.

Hutton, R. F. "Introduction to Simulation." *Agricultural Production Systems Simulation*, V. R. Eidman (ed.), Oklahoma State University, 1971.

Interim Price Standards for Planning and Evaluating Water and Land Resources. Water Resource Council, Washington, D.C., 1966.

Jensen, M. E. and W. H. Sletten. *Evapotranspiration and Soil Moisture-Fertilizer Interrelations with Irrigated Grain Sorghum in the Southern Great Plains*. U.S. Department of Agriculture Conservation Research Report No. 5, August, 1965.

__________. *Evapotranspiration and Soil Moisture-Fertilizer Interrelations with Irrigated Winter Wheat in the Southern High Plains*. U.S. Department of Agriculture Conservation Report No. 4, July, 1965.

Johnson, W. C. "Some Observations on the Contribution of an Inch of Seeding-Time Soil Moisture to Wheat Yield in the Great Plains." *Agronomy Journal*, Vol. 55 (1963).

Kelso, M. M. "The Stock Resource Value of Water." *Journal of Farm Economics*, Vol. 43, No. 5 (1961).

Kneese, A. V. *The Economics of Regional Water Quality Management.* Baltimore: The John Hopkins Press, 1964.

Ligon, James T., George R. Benoit and A. B. Elam, Jr. "A Procedure for Determining the Probability of Soil Moisture Deficiency and Excess." Department of Agricultural Engineering, Paper No. 64-211, University of Kentucky, 1964.

Marine, I. W. and S. L. Schoff. *Ground Water Beaver County.* Oklahoma Geological Survey, Bulletin 97, Norman, 1962.

Marsaglia, G. "Generating Discrete Random Variables in a Computer." *Communications of the ACM* (1963).

Marshall, Alfred. *Principles of Economics*, 8th edition. London: Macmillan and Company, 1966.

McPherson, W. K. "Can Water Be Allocated by Competitive Prices?" *Journal of Farm Economics*, Vol. 38, No. 5 (1956).

Milliman, J. W. "Commonality, the Price System and Use of Water Supplies." *The Southern Economic Journal*, Vol. 22, No. 4 (1956).

Moore, C. V. "A General Analytical Framework for Estimating the Production Function for Crops Using Irrigation Water." *Journal of Farm Economics*, Vol. 43, No. 4, Part 1 (1961).

Musick, J. T. *Irrigating Grain Sorghum with Limited Water.* Proceedings of the Texas A & M University Soil Conservation Service Conservation Workshop, College Station, Texas, July 15-16, 1968.

Musick, J. T., and D. A. Dusek. *Grain Sorghum Response to Number, Timing and Size of Irrigations in the Southern High Plains.* Unpublished manuscript, USDA Southwestern Great Plains Research Center, Bushland, Texas, 1969.

__________. *Grain Sorghum Row Spacing and Planting Rates Under Limited Irrigation in the Texas High Plains.* Texas Agricultural Experiment Station, MP-932, October, 1969.

Musick, J. T. and D. W. Grimes. *Water Management and Consumptive Use by Irrigated Grain Sorghum in Western Kansas.* Kansas Agricultural Experiment Station Technical Bulletin 113, Garden City, February, 1961.

Musick, J. T., D. W. Grimes and G. M. Herron. *Water Management, Consumptive Use, and Nitrogen Fertilization of Irrigated Winter Wheat in Western Kansas.* USDA Production Research Report No. 75, September, 1963.

Musick, J. T., D. W. Grimes and G. M. Herron. "Irrigation Water Management and Nitrogen Fertilization of Grain Sorghums." Agronomy Journal, Vol. 55 (1963).

Musick, J. T. and W. H. Sletten. "Grain Sorghum Irrigation-Water Management on Richfield and Pullman Soils." Transactions of the ASAE, Vol. 9, No. 3 (1966).

Musick, J. T., W. H. Sletten and D. A. Dusek. Irrigating Grain Sorghum for Efficient Use of Limited Water. Paper No. 64-208, Annual Meeting of Agricultural Engineers, Ft. Collins, Colorado, June 21-24, 1964.

Nakayama, F. S. and C. H. M. Van Bavel. "Root Activity Distribution Patterns of Sorghum and Soil Moisture Conditions." Agronomy Journal, Vol. 55 (1963).

Ogata, G., L. A. Richards and W. R. Gardner. "Transpiration of Alfalfa Determined from Soil Water Content Changes." Soil Science, Vol. 89, No. 4 (April, 1960).

Ostle, Benard. Statistics in Research. Ames: Iowa State University Press, 1963.

Plaxico, J. S. "Aggregation of Supply Concepts and Firm Supply Functions." Farm Size and Output Research, Southern Cooperative Series Bulletin 56 (June, 1958).

Porter, K. B., M. E. Jensen and W. H. Sletten. "The Effect of Row Spacing Fertilizer and Planting Rate on the Yield and Water Use of Irrigated Grain Sorghum." Agronomy Journal, Vol. 52 (1960).

Pruitt, W. O. "Empirical Method of Estimating Evapotranspiration Using Primary Evaporation Pans." American Society of Ag. Engineers, Conference Proceedings on Evapotranspiration and Its Role in Water Resource Management, December, 1966.

Renshaw, E. F. "The Management of Ground Water Reservoirs." Journal of Farm Economics, Vol. 45, No. 2 (1963).

Robins, J. S. and C. E. Domingo. "Moisture and Nitrogen Effects on Irrigated Spring Wheat." Agronomy Journal, Vol. 54 (1962).

__________. "Some Effects of Severe Soil Moisture Deficits at Specific Growth Stages in Corn." Agronomy Journal, Vol. 45 (1953).

Rules, Regulations and Modes of Procedure and Water Laws from the Oklahoma Statutes. Oklahoma Water Resources Board, Publication No. 8, 1964.

Sax, J. L. Water Law, Planning and Policy. New York: The Bobbs-Merrill Company, 1968.

Schneider, A. D. and A. C. Mathers. *Water Use by Irrigated Sugar Beets in the Texas High Plains*. Texas Agricultural Experiment Station, MP-935, October, 1969.

Schneider, A. D., J. T. Musick and D. A. Dusek. "Efficient Wheat Irrigation with Limited Water." *Transactions of the ASAE*, Vol. 12 (1969).

Sharples. J. A. "The Representative Farm Approach to Estimation of Supply Response." *American Journal of Agricultural Economics*, Vol. 51, No. 2 (1969).

Shaw, R. H. *Estimation of Soil Moisture Under Corn*. Iowa Agricultural Experiment Station, Research Bulletin 520, Ames, December, 1963.

Sheehy, S. J. and R. H. McAlexander. "Selection of Representative Benchmark Farms for Supply Estimation." *Journal of Farm Economics*, Vol. 47, No. 3 (1965).

Shipley, John and Cecil Regier. "Water Response in the Production of Irrigated Grain Sorghum, High Plains of Texas, 1969." Unpublished manuscript, Southwestern Great Plains Research Center, Bushland, Texas, 1969.

Shipley, J. L., C. Regier and J. S. Wehrly. "Soil Moisture Depletion Levels as a Basis for Timing Irrigation on Grain Sorghum." Texas Agricultural Experiment Station, Consolidated PR-2546-2555, June, 1968.

Siegel, Sidney. *Nonparametric Statistics*. New York: McGraw-Hill Book Company, 1956.

Smith, S. C. "Discussion: The Stock Resource Value of Water." *Journal of Farm Economics*, Vol. 43, No. 5 (1961).

Stone, J. F., R. H. Griffen and B. J. Ott. *Irrigation Studies of Grain Sorghum in the Oklahoma Panhandle, 1958 to 1962*. Oklahoma Agricultural Experiment Station, Bulletin B-619, January, 1964.

Summary, Agronomy Research Projects, 1962-1969. Panhandle Agricultural Experiment Station, Goodwell, Oklahoma.

Thornthwaite, C. W. "An Approach Toward a Rational Classification of Climate." *Geographical Review*, *38* (1948).

Thornthwaite, C. W. and J. R. Mather. "The Water Balance." *Publications in Climatology*, Vol. VIII, No. 1 (1955), Drexel Institute of Technology, Laboratory of Climatology, Centerton, New Jersey.

Timmons, J. F. "Theoretical Considerations of Water Allocation Among Competing Uses." *Journal of Farm Economics*, Vol. 38, No. 5 (1956).

Thompson, J. F. "Defining Typical Resource Situations." *Farm Size and Output Research*, Southern Cooperative Series Bulletin 56, June, 1958.

Van Bavel, C. H. M. "A Drought Criterion and Its Application in Evaluating Drought Incidence and Occurrence." *Agronomy Journal*, Vol. 45 (1953).

Voegeli, P. T. and L. A. Hershey. *Geology and Ground Water Resources of Prowers County, Colorado*. Geological Survey Water Supply Paper 1772, Washington, D.C., 1965.

Water and Choice in the Colorado Basin, An Example of Alternatives in Water Management. Committee on Water of the National Research Council, Publication 1689, National Academy of Sciences, Washington, D.C., 1968.

Water Resources and Economic Development of the West, Report No. 5, Ground Water Economics and the Law. Proceedings of Committee on the Economics of Water Resource Development of the Western Agricultural Economics Research Council and Western Regional Research Committee W-42, Berkeley, California, 1956.

Wehrly, J. S., J. L. Shipley and C. Regier. "Wheat Response to Spring Irrigation Northern High Plains of Texas." Texas Agricultural Experiment Station, Consolidated PR-2546-2555, June, 1968.

Wehrly, J. S., W. H. Sletten and M. E. Jensen. *Economic Decisions in Producing Irrigated Grain Sorghum on the Northern High Plains of Texas*. Texas Agricultural Experiment Station, MP-747, December, 1964.

APPENDIX A

INPUT DATA TABLES FOR FARM FIRM SIMULATION MODEL AND SAMPLE OUTPUT

TABLE XXXVI

INPUT ALLOWANCES

	Enterprise Class	1 Irrig. Grain Sorghum G1	2 Irrig. Grain Sorghum G2	3 Irrig. Grain Sorghum G3	4 Irrig. Grain Sorghum G4	5 Irrig. Grain Sorghum G5	6 Irrig. Wheat W1	7 Irrig. Wheat W2	8 Dryland Wheat W3	9 Irrig. Corn Grain C1	10 Irrig. Corn Grain C2	11 Irrig. Corn Silage CS1	12 Irrig. Corn Silage CS2	13 Small Grain Pasture	14 Native Pasture
1.Tractor 1	Hours	1.22	1.22	1.22	1.22	1.09	0.70	0.70	0.52	1.35	1.35	1.66	1.66	0.52	
2.Tractor 2	Hours	1.31	1.31	1.31	1.31	0.44	0.98	0.81	0.44	1.54	1.54	1.04	1.04	0.44	
3.Oneway	Hours					0.28			0.14					0.14	
4.Chisel	Hours	0.21	0.21	0.21	0.21					0.21	0.21	0.21	0.21		
5.Offset Disc	Hours	0.25	0.25	0.25	0.25	0.12	0.25	0.25		0.25	0.25	0.25	0.25		
6.Cultibedder	Hours	0.42	0.42	0.42	0.42	0.28	0.21	0.21		0.42	0.42	0.42	0.42		
7.Cultivator	Hours	0.48	0.48	0.48	0.48	0.71	0.24	0.24		0.48	0.48	0.48	0.48		
8.Sweep	Hours						0.20	0.20	0.40						
9.Drill	Hours						0.18	0.18	0.18					0.18	
10.Float	Hours	0.14	0.14	0.14	0.14		0.14	0.14		0.14	0.14	0.14	0.14		
11.Spray Rig	Hours	0.33	0.33	0.33	0.33					0.66	0.66	0.66	0.66		
12.Shredder	Hours	0.18	0.18	0.18	0.18					0.18	0.18				
13.Irrig. Cropland	Acres	1.0	1.0	1.0	1.0					1.0	1.0	1.0	1.0		
14.Dryland Cropland	Acres					1.0			1.0						
15.Pastureland	Acres														1.0
16.Diverted Land	Acres													1.0	
17.Labor 1(Jan-Feb)	Hours						0.21	0.21	0.21					0.21	
18.Labor 2(Mar-Apr)	Hours	0.82	0.82	0.82	0.82	0.18				1.88	1.88	1.88	1.88		
19.Labor 3(May-1-15)	Hours	1.04	1.04	0.29	1.04	0.25				0.40	0.40	0.40	0.40		
20.Labor 4(May16-31)	Hours	0.30	0.30	0.30	0.30	0.25	1.50	1.50		1.16	0.41	1.16	0.41		
21.Labor 5(Jun-Jul)	Hours	2.45	1.70	1.70	1.70	1.16	0.43	0.43	0.27	3.85	4.60	3.85	4.60	0.27	
22.Labor 6(Aug-S.15)	Hours	1.50	1.50	2.25	1.50		0.96	0.76	0.43					0.43	
23.Labor 7(Sep16-30)	Hours						1.91	0.41	0.25					0.25	
24.Labor 8(Oct-Dec)	Hours	0.67	0.67	0.67	0.67					0.67	0.67	0.44	0.44		

TABLE XXXVI (Continued)

	Enterprise Class	1 Irrig. Grain Sorghum G1	2 Irrig. Grain Sorghum G2	3 Irrig. Grain Sorghum G3	4 Irrig. Grain Sorghum G4	5 Irrig. Grain Sorghum G5	6 Irrig. Wheat W1	7 Irrig. Wheat W2	8 Dryland Wheat W3	9 Irrig. Corn Grain C1	10 Irrig. Corn Grain C2	11 Irrig. Corn Silage CS1	12 Irrig. Corn Silage CS2	13 Small Grain Pasture	14 Native Pasture
25.Irr. Water April	Hours									6.00	6.00	6.00	6.00		
26.Irr. Water 1	Ac.In.	4.50	4.50		1.50										
27.Irr. Water 2	Ac.In.						9.00	9.00		1.56		1.56			
28.Irr. Water 3	Ac.In.	9.00	5.43	4.50	4.50					18.00	20.25	18.00	20.25		
29.Irr. Water 4	Ac.In.	9.00	11.77	9.00											
30.Irr. Water 5	Ac.In.						8.91								
31.Cash Costs	Dol.	62.75	59.13	52.68	53.47	9.37	41.77	28.45	12.93	92.73	93.30	71.32	71.62	12.43	1.25
32.Farm Overhead	Dol.														
33.Irr. Well 1	Hours	13.06	10.98	9.44	8.70		10.39	5.22		14.83	15.23	14.83	15.23		
34.Irr. Pump 1	Hours	13.06	10.98	9.44	8.70		10.39	5.22		14.83	15.23	14.83	15.23		
35.Irr. Motor 1	Hours	13.06	10.98	9.44	8.70		10.39	5.22		14.83	15.23	14.83	15.23		
36.Irr.Dist.Sys. 1	Hours	13.06	10.98	9.44	8.70		10.39	5.22		14.83	15.23	14.83	15.23		
37.Irr. Well 2	Hours														
38.Irr. Pump 2	Hours														
39.Irr. Motor 2	Hours														
40.Irr.Dist.Sys. 2	Hours														
41.Irr. Well 3	Hours														
42.Irr. Pump 3	Hours														
43.Irr. Motor 3	Hours														
44.Irr.Dist.Sys. 3	Hours														

TABLE XXXVII

OUTPUT PER UNIT OF ACTIVITY, BASE YEAR PRICE AND TREND IN PRICE

	Enterprise Class	1	2	3	4	5 Dryland Grain Sorghum	6	7	8 Dryland Wheat	9	10	11	12	13 Small Grain Pasture	14 Native Pasture	15 Ave. Price	16 Yearly Trend in Price	17 Variance (Std.Dev. in Price)	18 Limit to Variance in Price (Std.Dev.)
		Irrig. Grain Sorghum					Irrig.Wheat			Irrig. Corn Grain		Irrig. Corn Silage							
		G1	G2	G3	G4	G5	W1	W2	W3	C1	C2	CS1	CS2						
1.Irr.Gr.Sorg. G1	Bu.	130.82														0.94			
2.Irr.Gr.Sorg. G2	Bu.		126.48													0.94			
3.Irr.Gr.Sorg. G3	Bu.			80.18												0.94			
4.Irr.Gr.Sorg. G4	Bu.				92.21											0.94			
5.Dryland Gr.Sorg. G5	Bu.					14.20										0.94			
6.Irr.Wheat W1	Bu.						51.02									1.29			
7.Irr.Wheat W2	Bu.							34.06								1.29			
8.Dryland Wheat W3	Bu.								10.75							1.29			
9.Irr. Corn Grain C1	Bu.									120.88						1.11			
10.Irr. Corn Grain C2	Bu.										122.44					1.11			
11.Irr.Corn Silage CS1	Ton											21.76				5.50			
12.Irr.Corn Silage CS2	Ton												22.04			5.50			
13.Sm.Gr.Past. 1	AUM													0.38		8.00			
14.Sm.Gr.Past. 2	AUM													1.16		8.00			
15.Native Pasture	AUM														1.0	3.00			
16.Feed Grain Payments	Dol.	6.67	6.67	6.67	6.67	6.67				8.21	8.21	8.21	8.21			1.00			
17.Wheat Certificates	Dol.						21.17	21.17	21.17							1.00			

TABLE XXXVIII

CHARACTERISTICS OF INPUT SERVICES

	1 Rental Rate	2 Purchase Cost	3 Units of Service Provided	4 Total Life	5 Security Class	6 Price Trend	7 Minimum Number Purchased	8 Minimum Units Rented	9 Price Increase Per Lot Purchased	10 Increase in Rent Per Lot Rented	11 Property Tax	12 Insurance Cost per Dol.Value	13 Hire Out Rate	14 Percent Rental Increase per Year	15 Repair Cost (Percent)	16 Income Tax Rate	17 Prod. Var.	18 Limit to Prod. Var.
1.Tractor 1		8905	600	10	2		1	4			.01	.006				.14		
2.Tractor 2		10935	600	10	2		1	4			.01	.006				.145		
3.Oneway		1305	80	10	2		1	4			.01	.006				.15		
4.Chisel		1260	90	10	2		1	4			.01	.006				.155		
5.Offset Disc		2340	100	10	2		1	4			.01	.006				.162		
6.Cultibedder		1982	150	8	2		1	4			.01	.006				.1667		
7.Cultivator		1400	175	8	2		1	4			.01	.006				.17		
8.Sweep		1125	200	10	2		1	4			.01	.006				.1725		
9.Drill		1150	95	10	2		1	4			.01	.006				.1778		
10.Float		3600	55	10	2		1	4			.01	.006				.1820		
11.Spray Rig		1000	125	8	2		1	4			.01	.006				.1855		
12.Shredder		1350	50	8	2		1	4			.01	.006				.1883		
13.Irrig.Cropland		275	1	100	1		40	40								.1930		
14.Dryland Cropland		125	1	100	1		40	40								.1971		
15.Pastureland		100	1	100	1		40	40								.2007		
16.Diverted Acres		200	1	100	1		40	40								.2003		
17.Labor 1 (Jan.-Feb.)	2.00		1	100				8								.2082		
18.Labor 2 (Mar.-Apr.)	2.00		1	100				8								.2122		
19.Labor 3 (May 1-15)	2.00		1	100				8								.2158		
20.Labor 4 (May 16-31)	2.00		1	100				8								.2190		
21.Labor 5 (June-July)	2.00		1	100				8								.2238		
22.Labor 6 (Aug.-Sept. 15)	2.00		1	100				8								.2282		

TABLE XXXVIII (Continued)

	1 Rental Rate	2 Purchase Cost	3 Units or Service Provided	4 Total Life	5 Security Class	6 Price Trend	7 Minimum Number Purchased	8 Minimum Units Rented	9 Price Increase Per Lot Purchased	10 Increase in Rent Per Lot Rented	11 Property Tax	12 Insurance Cost per Dol. Value	13 Hire Out Rate	14 Percent Rental Increase per Year	15 Repair Cost (Percent)	16 Income Tax Rate	17 Prod. Var.	18 Limit to Prod. Var.
23.Labor 7 (Sept. 16-30)	2.00		1	100				8								.2322		
24.Labor 8 (Oct.-Dec.)	2.00		1	100				8								.2358		
25.Irr.Water-Apr.			1	100												.2409		
26.Irr. Water 1			1	100														
27.Irr. Water 2			1	100														
28.Irr. Water 3			1	100														
29.Irr. Water 4			1	100														
30.Irr. Water 5			1	100														
31.Cash Costs	1.00		1															
32.Farm Overhead			1	100											3380			
33.Irr. Well 1		3125	4000	15	2		1				.0083							
34.Irr. Pump 1		3425	4000	10	2		1				.0086							
35.Irr. Engine 1		1975	4000	4	2		1				.0086	.0026						
36.Irr.Dist.Sys. 1		6666	4000	25	2		1				.0100	.0047						
37.Irr. Well 2		3125	2000	10	2		1				.0083							
38.Irr. Pump 2		3425	2000	10	2		1				.0086							
39.Irr. Motor 2		1575	2000	4	2		1				.0086	.0026						
40.Irr.Dist.Sys. 2		84	2000	10	2		1				.0100	.0047						
41.Irr. Well 3		3125	1500	5	2		1				.0083							
42.Irr. Pump 3		2152	1500	5	2		1				.0086							
43.Irr. Motor 3		765	1500	4	2		1				.0086	.0026						
44.Irr.Dist.Sys. 3		4508	1500	5	2		1				.0100	.0047						

TABLE XXXIX

INVENTORY OF CAPITAL ASSETS

Row Number	1 Class of Input Service (Row Corresponds to Row Nos. in Table I or III)	2 Number of Units of Capital	3 Age of Capital Asset
1	1	1	6
2	2	1	3
3	3	1	7
4	4	1	5
5	5	1	2
6	6	1	2
7	7	1	3
8	8	1	6
9	9	1	5
10	10	1	4
11	11	1	1
12	12	1	4
13	13	320	
14	14	141	
15	15	40	
16	16	84	
17	17	400	
18	18	400	
19	19	100	
20	20	100	
21	21	400	
22	22	300	
23	23	100	
24	24	600	
25	25	2200	
26	26	1000	
27	27	1500	
28	28	4000	
29	29	2800	
30	30	1000	
31	32	1	
32	33	1	5
33	34	1	5
34	35	1	1
35	36	1	5

TABLE XL

PART 1 -- ORGANIZATION OF PRODUCTION

Reference Row Number (Corresponds to Column Number in Table I)	Units of Activity in Organization (Column 1)
1	80
2	40
3	30
4	20
5	30
6	65
7	20
8	85
9	27
10	13
11	13
12	7
13	84
14	40

PART 2 -- PURCHASE OR SALE OF CAPITAL ASSETS

Reference Row Number (Corresponds to Rows in Table III)	Units of Capital Asset Purchased (Column 2)	Units of Capital Asset Sold (Column 3)

TABLE XLI

DEBT OUTSTANDING AND CREDIT TERMS BY SECURITY TYPE WITH MISCELLANEOUS DATA ON VARIOUS ASPECTS OF THE SITUATION

	6 Debt Outstanding	7 Debt Payment	8 Maximum Permitted Ratio of Debt to Security Value	9 Length of Loan Period (Years)	10 Interest Rate	11 Refinance Cost	12 Opening Cost	13 Amount Borrowed	14 Prepayment of Debt
1. Real Estate	42,000	2,800	.60	20	.07	75.00	75.00		
2. Chattle	5,234	1,300	.75	5	.08	3.00	3.00		
3. Other			.90	1	.08	3.00	3.00		

Row 1, Column 1: Contains cash on hand = 10,000
Row 1, Column 2: Contains number of years to be simulated = 1
Row 1, Column 3: Contains outside income =
Row 1, Column 4: Contains base year = 1971
Row 1, Column 5: Contains amount of capital gains = .40
Row 2, Column 1: Contains "safe" proportion of asset value to debt =
Row 2, Column 2: Contains minimum amount of cash to be on hand = 10,000
Row 2, Column 3: Contains the number of income tax deductions = 4
Row 2, Column 4: Contains change in case number =
Row 2, Column 5: Contains interest on excess cash reserves = .05
Row 3, Column 1: Contains the mode of the run = 0
Row 3, Column 2: Contains type of tax return (joint or individual) = 0
Row 3, Column 3: Contains current year = 1971
Row 3, Column 4: Contains amount of withdrawals = 7,500
Row 3, Column 5: (Blank) =

TABLE XLII

SAMPLE OUTPUT FROM GENERAL AGRICULTURAL FIRM SIMULATOR

```
        1.          RESOURCE SITUATION 2 - YEAR 1        1971.
 INPUT CLASS     SUPPLY         USE      HIRE-IN    HIRE-OUT   $ AMOUNT

 TRACTOR 1       600.00       484.40       0.0       115.60        0.0
 TRACTOR 2       600.00       456.87       0.0       143.13        0.0
 ONEWAY           80.00        43.82       0.0        36.18        0.0
 CHISEL           90.00        65.94       0.0        24.06        0.0
 OFFST DISC      100.00        82.35       0.0        17.65        0.0
 CULTIBEDER      150.00       122.85       0.0        27.15        0.0
 CULTIVATOR      175.00       147.30       0.0        27.70        0.0
 SWEEP           200.00        67.80       0.0       132.20        0.0
 DRILL            95.00        45.72       0.0        49.28        0.0
 FLOAT            55.00        44.10       0.0        10.90        0.0
 SPRAY RIG       125.00        95.70       0.0        29.30        0.0
 SHREDDER         50.00        34.20       0.0        15.80        0.0
 IRR CROPLD      320.00       315.00       0.0         5.00        0.0
 DRY CROPLD      141.00       115.00       0.0        26.00        0.0
 PASTURE LD       40.00        40.00       0.0         0.0         0.0
 DIVERTEDLD       84.00        84.00       0.0         0.0         0.0
 LABOR PD 1      400.00        32.30       0.0       367.70        0.0
 LABOR PD 2      400.00       240.90       0.0       159.10        0.0
 LABOR PD 3      100.00        74.00       0.0        26.00        0.0
 LABOR PD 4      100.00       137.75      37.75        0.0        80.00
 LABOR PD 5      400.00       712.27     312.27        0.0       640.00
 LABOR PD 6      300.00       320.30      20.30        0.0        48.00
 LABOR PD 7      100.00       115.60      15.60        0.0        32.00
 LABOR PD 8      600.00       125.80       0.0       474.20        0.0
 IR WATER A     2200.00       360.00       0.0      1840.00        0.0
 IR WATER 1     1000.00         0.0        0.0      1000.00        0.0
 IR WATER 2     1500.00       382.50       0.0      1117.50        0.0
 IR WATER 3     4000.00      2295.00       0.0      1705.00        0.0
 IR WATER 4     2800.00      1260.00       0.0      1540.00        0.0
 IR WATER 5     1000.00       382.50       0.0       617.50        0.0
 CASH COSTS        0.0      18218.59   18218.59        0.0     18218.59
 FARM OVHD         1.00         0.0        0.0         1.00        0.0
 IR WELL 1      4000.00      2118.05       0.0      1881.95        0.0
 IR PUMP 1      4000.00      2118.05       0.0      1881.95        0.0
 IR MOTOR 1     4000.00      2118.05       0.0      1881.95        0.0
 IR DIS SY1     4000.00      2118.05       0.0      1881.95        0.0
```

TABLE XLII (Continued)

1. RESOURCE SITUATION 2 - YEAR 1 1971.

ACTIVITY	PRODUCT	PROD/UNIT	NO. UNITS	TOTAL PROD	PRICE	$ VALUE
GRAIN SOR1	GR SORG G1	102.85	80.00	8228.00	0.94	7734.31
GRAIN SOR1	FEED GR PT	8.34	80.00	667.20	1.00	667.20
GRAIN SOR2	GR SORG G2	109.82	40.00	4392.80	0.94	4129.23
GRAIN SOR2	FEED GR PT	8.34	40.00	333.60	1.00	333.60
GRAIN SOR3	GR SORG G3	100.51	30.00	3015.30	0.94	2834.38
GRAIN SOR3	FEED GR PT	8.34	30.00	250.20	1.00	250.20
GRAIN SOR4	GR SORG G4	102.12	20.00	2042.40	0.94	1919.86
GRAIN SOR4	FEED GR PT	8.34	20.00	166.80	1.00	166.80
GRAIN SOR5	GR SORG G5	23.07	30.00	692.10	0.94	650.57
GRAIN SOR5	FEED GR PT	8.34	30.00	250.20	1.00	250.20
WHEAT 1	WHEAT W1	68.12	65.00	4427.80	1.29	5711.86
WHEAT 1	WHEAT CERT	37.46	65.00	2434.90	1.00	2434.90
WHEAT 2	WHEAT W2	66.31	20.00	1326.20	1.29	1710.80
WHEAT 2	WHEAT CERT	37.46	20.00	749.20	1.00	749.20
WHEAT 3	WHEAT W3	32.91	85.00	2797.35	1.29	3608.58
WHEAT 3	WHEAT CERT	37.46	85.00	3184.10	1.00	3184.10
CORN GRAN1	CORN GR C1	124.46	27.00	3360.42	1.11	3730.06
CORN GRAN1	FEED GR PT	9.95	27.00	268.65	1.00	268.65
CORN GRAN2	CORN GR C2	118.77	13.00	1544.01	1.11	1713.85
CORN GRAN2	FEED GR PT	9.95	13.00	129.35	1.00	129.35
CORN SILG1	CORN S CS1	22.40	13.00	291.20	5.50	1601.60
CORN SILG1	FEED GR PT	9.95	13.00	129.35	1.00	129.35
CORN SILG2	CORN S CS2	21.38	7.00	149.66	5.50	823.13
CORN SILG2	FEED GR PT	9.95	7.00	69.65	1.00	69.65
SM GR PAST	SM GR PAS1	1.41	84.00	118.44	8.00	947.52
SM GR PAST	SM GR PAS2	2.82	84.00	236.88	8.00	1895.04
NATIVE PAS	NATIVE PAS	1.00	40.00	40.00	8.00	320.00

TABLE XLII (Continued)

```
             1.                RESOURCE SITUATION 2 - YEAR 1                1971.
RESOURCES AND ORGANIZATION                       FINANCIAL SUMMARY
  ASSETS                                           OPERATING INCOME
       TRACTOR 1                      2671.50          GR SORG G1                           7734.31
       TRACTOR 2                      6561.00          GR SORG G2                           4129.23
       ONEWAY                          261.00          GR SORG G3                           2834.38
       CHISEL                          504.00          GR SORG G4                           1919.86
       OFFST DISC                     1638.00          GR SORG G5                            650.57
       CULTIBEDER                     1238.75          WHEAT W1                             5711.86
       CULTIVATOR                      700.00          WHEAT W2                             1710.80
       SWEEP                           337.50          WHEAT W3                             3608.58
       DRILL                           460.00          CORN GR C1                           3730.06
       FLOAT                          1800.00          CORN GR C2                           1713.85
       SPRAY RIG                       750.00          CORN S CS1                           1601.60
       SHREDDER                        506.25          CORN S CS2                            823.13
       IRR CROPLO                    88000.00          SM GR PAS1                            947.52
       DRY CROPLD                    17625.00          SM GR PAS2                           1895.04
       PASTURE LD                     4000.00          NATIVE PAS                            320.00
       DIVERTEDLD                    16800.00          FEED GR PT                           2265.00
       IR WELL 1                      2439.00          WHEAT CERT                           6368.20
       IR PUMP 1                      2196.40
       IR MOTOR 1                     1295.00             CASH OPERATING INCOME            47963.96
       IR DIS SY1                     3655.60
       CASH                          17438.02
                                                              GROSS FARM INCOME            47963.96
          TOTAL ASSETS              170876.81
                                                  OPERATING EXPENSE
  DEBTS                                                REPAIR AND MAINTENANCE               3380.00
       REAL ESTATE DEBT              39200.00          PROPERTY TAXES                        313.35
       CHATTLE DEBT                   3934.00          INSURANCE                             150.37
       OTHER DEBT                         0.0          INTEREST                             3358.72
                                                       LABOR PD 4                             80.00
          TOTAL DEBTS                43134.00          LABOR PD 5                            640.00
                                                       LABOR PD 6                             48.00
          NET WORTH                 127742.81          LABOR PD 7                             32.00
                                                       CASH COSTS                          18218.59
  LABOR
       FAMILY HOURS                   2400.00             CASH OPERATING EXPENSE           26221.04
       HIRED HOURS                     385.92
                                                          NET CASH OPERATING INCOME        21742.92
          TOTAL LABOR                 2785.92
                                                       INVENTORY DECREASE                   5438.50
          MAN EQUIV.                     1.16
                                                          GROSS FARM EXPENSE               31659.54
  CROPS
        GRAIN SOR1                      80.00     NET FARM INCOME                          16304.42
        GRAIN SOR2                      40.00
        GRAIN SOR3                      30.00     INCOME TAX                                2355.45
        GRAIN SOR4                      20.00     SOCIAL SECURITY TAX                        349.44
        GRAIN SOR5                      30.00     PAYMENT ON DEBT PRINCIPAL                 4100.00
        WHEAT 1                         65.00     INTEREST ON INVESTMENT                    9369.48
        WHEAT 2                         20.00     LABOR AND MGT.RETURNS                    10293.66
        WHEAT 3                         85.00     RETURNS PER MAN                           8867.75
        CORN GRAN1                      27.00     WITHDRAWALS                               7500.00
        CORN GRAN2                      13.00
        CORN SILG1                      13.00
        CORN SILG2                       7.00
        SM GR PAST                      84.00
        NATIVE PAS                      40.00
```

APPENDIX B

STATISTICAL CONCEPTS AND TESTS EMPLOYED TO VERIFY THE MODEL AND EVALUATE THE RESULTS

The Mann-Whitney U Test

Among the most powerful of statistical tests is the parametric t test. That is, when the assumptions of the test are met, it is a test most likely to reject a null hypothesis (H_0) when H_0 is false. The assumptions are very stringent. Among them are the following:[1]

(1) The observations must be independent.

(2) The observations must be drawn from normally distributed populations.

(3) The populations must have equal variances.

(4) The variables must have been measured in at least an interval scale.

However, when one or more of the underlying assumptions is not met, little confidence can be placed in probability statements stemming from use of the t test. Unfortunately, nonparametric tests exist that permit testing of hypotheses without requiring the restrictive assumptions of the t test.

One of the most powerful of nonparametric tests, and a most useful alternative to the parametric t test, is the Mann-Whitney U test. It may be used to test whether two independent groups have been drawn from the same population or, stating if somewhat differently, have the same distribution. The null hypothesis is that two independent groups, A and B, have the same distribution. The alternative hypothesis, for a one-tailed test, is that one is stochastically larger than the other, a directional hypothesis. If the probability that A is greater than B exceeds one-half, H_1 is accepted.[2] For a two-tailed test, H_0 is the same, but H_1 does not state the direction of difference between the distributions. It simply states that the probability is unequal to one-half. The one-tailed test is more powerful. It is more likely to reject H_0 when H_0 is false.

The test statistic for the Mann-Whitney U Test is computed using Equation (B-1) or (B-2), depending upon which gives the smallest value of U. The equations are

$$U = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - R_1 \qquad \text{(B-1)}$$

and

$$U = n_1 n_2 + \frac{n_2(n_2 + 1)}{2} - R_2 \qquad \text{(B-2)}$$

where n_1 equals the number of observations in the smaller of the two groups; n_2 equals the number of observations in the larger of the two groups; R_1 equals the sum of ranks assigned to the observations in the smaller of the two groups; and R_2 equals the sum of ranks assigned to the observations in the larger of the two groups.

For sample sizes between nine and 20, the test statistic is computed from (B-1) or (B-2) and compared with a tabular value at the appropriate α level of the test. An α level of 0.05 is commonly used. If the computed value of U is equal to or less than the tabular value of U, H_0 may be rejected at the appropriate α level for the test.

For samples larger than 20, the sampling distribution of U approaches the normal distribution with mean and variance as specified in (B-3) and (B-4), respectively.[3]

$$\mu_u = \frac{n_1 n_2}{2} \qquad \text{(B-3)}$$

$$\sigma_u{}^2 = \frac{n_1\ n_2(n_1 + n_2 + 1)}{12} \qquad \text{(B-4)}$$

The existence of ties (equal observations within and between groups) necessitates correction of the variance equation[4] to

$$\sigma_u{}^2 = \frac{n_1\ n_2}{N(N - 1)} \left(\frac{N^3 - N}{12} - \Sigma T\right) \qquad \text{(B-5)}$$

where N equals the sum of $n_1 + n_2$; t equals the number of observations tied for a given rank; and T equals $t^3 - t/12$.

The significance of an observed value of U may be tested by computing a test statistic Z which is approximately normally distributed with zero mean and unit variance.

$$Z = \frac{U - \mu_u}{\sigma_u} = \frac{\dfrac{U - n_1\ n_2}{12}}{\sqrt{\dfrac{n_1\ n_2}{N(N - 1)} \left(\dfrac{N^3 - N}{12} - \Sigma T\right)}} \qquad \text{(B-6)}$$

The computed value of Z is located in a table of probabilities associated with values as extreme as observed values of Z in the normal distribution. If the probability of an observed value as extreme as Z under the null hypothesis is less than $\alpha = 0.05$, the null hypothesis may be rejected.

This version of the Mann-Whitney U test was utilized in Chapter III to test the hypothesis of no difference between actual and simulated soil moisture distributions. The values of U, μ_u and σ_u were determined in (B-7), (B-8) and (B-9).

$$U = n_1\ n_2 + \frac{n_1(N_1 + 1)}{2} - R_1 = 441.0 + \frac{462.0}{2} - 516.0 = 156.0 \quad \text{(B-7)}$$

$$\mu_u = \frac{n_1\ n_2}{2} = \frac{441.0}{2} = 220.5 \quad \text{(B-8)}$$

$$\sigma_u = \sqrt{\frac{n_1\ n_2}{N(N - 1)}\ \frac{N^3 - N}{12} - \Sigma T} = \sqrt{\frac{441}{420}\ \frac{74088}{12} - 14.5} = \quad \text{(B-9)}$$

$$\sqrt{6467.475} = 80.42061$$

Then the test statistic, Z, was computed as

$$Z = \frac{U - \mu_u}{\sigma_u} = \frac{156.0 - 220.5}{80.42061} = -.80203 \quad \text{(B-10)}$$

The value of Z = -.892 was located in a table of probabilities associated with values as extreme as observed values of Z in the normal distribution. For a two-tailed test, the probability of a value of Z as extreme as -.802 under the null hypothesis is .412. Since the probability .412 is greater than the alpha level for the test ($\alpha = 0.05$), there is no statistical basis for rejecting the null hypothesis of no difference between the actual and simulated soil moisture distributions.

The Wilcoxon Matched-Pairs, Signed Ranks Test

The Wilcoxon Matched-Pairs, Signed Ranks Test is a powerful nonparametric statistical test that may be utilized when the direction and magnitude of differences between pairs of observations is known.[5] The sets of mean values resulting from two alternative water-use regulatory alternatives consist of a pair of observations for each year of a 20-year simulation run. This statistical procedure tests the null hypothesis, H_0, that means under the two alternatives are equivalent. The alternative hypothesis, H_1, may be that the means are different, without predicting the difference (for a two-tailed test) or may predict the direction of the difference between means (for a one-tailed test).

To utilize the test, the difference between each pair of observations is computed. The differences are ranked from smallest to largest without regard to sign of the difference. Then, the appropriate sign of each difference is attached to the rank. Ranks with the same sign are summed. The smaller of the two sums is the test statistic, T. The computed value of T is compared with a tabular value at the selected level of significance. If the computed value of T is equal to or less than the tabular value under a particular significance level for the appropriate number of observations, the null hypothesis may be rejected at that level of significance. The Wilcoxon Matched-Pairs, Signed Ranks Test is used extensively in Chapter V to test for significant differences between mean values of variables resulting from the three water-use regulatory alternatives.

FOOTNOTES

[1] Sidney Siegel, *Nonparametric Statistics* (New York, 1956), p. 19.

[2] Ibid., p. 116.

[3] Ibid., p. 121.

[4] Ibid., p. 124.

[5] Ibid., p. 76.

APPENDIX C

EXPLANATION OF THE PRODUCTION SUBSET OF THE FARM FIRM SIMULATION MODEL AND SAMPLE OUTPUT

This Appendix is designed to familiarize readers with computer programming aspects of the Production Subset of the Farm Firm Simulation Model. The Production Subset consists of a main program and the three subroutines RAIN, SMBAL and OUTPUT. The entire program has been discussed in detail in the body of this dissertation. Thus, discussion here is limited to defining data arrays and matrices, specification of dimensions and a discussion of input data required to execute the Production Subset. A listing of the entire Production Subset and a sample copy of the output produced are attached at the end of this Appendix.

Generalized notation is used where possible in specifying dimensions of arrays and matrices to facilitate modifications of the program. First, the generalized array dimension notation is explained.

CPS: The number of crop blocks the model contains. The current version of the Production Subset contains ten crop blocks, so CPS equals ten.

DYS: The number of days in the growing season. The growing season was assumed to last from May 1 through October 31. DYS was set equal to 185.

RDYS: The number of days during the growing season when soil moisture and/or atmospheric conditions can cause a reduction in final crop yield. In this version of the program RDYS equals 145.

TDYS: The number of days for which rainfall values were generated. Rainfall distributions were constructed for two-week intervals from April 1 through October 31. TDYS equals 215.

The following is an alphabetical list of matrix, array and variable names, their definitions and, where applicable, their dimensions.

AC(CPS): Array containing the organization of productions by acres of each crop. The first four arguments refer to blocks 1, 2, 3, and 4 of irrigated grain sorghum; argument 5 refers to the acres of dryland grain sorghum; arguments 6 and 7 refer to the acres of blocks 1 and 2 of irrigated wheat; argument 8 refers to the acres of dryland wheat; and arguments 9 and 10 refer to blocks 1 and 2 of irrigated corn.

ACA, AC1, AC2, AC3, AC4, AC5: Annual irrigation capital required during April and periods 1, 2, 3, 4 and 5, respectively.

ACRES: The total number of acres overlying the water resource situation being simulated, or total farm size in acres.

AE(DYS,CPS): Matrix of daily values for actual evapotranspiration which, for a given year, vary from crop to crop.

AFW: Total acre feet of irrigation water pumped during the growing season.

AIAPD: Acre inches applied to the soil profile per acre per day.

AIPCA, AIPC1, AIPC2, AIPC3, AIPC4, AIPC5: Total acre inches of pumping capacity remaining at the end of the current growing season for April and periods 1, 2, 3, 4 and 5, respectively.

AIPD: Acre-inches of pumping capacity remaining at the end of the current growing season.

AMU(9,12): Matrix of machine usage in hours required per implement per acre by crop blocks. The values stored in AMU for a given year depend upon the level of irrigation application on each crop block.

ASMW, ASM1, ASM2, ASM3, ASM4, ASM5: Coefficients reflecting inches of soil moisture in the total profile at permanent wilting point, 10 percent, 20 percent, 30 percent, 40 percent and 50 percent available soil moisture, respectively.

ATM(RDYS,CPS): Matrix containing daily atmospheric stress values to be used in final yield reduction computations due to atmospheric stress for each crop.

BIPCA, BIPC1, BIPC2, BIPC3, BIPC4, BIPC5: Beginning acre-inches of pumping capacity for the six periods of the current growing season, given the pumping capacity of the entire irrigation system. The BIPC common to each variable represents "beginning inches of pumping capacity." The six periods of the growing season are represented by the ending notation A, 1, 2, 3, 4 and 5, respectively.

BIPD: Beginning pumping capacity of the entire irrigation system, in acre-inches per day.

BSAT: Beginning feet of saturated thickness of the underground aquifer for the water resource situation being simulated.

C(DYS,CPS): Matrix of daily changes in soil moisture by crop blocks.

CC(CPS): Array of cash costs (total variable costs) per acre by crop block.

CCCS1 and CCCS2: Cash costs per acre for blocks 1 and 2, respectively, of corn silage.

CCSGP1 and CCSGP2: Cash costs per acre for small grain graze-out for the period November 1 to March 1 and April 1 through May 15, respectively.

CEF1: Corn water use coefficient which indicates the proportion potential evapotranspiration is of pan evaporation from the beginning of the growing season to plant emergence.

CEF2: Corn water use coefficient which indicates the maximum proportion potential evapotranspiration is of pan evaporation during any water use stage.

CEF3: Corn atmospheric coefficient which represents the critical level of pan evaporation above which atmospheric stress causes a reduction in final yield.

CEF4: Corn water use coefficient which equals the difference between CEF1 and CEF2. This coefficient is used in an equation that approximates the daily increase in the proportion potential evapotranspiration is of pan evaporation as the growing season progresses from emergence to vegetative stage of plant development.

CEF5: Corn water use coefficient which equals the difference between CEF2 and .50. This coefficient is used in an equation which approximates the daily decline in the proportion potential evapotranspiration is of pan evaporation as the growing season progresses from the end of silking stage through dough stage of plant development.

CGNIL(8): Array of nonirrigation labor requirements per acre for irrigated corn for grain. These requirements are read in as data.

CLA(CPS): Cost of irrigation labor per acre by crop block during the crop year.

CLI(CPS): Cost of irrigation labor per acre inch by crop blocks.

CM(DYS,CPS): Matrix of daily changes in soil moisture by crop blocks.

CRA(CPS): Array containing total per acre water requirements for each block of corn during April.

CRV1M, CRV1A, CRV2M, CRV2A, CRFSM, CRFSA, CRFMM, CRFMA, CRFDM, CRFDA:	Corn yield reduction factors which are read in as data. The CRF common to all but four coefficients represents "corn reduction factor". The V1, V2, S, M and D represent early vegetative, late vegetative, silk, milk and dough stages of plant development, respectively. The M or A at the end of each coefficient indicates whether the reduction is due to soil moisture or atmospheric conditions.
CS1 and CS2:	Final yield for blocks 1 and 2, respectively, of irrigated corn silage.
CSNIL(8):	Array of nonirrigation labor requirements per acre for irrigated corn silage. These requirements are read in as data.
CSYP:	Coefficient relating yield of corn for grain in bushels per acre to yield of corn silage in tons per acre.
CYLD5, CYLD4, CYLD3, CYLD2, CYLD1:	Corn grain yield during each of the past five years. Government payments per acre are based on a five-year moving average of yields.
D(DYS):	Array of random normal deviates used to determine daily pan evaporation throughout the growing season.
DAP:	Number of days required to complete an irrigation on a specific crop block.
DAU:	Days of annual use of the irrigation system.
DAYSL:	The number of days remaining in the current crop year.
DECL:	Number of feet decline in saturated thickness of the underground aquifer during the current crop year.
DREQ:	Total number of days required for a specific irrigation application.
E(DYS,CPS):	Matrix of daily potential evapotranspiration values by crop block.
EP(DYS):	Array of daily pan evaporation values.
FGTP:	Final grand total pumping in acre inches by the entire irrigation system during the current crop year.
GEF1:	Grain sorghum water use coefficients relating the proportion potential evapotranspiration is of pan evaporation during the first water use stage (from planting to emergence).

GEF2: Grain sorghum water use coefficient which equals the maximum proportion potential evapotranspiration is of pan evaporation during any water use stage.

GEF3: Grain sorghum atmospheric coefficient which represents the critical level of pan evaporation above which atmospheric stress causes a reduction in final yield.

GEF4: Grain sorghum water use coefficient which equals the difference between GEF1 and GEF2. This coefficient is used in an equation that approximates the daily increase in the proportion potential evapotranspiration is of pan evaporation as the growing season progresses from plant emergence to boot-heading stage of development.

GEF5: Grain sorghum water use coefficient representing the maximum proportion potential evapotranspiration is of pan evaporation for dryland grain sorghum.

GNIL1(8), GNIL2(8), GNIL3(8): Arrays representing nonirrigation labor requirements per acre for three levels of grain sorghum irrigation. Nonirrigation labor per acre varies with irrigation level due to differences in fertilizer and insecticide application levels. These requirements are read in as data.

GONIL(8): Array of nonirrigation labor requirements per acre for graze-out small grain. These requirements are read in as data.

GPA(CPS): Array of government payments per acre by crop block.

GPM: Pumping capacity of the irrigation system in gallons per minute.

GPM1, GPM2, GPM3: Pumping capacity during the current year for irrigation systems 1, 2 and 3, respectively.

GRFPM, GRFPA, GRFBM, GRFBA, GRFGM, GRFGA: Grain sorghum yield reduction factors or coefficients. The GRF common to each stands for "grain reduction factor"; P, B and G represent the preboot, boot-heading and grain-filling stages of development, respectively; and, M and A represent moisture and atmospheric reductions, respectively.

GTL1(CPS), GTL2(CPS), GTL3(CPS), GTL4(CPS), GTL5(CPS), GTL6(CPS), GTL7(CPS), GTL8(CPS): Total labor requirements per crop block for labor periods 1 through 8, respectively.

GTPA, GTP1, GTP2, GTP3, GTP4, GTP5: Grand total number of acre-inches pumped (1.5 times acre-inches added to the soil profile) during April and periods 1, 2, 3, 4 and 5, respectively.

GTWA, GTW1, GTW2, GTW3, GTW4, GTW5: Grand total number of acre-inches added to the soil profile during April and periods 1, 2, 3, 4 and 5, respectively.

GYLD5, GYLD4, GYLD3, GYLD2, GYLD1: Grain sorghum yield during each of the past five years. Government payments per acre are based on a five-year moving average of yields.

HAMU(9,12): Matrix of values for machine use per acre expressed in hours. The matrix is dimensioned with nine rows to represent the nine implements included in the machinery complement. The 12 columns allow one column for each crop block included in the model. These values are read in as data.

HAU: Hours of annual use of the irrigation system.

HAUPW: Hours of annual use per well.

HIPA(CPS): Hours of annual pumping per crop block.

HPPW(CPS): Hours of annual pumping per well per crop block.

IBYR: The beginning year of a multi-year run.

ITAG: An integer variable incremented when the quantity limitation is reached during computer runs simulating the graduated tax on water use.

IX1 and IX2: Bases for the random number generators used in Subroutine RAIN to produce daily rainfall and pan evaporation values. These values are read in as data and must be odd integer values equal to or less than nine digits in magnitude.

KMAP: A variable indicating type of output desired from the Production Subset. If KMAP = 0, only printed output is produced. If KMAP = 1, only punched output is produced. If KMAP is greater than one, both printed and punched output are produced.

KNT1 and KNT2: Integer values used in Subroutine RAIN to increment the years of a multiperiod run and generate a new base for the generation of random numbers.

KOUNT: An integer variable used to count the number of years of a simulation run that have been completed.

N(TDYS): Array of values obtained by multiplying the uniform deviates by 1,000 and truncating the resultant to a three digit integer. These values are then used to determine daily rainfall values from discrete distributions.

ND: An integer variable representing the current day of the growing season.

NDA: An integer accounting variable equal to the current day during the growing season plus the number of days required to apply the current irrigation application. This variable prevents the scheduling of a new irrigation until the current application has been completed.

NDL: An integer variable indicating the number of days remaining in the current crop year.

NDREQ: An integer value representing total days required for a specific irrigation application.

NI(CPS): Total number of irrigations required by a crop block during the crop year.

NWELL: The number of wells which, at any point in time, are pumping as part of the total irrigation system.

NYRS: The number of years to be simulated.

NIA(CPS), NI1(CPS), NI2(CPS), NI3(CPS), NI4(CPS), NI5(CPS): The number of irrigations required per crop block during April and periods 1, 2, 3, 4 and 5, respectively.

PYA, PY1, PY2, PY3, PY4, PY5: The proportion of the crop year during which annual capital is committed if expenditures are made in April or periods 1, 2, 3, 4 or 5, respectively.

PYR(CPS): Array indicating the potential yield reduction during the remainder of the crop year.

R(DYS,CPS): Matrix of daily rainfall values for each crop block. Irrigation applications for each crop block are added to the appropriate row and column of the R matrix.

R1M(CPS), R2M(CPS), R3M(CPS), R4M(CPS), R5M(CPS): Sum of daily yield reductions due to moisture stress for periods 1 through 5 for each crop block.

RA1(1000) and RA2(1000): Arrays containing the discrete rainfall probability distributions for the month of August.

RAI1, RAI2, RAI3, RAI4, RAI5: The remaining acre inches of pumping capacity for periods 1, 2, 3, 4 and 5, respectively.

RAP1(1000) and RAP2(1000): Arrays containing the discrete rainfall probability distribution for the month of April.

RDYS: The number of days of the growing season during which yield reductions can occur due to soil moisture or atmospheric stress. In this version of the program, RDYS = 145.

RGPM: A variable indicating whether the computer run will simulate a constant or declining water supply within the underground aquifer. If RGPM equals 1.0, no drawdown is simulated. If RGPM equals 2.0, drawdown is simulated.

R1A(CPS), R2A(CPS), R3A(CPS), R4A(CPS), R5A(CPS): Sum of daily yield reductions due to atmospheric stress for periods 1 through 5 for each crop block.

RJL1(1000) and RJL2(1000): Arrays containing the discrete rainfall probability distributions for the month of July.

RJU1(1000) and RJU2(1000): Arrays containing the discrete rainfall probability distributions for the month of June.

RM1(1000) and RM2(1000): Arrays containing the discrete rainfall probability distributions for the month of May.

RN(TDYS): Array of daily rainfall values for the April 1 through October 31 period.

RO1(1000) and RO2(1000): Arrays containing the discrete rainfall probability distributions for the month of October.

RS1(1000) and RS2(1000): Arrays containing the discrete rainfall probability distributions for the month of September.

RSAT: Remaining feet of saturated thickness of the underground aquifer for the water resource situation being simulated.

SGPY1: Final yield of small grain grazing for the period November 1 to March 31.

SGPY2: Final yield of small grain graze-out for the period March 1 through May 15.

SMD(RDYS,CPS): Matrix of daily soil moisture depletion values to be used in computing final yield reductions for each crop due to moisture stress.

SML(DYS,CPS): Matrix of daily soil moisture values in the lower layer of the soil profile.

SMT(DYS,CPS): Matrix of soil moisture values in the total soil profile.

SMU(DYS,CPS): Matrix of daily soil moisture values in the upper layer of the soil profile.

T1(44,13): Matrix of values contained in Table XXXVI, Appendix A. The column dimension represents 13 crops or crop blocks for which changes occur in machinery, labor or irrigation requirements. The table contains 44 rows and thus T1 is dimensioned 44 by 13.

TAC(CPS): Total annual irrigation capital required for the current crop year by crop block.

TACI(CPS): Interest on total annual irrigation capital required during the current crop year by crop block.

TAX(CPS): Array which reflects the number of acre inches which have been applied per acre for each crop block when the quantity limitation is reached.

TCLA: Total cost of irrigation labor for the current crop year.

TLA, TL1, TL2, TL3, TL4, TL5: Total hours of irrigation labor required during April and periods 1, 2, 3, 4 and 5, respectively.

TNIA(CPS), TNI1(CPS), TNI2(CPS), TNI3(CPS), TNI4(CPS), TNI5(CPS): The number of hours of irrigation labor required per crop block during April and periods 1, 2, 3, 4 and 5, respectively.

TNRAP: Net returns per acre above all variable costs for small grain graze-out.

TNRS1 and TNRS2: Net returns per acre above all variable costs for corn silage blocks 1 and 2, respectively.

TNRA(CPS): Net returns per acre above all variable costs by crop block.

TPA(CPS), TP1(CPS), TP2(CPS), TP3(CPS), TP4(CPS), TP5(CPS), TWP(CPS): Arrays containing total inches of water pumped for April, periods 1 through 5, and the growing season, respectively, by crop block.

TP: Total acre inches of irrigation water pumped during the growing season.

TR(CPS): Array containing the total moisture and atmospheric yield reductions for the growing season by crop block.

TRM(CPS) and TRA(CPS): Arrays containing the total yield reductions due to moisture and atmospheric stress, respectively, for the total growing season by crop block.

TW(CPS): Array containing total acre inches added to the soil profile by crops for the growing season.

TW1(CPS), TW2(CPS), TW3(CPS), TW4(CPS), TW5(CPS): Arrays containing the number of acre inches applied per acre for each crop block during periods 1, 2, 3, 4 and 5, respectively.

TWA(DYS,CPS): Matrix of values of total water actually applied to the soil profile during all irrigation for each crop during the growing season.

TWPDCY: Total water pumped during the crop year in acre inches.

TWCA(CPS): Array containing the number of acre inches applied per acre for each block of corn during April.

UD(TDYS): Array of uniform deviates used to generate daily rainfall values from April 1 through October 31.

VC1(40), VC2(30), VC3(15): Arrays of variable pumping costs per acre inch of irrigation water pumped by irrigation wells 1, 2 and 3, respectively. These costs per acre inch are read in as data.

VPCAI: Variable pumping cost per acre inch for the irrigation system.

WNIL1(8), WNIL2(8), WNIL3(8): Arrays representing nonirrigation labor requirements per acre for three levels of wheat irrigation. Nonirrigation labor per acre varies with irrigation level due to differences in fertilizer and insecticide application. These requirements are read in as data.

WR1(CPS), WR2(CPS), WR3(CPS), WR4(CPS), WR5(CPS): Arrays containing total water requirements per irrigation for each crop block for periods 1, 2, 3, 4 and 5, respectively.

WRFPM, WRFPA, WRFBM, WRFBA, WRFFM, WRFFA, WRFMM, WRFMA: Wheat yield reduction factors, or coefficients, which are read in as data. The WRF common to each coefficient represents "wheat reduction factor". The letters P, B, F and M represent preboot, boot, flower and milk stages of plant development, respectively. M and A indicate whether the coefficient is a moisture or atmospheric reduction factor.

WYLD5, WYLD4, WYLD3, WYLD2, WYLD1: Wheat yield during each of the past five years. Government payments per acre are based on a five-year moving average of yields.

YGTPA, YGTP1, YGTP2, YGTP3, YGTP4, YGTP5: Yearly grand total pumping (acre inches pumped per acre per crop block) for April, and periods 1, 2, 3, 4 and 5, respectively.

YLD(CPS): Array containing final yield for the growing season in units per acre by crop blocks.

YR1M(RDYS,CPS) and YR1A(RDYS,CPS): Matrices of daily yield reduction values for period 1 due to moisture stress and atmospheric stress, respectively.

YR2M(RDYS,CPS) and YR2A(RDYS,CPS): Matrices of daily yield reduction values for period 2 due to moisture stress and atmospheric stress, respectively.

YR3M(RDYS,CPS) and YR3A(RDYS,CPS): Matrices of daily yield reduction values for period 3 due to moisture stress and atmospheric stress, respectively.

YR4M(RDYS,CPS) and YR4A(RDYS,CPS): Matrices of daily yield reduction values for period 4 due to moisture stress and atmospheric stress, respectively.

YR5M(RDYS,CPS) and YR5A(RDYS,CPS): Matrices of daily yield reduction values for period 5 due to moisture stress and atmospheric stress, respectively.

YTPA(CPS), YTP1(CPS), YTP2(CPS), YTP3(CPS), YTP4(CPS), YTP5(CPS): Total acre inches pumped for each crop block during April and periods 1, 2, 3, 4 and 5, respectively.

Execution of the attached program necessitates preparation of a number of data sets to be read into the program from cards. The following section explains the card input requirements in the order in which data sets must be read into the program.

Data Set 1: Consists of one card containing the beginning and ending years of the simulation run. Each integer value is entered flush right in a five-column field.

Data Set 2: Consists of one card containing six values in ten-column fields. The first value (GPM) is the beginning capacity of the irrigation system. The second value (ACRES) is the number of acres in the farm situation being simulated. The third value (BSAT) is the beginning saturated thickness of the underground aquifer during the current year of the simulation run. The fourth value (RGPM) indicates whether or not during a multiperiod run, drawdown of the water table and declining well yields are to be considered in computing pumping capability for the following year. A 1.0 indicates no drawdown is to be simulated and a 2.0 indicates drawdown will be simulated. The fifth value (NWELL) indicates the number of wells at the beginning of the current year. The final value (KMAP) indicates the type of output desired. If KMAP = 0, only printed output is produced. If KMAP = 1, only punched output for the Farm Firm Simulation Model is produced. If KMAP = 2, both printed and punched output are produced.

Data Set 3: Consists of the six grain sorghum yield reduction coefficients entered in ten-column fields on a single card.

Data Set 4: Consists of the eight wheat yield reduction coefficients entered in ten-column fields on a single card.

Data Set 5: Consists of the ten corn yield reduction coefficients and the coefficient relating corn grain yields to corn silage yields entered in 11 seven-column fields on a single card.

Data Set 6: Consists of ten water use parameters for grain sorghum and corn entered in ten eight-column fields on a single card.

Data Set 7: Consists of six levels of available soil moisture at which irrigations may be scheduled entered in ten-column fields on a single card.

Data Set 8: Consists of ten acreages to represent the ten crop blocks in the organization of production. These acreages are entered in ten five-column fields on a single card.

Data Set 9: Consists of 40 values for variable pumping costs per acre inch as pumping capacity ranges from 25 to 1,000 gallons per minute for irrigation well 1. Pumping cost per acre inch for 25 GPM capacity is the first value entered and that for 1,000 GPM capacity is last. Ten cost figures are entered in five-column fields on each of four cards in this data set.

Data Set 10: Contains 30 values for variable pumping costs per acre inch for the second well in the irrigation system. A cost figure is entered for 25 GPM capacity first and an additional figure each 25 gallons per minute until 700 GPM is reached. The 30 values are entered in 15 five-column fields on two cards.

Data Set 11: Contains 15 values representing variable pumping cost per acre inch for the third well of the irrigation system. The first cost figure entered is for 25 GPM capacity and a new cost figure is entered each 25 GPM until 350 GPM capacity is reached. The 15 values are entered in five-column fields on a single card.

Data Set 12: Consists of nonirrigation labor requirements for each of the eight labor periods specified in the model for each crop being produced. This data set contains eight cards with each card containing nine values. Card one contains the nonirrigation labor requirements during labor period 1 for three wheat irrigation levels, three grain sorghum irrigation levels, corn for grain, corn silage and graze-out small grain. Succeeding cards contain similar values for periods 2 through 8.

Data Set 13: Consists of a matrix of values for machine use expressed in hours per acre. The data set consists of 12 cards, one for each of the implements contained in the machinery compliment. Each card contains nine values--one each for three levels of grain sorghum irrigation, three levels of wheat irrigation, corn for grain, corn silage and graze-out small grain. Values are entered in nine five-column fields.

Data Set 14: Consists of machinery ownership costs per acre for three levels of grain sorghum irrigation, three levels of wheat irrigation, corn for grain, corn silage, graze-out small grain and native pasture. Each value is entered in an eight-column field and all ten values are contained on a single card.

Data Set 15: Consists of the bases for two random number generators built into the model. Each base must be an odd integer value equal to or less than nine digits in magnitude. Each base is entered in a ten-column field.

One additional data set is required to execute the model in its current form. Discrete rainfall probability distributions were constructed for each two-week interval of the growing season. These probability distributions were then stored on disk to eliminate the necessity of reading the distributions from cards. At the beginning of each multiperiod simulation run, the probability distributions are read once from disk and utilized each year during the simulation run. The user has the option of constructing discrete rainfall distributions for his region or fitting a continuous probability distribution which would eliminate the requirement to read discrete distributions from disk.

The Production Subset with Subroutines RAIN, SMBAL and OUTPUT can be compiled, stored on disk and executed by reading the above data sets from card images. Any number of years may be simulated by merely specifying the length of run on the card in Data Set 1. A listing of the Production Subset and Subroutines is attached to this appendix.

The output generated by the Production Subset is designed specifically for use by the Farm Firm Simulation Model. A sample copy of the output is also attached to this appendix. The first block of output consists of the hours of machine use by crop block for each machine in the complement specified in Table XXXVI, Appendix A. The second output block consists of the total hours of irrigation and nonirrigation labor required per acre of each crop block during each of eight specified labor periods. The third block of output specifies the number of acre inches of water pumped per acre for each crop block during April and irrigation periods 1, 2, 3, 4 and 5, respectively. Total irrigation water pumped per acre for each crop block is also printed.

Additional output includes total variable costs per acre by crop block; hours pumped per well by crop block; final crop yield by crop block; government support payments per acre by crop block; net returns per acre above total variable costs by crop block; and acres planted by crop block. In addition to final crop yield, a detailed breakdown of yield reductions due to soil moisture and atmospheric stress by critical period of the crop year is printed along with the total reduction in yield.

Pumping capacity by period at the beginning of the crop year and the unused capacity each period is printed. Also, total acre inches and acre feet pumped, beginning saturated thickness, decline in the static water table and ending saturated thickness are specified. Well information includes the number, GPM pumping capacity of the entire system, days of annual use, hours of annual use, hours of annual use per well, gallons per minute of pumping capacity per well and variable pumping costs per acre inch for the system.

TABLE XLIII

LISTING OF PRODUCTION SUBSET COMPUTER PROGRAM

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
C***********************************************************************
C***********************************************************************
C                  PRODUCTION SUBSET OF FARM FIRM SIMULATOR
C***********************************************************************
C***********************************************************************
C
C***********************************************************************
C     DIMENSION AND INITIALIZE OATA ARRAYS
C***********************************************************************
      COMMON SMT(185,10),SMU(185,10),SML(185,10),R(185,10),E(185,10),I,J
     1,AE(185,10),CM(185,10),C(185,10)
      COMMON/OUTPT/K,YGTPA,YGTP1,YGTP2,YGTP3,YGTP4,YGTP5,FGTP,CCCS1,CCCS
     12,CCSGP,HWCS1,HWCS2,CS1,CS2,SGPY1,SGPY2,GPACS1,GPACS2,TNRS1,TNRS2,
     1TNRAP,BIPCA,BIPC1,8IPC2,BIPC3,BIPC4,BIPC5,BIPD,AIPCA,AIPC1,AIPC2,A
     1IPC3,AIPC4,AIPC5,AIPD,AFW,BSAT,DECL,RSAT,GPM,NWELL,DAU,HAU,HAUPW,G
     1PM1,GPM2,GPM3,VPCAI,KMAP,AMU(12,13),GTL1(10),GDNIL(8),GTL2(10),GTL
     13(10),GTL4(10),GTL5(10),GTL6(10),GTL7(10),GTL8(10),TPA(10),TP1(10)
     1,TP2(10),TP3(10),TP4(10),TP5(10),TWP(10),CC(10),HPPW(10),YLD(10),G
     1PA(10),TNRA(10),AC(10),R1M(10),R2M(10),R3M(10),R4M(10),R5M(10),R1A
     1(10),R2A(10),R3A(10),R4A(10),R5A(10),TR(10),T1(44,13),TY2(13),CSNI
     1L(8)
      COMMON/RF/RAP1(1000),RAP2(1000),RM1(1000),RM2(1000),RJU1(1000),RJU
     12(1000),RJL1(1000),RJL2(1000),RA1(1000),RA2(1000),RS1(1000),RS2(10
     100),RO1(1000),RO2(1000),IX1,IX2,UD(215),N(215),RN(215),EP(185),D(1
     185),KNT1,KNT2,IY
      DIMENSION ATM(145,10),SMD(145,10),YR1M(145,10),YR1A(145,10),YR2M(1
     145,10),YR2A(145,10),YR3M(145,10),YR3A(145,10),YR4M(145,10),YR4A(14
     15,10),YR5M(145,10),YR5A(145,10)
      DIMENSION YTPA(10),YTP1(10),YTP2(10),YTP3(10),YTP4(10),YTP5(10),YG
     1TP(10),TWA(185,10)
      DIMENSION NIA(10),NI1(10),NI2(10),NI3(10),NI4(10),NI5(10),NI(10),T
     1NIA(10),TNI1(10),TNI2(10),TNI3(10),TNI4(10),TNI5(10),TNI(10),CLA(1
     20),CLI(10)
      DIMENSION CRA(10),TWCA(10),WR1(10),WR2(10),WR3(10),WR4(10),WR5(10)
     1,TW1(10),TW2(10),TW3(10),TW4(10),TW5(10),TW(10),HIPA(10),ACA(10),A
     1C1(10),AC2(10),AC3(10),AC4(10),AC5(10),TAC(10),TACI(10),VC1(40),VC
     12(30),VC3(15),HAMU(12,9),VYLD(10),WNIL1(8),WNIL2(8),WNIL3(8),GNIL1
     1(8),GNIL2(8),GNIL3(8),CGNIL(8),CEI(10),TRM(10),TRA(10)
      DIMENSION PYR(10),TAX(10)
      DO 1 I=1,1000
      RAP1(I)=0.0
      RAP2(I)=0.0
      RM1(I)=0.0
      RM2(I)=0.0
      RJU1(I)=0.0
      RJU2(I)=0.0
      RJL1(I)=0.0
      RJL2(I)=0.0
      RA1(I)=0.0
      RA2(I)=0.0
      RS1(I)=0.0
      RS2(I)=0.0
      RO1(I)=0.0
      RO2(I)=0.0
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
    1 CONTINUE
      DO 2 I=1,215
      UD(I)=0.0
      N(I)=0.0
      RN(I)=0.0
    2 CONTINUE
      DO 3 I=1,185
      EP(I)=0.0
      D(I)=0.0
    3 CONTINUE
      DO 4 J=1,10
      AC(J)=0.0
      TNRA(J)=0.0
      DO 4 I=1,185
      SMT(I,J)=0.0
      SMU(I,J)=0.0
      SML(I,J)=0.0
      E(I,J)=0.0
      R(I,J)=0.0
      AE(I,J)=0.0
      CM(I,J)=0.0
      C(1,J)=0.0
    4 CONTINUE
      DO 28 J=1,40
      VC1(J)=0.0
   28 CONTINUE
      DO 29 J=1,15
      VC3(J)=0.0
   29 CONTINUE
      DO 30 I=1,8
      WNIL1(I)=0.0
      WNIL2(I)=0.0
      WNIL3(I)=0.0
      GNIL1(I)=0.0
      GNIL2(I)=0.0
      GNIL3(I)=0.0
      CGNIL(I)=0.0
      CSNIL(I)=0.0
      GDNIL(1)=0.0
   30 CONTINUE
      DO 51 I=1,12
      DO 51 J=1,9
      HAMU(I,J)=0.0
   51 CONTINUE
      DO 80 I=1,30
      VC2(I)=0.0
   80 CONTINUE
      GPM1=0.0
      GPM2=0.0
      GPM3=0.0
      KG1=0
      KG2=0
      KG3=0
      KG4=0
```

TABLE XLIII (Continued)

```
                                   80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      KW1=0
      KW2=0
      KC1=0
      KC2=0
C***********************************************************************
C     READ BEGINNING YEAR AND NUMBER OF YEARS TO BE SIMULATED
C***********************************************************************
      READ(5,6)IBYR,NYRS
    6 FORMAT(2I5)
C***********************************************************************
C     READ BEGINNING GALLONS PER MINUTE OF PUMPING CAPACITY FOR THE
C     IRRIGATION SYSTEM, NUMBER OF ACRES OVERLYING THE AQUIFER FOR
C     THIS RESOURCE SITUATION AND BEGINNING SATURATED THICKNESS
C***********************************************************************
      READ(5,7)GPM,ACRES,BSAT,RGPM,NWELL,KMAP
    7 FORMAT(4F10.2,2I10)
C***********************************************************************
C     READ SOIL MOISTURE AND ATMOSPHERIC YIELD REDUCTION PARAMETERS FOR
C     GRAIN SORGHUM, WHEAT AND CORN BY STAGES OF PLANT DEVELOPMENT
C***********************************************************************
      READ(5,8)GRFPM,GRFPA,GRFBM,GRFBA,GRFGM,GRFGA
    8 FORMAT(6F10.2)
      READ(5,9)WRFPM,WRFPA,WRFBM,WRFBA,WRFFM,WRFFA,WRFMM,WRFMA
    9 FORMAT(8F10.2)
      READ(5,10)CRV1M,CRV1A,CRV2M,CRV2A,CRFSM,CRFSA,CRFMM,CRFMA,CRFDM,CR
     1FDA,CSYP
   10 FORMAT(11F7.2)
C***********************************************************************
C     READ WATER USE PARAMETERS
C***********************************************************************
      READ(5,11)GEF1,GEF2,GEF3,GEF4,GEF5,CEF1,CEF2,CEF3,CEF4,CEF5
   11 FORMAT(10F8.2)
C***********************************************************************
C     READ INCHES OF AVAILABLE SOIL MOISTURE AT WHICH IRRIGATIONS ARE
C     SCHEDULED
C***********************************************************************
      READ(5,12)ASMW,ASM1,ASM2,ASM3,ASM4,ASM5
   12 FORMAT(6F10.2)
C***********************************************************************
C     READ ORGANIZATION OF PRODUCTION
C***********************************************************************
      READ(5,13)(AC(J),J=1,10)
   13 FORMAT(10F5.1)
C***********************************************************************
C     READ IRRIGATION PUMPING COSTS PER ACRE INCH
C***********************************************************************
      READ(5,25)(VCI(J),J=1,40)
   25 FORMAT(10F5.2/10F5.2/10F5.2/10F5.2)
      READ(5,26)(VC2(J),J=1,30)
   26 FORMAT(15F5.2/15F5.2)
      READ(5,27)(VC3(J),J=1,15)
   27 FORMAT(15F5.2)
C***********************************************************************
C     READ NONIRRIGATION LABOR REQUIREMENTS
```

```
                                   80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
C***********************************************************************
      DO 40 I=1,8
      READ(5,41)WNIL1(I),WNIL2(I),WNIL3(1),GNIL1(1),GNIL2(I),GNIL3(I),CG
     1NIL(I),CSNIL(1),GONIL(I)
   40 CONTINUE
   41 FORMAT(9F5.2)
C***********************************************************************
C     READ MACHINE USE PER ACRE IN HOURS
C***********************************************************************
      READ(5,54)((HAMU(I,J),J=1,9),I=1,12)
   54 FORMAT(9F5.2)
C***********************************************************************
C     READ MACHINERY OWNERSHIP COSTS PER ACRE
C***********************************************************************
      READ(5,55)GFC1,GFC2,GFC3,WFC1,WFC2,WFC3,CFC1,CFC2,PFC1,PFC2
   55 FORMAT(10F8.2)
C***********************************************************************
C     READ BASES FOR RANDOM NUMBER GENERATORS
C***********************************************************************
      READ(5,81)IX1,IX2
   81 FORMAT(2I10)
C***********************************************************************
C     READ RAINFALL PROBABILITY DISTRIBUTIONS FROM DISK
C***********************************************************************
      READ(99,15)(RM1(I),I=1,990)
      READ(99,16)(RM1(I),I=991,1000)
      READ(99,15)(RM2(I),I=1,990)
      READ(99,16)(RM2(1),I=991,1000)
      READ(99,15)(RJU1(I),I=1,990)
      READ(99,16)(RJU1(I),I=991,1000)
      READ(99,15)(RJU2(I),I=1,990)
      READ(99,16)(RJU2(I),I=991,1000)
      READ(99,15)(RJL1(I),I=1,990)
      READ(99,16)(RJL1(I),I=991,1000)
      READ(99,15)(RJL2(I),I=1,990)
      READ(99,16)(RJL2(I),I=991,1000)
      READ(99,15)(RA1(1),I=1,990)
      READ(99,16)(RA1(I),I=991,1000)
      READ(99,15)(RA2(I),I=1,990)
      READ(99,16)(RA2(I),I=991,1000)
      READ(99,15)(RS1(I),I=1,990)
      READ(99,16)(RS1(I),1=991,1000)
      READ(99,15)(RS2(I),I=1,990)
      READ(99,16)(RS2(1),I=991,1000)
      READ(99,15)(RO1(I),l=1,990)
      READ(99,16)(RO1(I),I=991,1000)
      READ(99,15)(RO2(I),I=1,990)
      READ(99,16)(RO2(I),I=991,1000)
      READ(99,15)(RAP1(I),I=1,990)
      READ(99,16)(RAP1(I),I=991,1000)
      READ(99,15)(RAP2(1),I=1,990)
      READ(99,16)(RAP2(I),I=991,1000)
   15 FORMAT(15F5.2)
   16 FORMAT(10F5.2)
```

TABLE XLIII (Continued)

```
80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
      KNT1=0
      KNT2=0
      KOUNT=1
C***********************************************************************
C     BEGIN THE SIMULATION PROCEDURE FOR ANY DESIRED NUMBER OF YEARS
C***********************************************************************
      DO 1000 K=IBYR,NYRS
C***********************************************************************
C     SUBROUTINE RAIN GENERATES DAILY RAINFALL AND PAN EVAPORATION
C***********************************************************************
      CALL RAIN
      DO 5 J=1,10
      CRA(J)=0.0
      WR1(J)=0.0
      WR2(J)=0.0
      WR3(J)=0.0
      WR4(J)=0.0
      WR5(J)=0.0
      VYLD(J)=0.0
      GPA(J)=0.0
      DO 5 I=1,145
      ATM(I,J)=0.0
      SMD(I,J)=0.0
      YR1M(I,J)=0.0
      YR1A(I,J)=0.0
      YR2M(I,J)=0.0
      YR2A(I,J)=0.0
      YR3M(I,J)=0.0
      YR3A(I,J)=0.0
      YR4M(I,J)=0.0
      YR4A(I,J)=0.0
      YR5M(I,J)=0.0
      YR5A(I,J)=0.0
    5 CONTINUE
      DO 14 J=1,10
      PYR(J)=0.0
      TAX(J)=0.0
      TWCA(J)=0.0
      TW1(J)=0.0
      TW2(J)=0.0
      TW3(J)=0.0
      TW4(J)=0.0
      TW5(J)=0.0
      TPA(J)=0.0
      TP1(J)=0.0
      TP2(J)=0.0
      TP3(J)=0.0
      TP4(J)=0.0
      TP5(J)=0.0
      TW(J)=0.0
      TWP(J)=0.0
      R1M(J)=0.0
      R1A(J)=0.0
      R2M(J)=0.0
```

```
80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
      R2A(J)=0.0
      R3M(J)=0.0
      R3A(J)=0.0
      R4M(J)=0.0
      R4A(J)=0.0
      R5M(J)=0.0
      R5A(J)=0.0
      TRM(J)=0.0
      TRA(J)=0.0
      TR(J)=0.0
      YLD(J)=0.0
      YTPA(J)=0.0
      YTP1(J)=0.0
      YTP2(J)=0.0
      YTP3(J)=0.0
      YTP4(J)=0.0
      YTP5(J)=0.0
      YGTP(J)=0.0
      HIPA(J)=0.0
      HPPW(J)=0.0
      CC(J)=0.0
      CEI(J)=0.0
      ACA(J)=0.0
      AC1(J)=0.0
      AC2(J)=0.0
      AC3(J)=0.0
      AC4(J)=0.0
      AC5(J)=0.0
      TAC(J)=0.0
      TACI(J)=0.0
      GTL1(J)=0.0
      GTL2(J)=0.0
      GTL3(J)=0.0
      GTL4(J)=0.0
      GTL5(J)=0.0
      GTL6(J)=0.0
      GTL7(J)=0.0
      GTL8(J)=0.0
      DO 14 I=1,185
      TWA(I,J)=0.0
      NIA(J)=0.0
      NI1(J)=0.0
      NI2(J)=0.0
      NI3(J)=0.0
      NI4(J)=0.0
      NI5(J)=0.0
      NI(J)=0.0
      TNIA(J)=0.0
      TNI1(J)=0.0
      TNI2(J)=0.0
      TNI3(J)=0.0
      TNI4(J)=0.0
      TNI5(J)=0.0
      TNI(J)=0.0
```

TABLE XLIII (Continued)

```
                                80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      CLA(J)=0.0
      CLI(J)=0.0
   14 CONTINUE
      DO 52 I=1,12
      DO 52 J=1,13
      AMU(1,J)=0.0
   52 CONTINUE
      DO 53 I=1,44
      DO 53 J=1,13
      T1(I,J)=0.0
      TY2(J)=0.0
   53 CONTINUE
C***********************************************************************
C     COMPUTE PUMPING CAPACITY FOR THE CURRENT YEAR, ADD ADDITIONAL WELL
C     IF JUSTIFIED AND INCREMENT PUMPING CAPACITY FOR THE CURRENT YEAR.
C***********************************************************************
      IF(K.EQ.1)GO TO 90
      IF(RGPM.EQ.1.0)GO TO 90
      IF(RSAT.GE.125.0)GO TO 90
      IF(KOUNT.GT.1)GO TO 17
      GPM=(((RSAT/BSAT)**2)*GPM)
   17 IF(RGPM.EQ.2.0)GO TO 90
      GO TO (90,18,21),KOUNT
   18 IF(NWELL-2)19,20,90
   19 NWELL=2
      GPM=(((RSAT/BSAT)**2)*GPM)
      GPM1=GPM
      GPM2=GPM
      GPM=GPM1+GPM2
      GO TO 90
   20 GPM1=(((RSAT/BSAT)**2)*GPM1)
      GPM2=(((RSAT/BSAT)**2)*GPM2)
      GPM=(((RSAT/BSAT)**2)*GPM)
      GO TO 90
   21 IF(NWELL-3)22,23,90
   22 NWELL=3
      GPM1=(((RSAT/BSAT)**2)*GPM1)
      GPM2=GPM1
      GPM3=GPM2
      GPM=GPM1+GPM2+GPM3
      GO TO 90
   23 GPM1=(((RSAT/BSAT)**2)*GPM1)
      GPM2=(((RSAT/BSAT)**2)*GPM2)
      GPM3=(((RSAT/BSAT)**2)*GPM3)
      GPM=(((RSAT/BSAT)**2)*GPM)
C***********************************************************************
C     CALCULATE BEGINNING SOIL MOISTURE
C***********************************************************************
   90 SUM=0.0
      SUM1=0.0
      DO 91 I=185,214
      SUM=SUM+RN(I)
   91 CONTINUE
      DO 92 I=208,214
```

```
                                80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      SUM1=SUM1+RN(I)
   92 CONTINUE
      DO 93 J=1,IO
      SMT(1,J)=8.69+.22409*SUM+2.33463*SUM1
      SML(1,J)=SMT(1,J)*.82
      SMU(1,J)=SMT(1,J)-SML(1,J)
   93 CONTINUE
      DO 94 I=1,185
      DO 94 J=1,10
      E(I,J)=EP(I)
      R(I,J)=RN(I)
   94 CONTINUE
C***********************************************************************
C     COMPUTE GRAIN SORGHUM WATER USE RATES BY CRITICAL STAGES OF PLANT
C     DEVELOPMENT
C***********************************************************************
      DO 95 I=1,37
      DO 95 J=1,4
      E(I,J)=GEF1*E(I,J)
   95 CONTINUE
      Z=1.0
      DO 96 I=38,75
      DO 96 J=1,4
      E(I,J)=GEF1*E(I,J)+(((GEF4*E(I,J))*Z)/38.0)
      Z=Z+1.0
      1F(E(I,J).LE.1.00)GO TO 96
      E(I,J)=1.00
   96 CONTINUE
      DO 97 I=76,124
      DO 97 J=1,4
      E(I,J)=GEF2*E(1,J)
   97 CONTINUE
      DO 98 I=125,185
      DO 98 J=1,4
      E(I,J)=.5*E(I,J)
   98 CONTINUE
      DO 99 I=1,75
      E(I,5)=.25*E(I,5)
   99 CONTINUE
      DO 100 I=76,124
      E(I,5)=GEF5*E(I,5)
  100 CONTINUE
      DO 101 I=125,185
      E(I,5)=.5*E(I,5)
  101 CONTINUE
C***********************************************************************
C     COMPUTE WHEAT WATER USE RATES BY CRITICAL STAGES OF PLANT
C     DEVELOPMENT
C***********************************************************************
      DO 102 I=1,185
      DO 102 J=6,8
      E(I,J)=.5*E(1,J)
  102 CONTINUE
C*******************************************************************************
```

TABLE XLIII (Continued)

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
C     COMPUTE CORN WATER USE RATES BY CRITICAL STAGES OF PLANT
C     DEVELOPMENT
C***********************************************************************
      DO 103 I=1,6
      DO 103 J=9,10
      E(I,J)=CEF1*E(I,J)
  103 CONTINUE
      Z1=1.0
      DO 104 I=7,63
      DO 104 J=9,10
      E(I,J)=CEF1*E(1,J)+(((CEF4*E(I,J))*Z1)/57.0)
      Z1=Z1+1.0
  104 CONTINUE
      DO 105 I=64,79
      DO 105 J=9,10
      E(I,J)=CEF2*E(I,J)
  105 CONTINUE
      Z2=1.0
      DO 106 I=80,116
      DO 106 J=9,10
      E(I,J)=CEF2*E(I,J)-(((CEF5*E(I,J))*Z2)/37.0)
      Z2=Z2+1.0
  106 CONTINUE
      DO 107 I=117,185
      DO 107 J=9,10
      E(I,J)=.5*E(I,J)
  107 CONTINUE
C***********************************************************************
C     COMPUTE ACRE INCHES OF PUMPING CAPABILITY BY PERIODS OF THE
C     GROWING SEASON
C***********************************************************************
      BIPCA=((GPM*43200.0)/27155.0)
      BIPC1=((GPM*20160.0)/27155.0)
      BIPC2=((GPM*28800.0)/27155.0)
      BIPC3=((GPM*80640.0)/27155.0)
      BIPC4=((GPM*56160.0)/27155.0)
      BIPC5=((GPM*20160.0)/27155.0)
      BIPD=((GPM*1440.0)/27155.0)
      AIPCA=BIPCA
      AIPC1=BIPC1
      AIPC2=BIPC2
      AIPC3=BIPC3
      AIPC4=BIPC4
      AIPC5=BIPC5
      AIPD=BIPD
      TWPDCY=0.0
      IF(KG1-0)1071,1071,1070
 1070 AC(8)=AC(8)+AC(1)
      AC(1)=0.0
 1071 IF(KG2-0)1073,1073,1072
 1072 AC(8)=AC(8)+AC(2)
      AC(2)=0.0
 1073 IF(KG3-0)1075,1075,1074
 1074 AC(8)=AC(8)+AC(3)
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      AC(3)=0.0
 1075 IF(KG4-0)1077,1077,1076
 1076 AC(8)=AC(8)+AC(4)
      AC(4)=0.0
 1077 IF(KW1-0)1079,1079,1078
 1078 AC(8)=AC(8)+AC(6)
      AC(6)=0.0
 1079 IF(KW2-0)1081,1081,1080
 1080 AC(8)=AC(8)+AC(7)
      AC(7)=0.0
 1081 IF(KC1-0)1083,1083,1082
 1082 AC(8)=AC(8)+AC(9)
      AC(9)=0.0
 1083 IF(KC2-0)1085,1085,1084
 1084 AC(8)=AC(8)+AC(10)
      AC(10)=0.0
C***********************************************************************
C                              IRRIGATION STRATEGIES
C***********************************************************************
C     CORN PREPLANT IRRIGATION
C***********************************************************************
 1085 CWA=4.0
      DO 110 J=9,10
      IF(AC(J).EQ.0.0)GO TO 110
      CRA(J)=AC(J)*CWA
      TWPDCY=TWPDCY+(CRA(J)*1.5)
      IF(CRA(J)-AIPCA)108,108,109
  108 AIPCA=AIPCA-(AC(J)*6.0)
      R(1,J)=R(1,J)+3.0
      TWCA(J)=TWCA(J)+CWA
      GO TO 110
  109 AIAA=AIPCA/AC(J)
      R(1,J)=R(1,J)+AIAA
      TWCA(J)=TWCA(J)+AIAA
      AIPCA=AIPCA-(AC(J)*AIAA)
  110 CONTINUE
C***********************************************************************
C     PERIOD 1: IRRIGATION PRIORITIES =(1) GRAIN SORGHUM (2) WHEAT AND
C     (3) CORN
C***********************************************************************
      ND=1
      NDA=0
      NC1=1
  111 CONTINUE
      I=ND
  112 DO 146 J=NC1,10
      W1=4.5
      IF(I.LT.NDA)GO TO 145
      IF(AC(J).EQ.0.0)GO TO 146
      GO TO (113,114,117,122,145,129,130,145,133,134),J
  113 IF(TW1(1).GT.2.95)GO TO 145
      IF(SMT(I,J)-ASM5)138,145,145
  114 IF(TW1(2).GT.2.95)GO TO 145
      IF(SMT(I,J)-ASM5)115,145,145
```

TABLE XLIII (Continued)

```
                                   80/80 LIST

      00000000011111111112222222222333333333344444444445555555555666666666677777777778
      12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
0541    115 IF(SMT(I,1)-ASM1)137,138,138
0542    117 IF(TW1(3).GT.2.95)GO TO 145
0543        IF(SMT(I,J)-ASM5)118,145,145
0544    118 IF(SMT(I,1)-ASM1)137,120,120
0545    120 IF(SMT(I,2)-ASM1)137,138,138
0546    122 IF(TW1(4).GT.2.95)GO TO 145
0547        IF(SMT(I,J)-ASM5)123,145,145
0548    123 IF(SMT(I,1)-ASM1)137,125,125
0549    125 IF(SMT(I,2)-ASM1)137,127,127
0550    127 IF(SMT(I,3)-ASM1)137,138,138
0551    129 IF(TW1(6).GT.2.95)GO TO 145
0552        IF(SMT(I,J)-ASM3)138,145,145
0553    130 IF(TW1(7).GT.2.95)GO TO 145
0554        IF(SMT(I,J)-ASM3)131,145,145
0555    131 IF(SMT(I,6)-ASM3)137,138,138
0556    133 IF(SMT(I,J)-ASM3)138,145,145
0557    134 IF(SMT(I,J)-ASM3)135,145,145
0558    135 IF(SMT(I,9)-ASM3)137,138,138
0559    137 W1=1.5
0560    138 WR1(J)=AC(J)*W1
0561        IF(WR1(J)-AIPC1)139,139,143
0562    139 DRED=WR1(J)/AIPD
0563        NDREQ=DRED+.5
0564        IF(NDREQ.GT.0)GO TO 1390
0565        NDREQ=1
0566   1390 NDA=ND+NDREQ
0567        NDAA=NDA-1
0568        DAP=NDREQ
0569        AIAPD=(W1/1.5)/DAP
0570    140 IF(NDAA.LE.15)GO TO 141
0571        NDAA=15
0572        NDA=15
0573    141 ND1=ND
0574        DO 142 L=ND1,NDAA
0575        R(L,J)=R(L,J)+AIAPD
0576        TWA(L,J)=TWA(L,J)+AIAPD
0577        TW1(J)=TW1(J)+TWA(L,J)
0578        AIPC1=AIPC1-((TWA(L,J)*1.5)*AC(J))
0579        TWPDCY=TWPDCY+(((TWA(L,J)*1.5)*AC(J)))
0580        IF(AIPC1-0.00001)1420,142,142
0581   1420 AIPC1=0.0
0582    142 CONTINUE
0583        GO TO 145
0584    143 RAI1=AIPC1/AC(J)
0585        IF(1.5-RAI1)144,144,145
0586    144 DRED=AIPC1/AIPD
0587        NDREQ=DRED+.5
0588        IF(NDREQ.GT.0)GO TO 1440
0589        NDREQ=1
0590   1440 NDA=ND+NDREQ
0591        NDAA=NDA-1
0592        DAP=NDREQ
0593        W1=RAI1/1.5
0594        AIAPD=W1/DAP
```

```
                                   80/80 LIST

      00000000011111111112222222222333333333344444444445555555555666666666677777777778
      12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
0595        GO TO 140
0596  C***********************************************************************
0597  C     SUBROUTINE SMBAL GENERATES DAILY SOIL MOISTURE FOR EACH CROP
0598  C***********************************************************************
0599    145 CALL SMBAL
0600    146 CONTINUE
0601        IF(I.GE.15)GO TO 150
0602    149 ND=ND+1
0603        GO TO 111
0604    150 CONTINUE
0605  C***********************************************************************
0606  C     PERIOD 2= IRRIGATION PRIORITIES =(1) WHEAT, (2) CORN AND (3) GRAIN
0607  C     SORGHUM
0608  C***********************************************************************
0609        ND=16
0610        J=0
0611    200 CONTINUE
0612        I=ND
0613    202 IF(J-5)203,203,204
0614    203 NC21=6
0615        NC22=10
0616        GO TO 208
0617    204 NC21=1
0618        NC22=5
0619    208 DO 242 J=NC21,NC22
0620        W2=4.5
0621        IF(I.LT.NDA)GO TO 241
0622        IF(AC(J).EQ.0.0)GO TO 242
0623        GO TO (217,218,221,226,241,209,210,241,213,214),J
0624    209 IF(TW2(6).GT.5.95)GO TO 241
0625        IF(SMT(I,J)-ASM5)234,241,241
0626    210 IF(TW2(7).GT.5.95)GO TO 241
0627        IF(SMT(I,J)-ASM5)211,241,241
0628    211 IF(SMT(I,6)-ASM3)233,234,234
0629    213 IF(TW2(9).GT.2.95)GO TO 241
0630        IF(SMT(I,J)-ASM5)234,241,241
0631    214 IF(TW2(10).GT.2.95)GO TO 241
0632        IF(SMT(I,J)-ASM5)215,241,241
0633    215 IF(SMT(I,9)-ASM3)233,234,234
0634    217 IF(TW2(1).GT.2.95)GO TO 241
0635        IF(SMT(I,J)-ASM5)234,241,241
0636    218 IF(TW2(2).GT.2.95)GO TO 241
0637        IF(SMT(I,J)-ASM5)219,241,241
0638    219 IF(SMT(I,1)-ASM3)233,234,234
0639    221 IF(TW2(3).GT.2.95)GO TO 241
0640        IF(SMT(I,J)-ASM5)222,241,241
0641    222 IF(SMT(I,1)-ASM3)233,224,224
0642    224 IF(SMT(I,2)-ASM3)233,234,234
0643    226 IF(TW2(4).GT.2.95)GO TO 241
0644        IF(SMT(I,J)-ASM5)227,241,241
0645    227 IF(SMT(I,1)-ASM3)233,229,229
0646    229 IF(SMT(I,2)-ASM3)233,231,231
0647    231 IF(SMT(I,3)-ASM3)233,234,234
0648    233 W2=1.5
```

TABLE XLIII (Continued)

```
                              80/80 LIST

      00000000011111111112222222222333333333344444444445555555555666666666677777777778
      12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
        234 WR2(J)=AC(J)*W2
            IF(WR2(J)-AIPC2)235,235,239
        235 DREQ=WR2(J)/AIPD
            NDREQ=DREQ+.5
            AIAPD=W2/DAP
            IF(NDREQ.GT.0)GO TO 2350
            NDREQ=1
       2350 NDA=ND+NDREQ
            NDAA=NDA-1
            DAP=NDREQ
            AIAPD=(W2/1.5)/DAP
        236 IF(NDAA.LE.36)GO TO 237
            NDAA=36
            NDA=36
        237 ND2=ND
            DO 238 L=ND2,NDAA
            R(L,J)=R(L,J)+AIAPD
            TWA(L,J)=TWA(L,J)+AIAPD
            TW2(J)=TW2(J)+TWA(L,J)
            AIPC2=AIPC2-((TWA(L,J)*1.5)*AC(J))
            TWPDCY=TWPDCY+((TWA(L,J)*1.5)*AC(J))
            IF(AIPC2-0.00001)2380,238,238
       2380 AIPC2=0.0
        238 CONTINUE
            GO TO 241
        239 RAI2=AIPC2/AC(J)
            IF(1.5-RAI2)240,240,241
        240 DREQ=AIPC2/AIPD
            NDREQ=DREQ+.5
            IF(NDREQ.GT.0)GO TO 2400
            NDREQ=1
       2400 NDA=ND+NDREQ
            NDAA=NDA-1
            DAP=NDREQ
            W2=RAI2/1.5
            AIAPD=W2/DAP
            GO TO 236
        241 CALL SWBAL
        242 CONTINUE
            IF(I.GE.36)GO TO 245
            IF(J-5)244,243,244
        243 ND=ND+1
        244 GO TO 200
        245 IF(J-5)246,247,246
        246 GO TO 200
        247 CONTINUE
      C***********************************************************************
      C     PERIOD 3: IRRIGATION PRIORITIES= (1) CORN AND (2) GRAIN SORGHUM
      C***********************************************************************
            ND=37
            J=0
        300 CONTINUE
            I=ND
        302 IF(J-8)303,303,304
```

```
                              80/80 LIST

      00000000011111111112222222222333333333344444444445555555555666666666677777777778
      12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
        303 NC31=9
            NC32=10
            GO TO 308
        304 NC31=1
            NC32=8
        308 DO 338 J=NC31,NC32
            W3=4.5
            IF(I.LT.NDA)GO TO 337
            IF(AC(J).EQ.0.0)GO TO 338
            GO TO (313,314,317,322,337,337,337,337,309,310),J
        309 IF(TW3(9).GT.11.95)GO TO 337
            IF(SMT(I,J)-ASM5)330,337,337
        310 IF(TW3(10).GT.11.95)GO TO 337
            IF(SMT(I,J)-ASM5)311,337,337
        311 IF(SMT(I,9)-ASM3)329,330,330
        313 IF(TW3(1).GT.5.95)GO TO 337
            IF(SMT(I,J)-ASM3)330,337,337
        314 IF(TW3(2).GT.5.95)GO TO 337
            IF(SMT(I,J)-ASM3)315,337,337
        315 IF(SMT(I,1)-ASM1)329,330,330
        317 IF(TW3(3).GT.5.95)GO TO 337
            IF(SMT(I,J)-ASM3)318,337,337
        318 IF(SMT(I,1)-ASM1)329,320,320
        320 IF(SMT(I,2)-ASM1)329,330,330
        322 IF(TW3(4).GT.5.95)GO TO 337
            IF(SMT(I,J)-ASM3)323,337,337
        323 IF(SMT(I,1)-ASM1)329,325,325
        325 IF(SMT(I,2)-ASM1)329,327,327
        327 IF(SMT(I,3)-ASM1)329,330,330
        329 W3=1.5
        330 WR3(J)=AC(J)*W3
            IF(J.GT.8)GO TO 3300
            IF(TW3(J).GT.3.0)GO TO 337
       3300 IF(WR3(J)-AIPC3)331,331,335
        331 DREQ=WR3(J)/AIPD
            NDREQ=DREQ+.5
            IF(NDREQ.GT.0)GO TO 3310
            NDREQ=1
       3310 NDA=ND+NDREQ
            NDAA=NDA-1
            DAP=NDREQ
            AIAPD=(W3/1.5)/DAP
        332 IF(NDAA.LE.96)GO TO 333
            NDAA=96
            NDA=96
        333 ND3=ND
            DO 334 L=ND3,NDAA
            R(L,J)=R(L,J)+AIAPD
            TWA(L,J)=TWA(L,J)+AIAPD
            TW3(J)=TW3(J)+TWA(L,J)
            AIPC3=AIPC3-((TWA(L,J)*1.5)*AC(J))
            TWPDCY=TWPDCY+((TWA(L,J)*1.5)*AC(J))
            IF(AIPC3-0.00001)3340,334,334
       3340 AIPC3=0.0
```

TABLE XLIII (Continued)

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
  334 CONTINUE
      GO TO 337
  335 RAI3=AIPC3/AC(J)
      IF(1.5-RAI3)336,336,337
  336 DREQ=AIPC3/AIPD
      NDREQ=DREQ+.5
      IF(NDREQ.GT.0)GO TO 3360
      NDREQ=1
 3360 NDA=ND+NDREQ
      NDAA=NDA-1
      DAP=NDREQ
      W3=RAI3/1.5
      AIAPD=W3/DAP
      GO TO 332
  337 CALL SM8AL
  338 CONTINUE
      IF(1.GE.96)GO TO 341
      IF(J-8)340,339,340
  339 ND=ND+1
  340 GO TO 300
  341 IF(J-8)342,343,342
  342 GO TO 300
  343 CONTINUE
C************************************************************************
C     PERIOD 4: IRRIGATION PRIORITIES=(1)GRAIN SORGHUM AND (2)CORN
C************************************************************************
      ITAG=0
      ND=97
      NC4=1
  400 CONTINUE
      NDL=139-ND
      DAYSL=NDL
      I=ND
  401 DO 431 J=NC4,10
      W4=4.5
      IF(I.LT.NDA)GO TO 430
      IF(AC(J).EQ.0.0)GO TO 431
      IF(TWPDCY-5670.0)4004,4001,4001
 4001 IF(J.GT.4)GO TO 4004
      IF(NDL.LT.8)GO TO 430
      IF(NDL.GT.14)GO TO 4002
      PYR(J)=1.27*((13.8-SMT(I,J))/5.11)*DAYSL
      GO TO 4003
 4002 PYR(J)=(1.27*((13.8-SMT(I,J))/5.11)*14.0)+(2.04*((13.8-SMT(1,J))/5
     1.11)*(DAYSL-14.0))
 4003 IF(PYR(J)-10.0)430,423,423
 4004 CONTINUE
      GO TO (402,403,406,411,430,430,430,430,430,430),J
  402 IF(TW4(1).GT.8.95)GO TO 430
      IF(SMT(1,J)-ASM5)423,430,430
  403 IF(TW4(2).GT.8.95)GO TO 430
      IF(SMT(I,J)-ASM5)404,430,430
  404 IF(SMT(I,1)-ASM3)422,423,423
  406 IF(TW4(3).GT.8.95)GO TO 430
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      IF(SMT(I,J)-ASM5)407,430,430
  407 IF(SMT(I,1)-ASM3)422,409,409
  409 IF(SMT(I,2)-ASM3)422,423,423
  411 IF(TW4(4).GT.8.95)GO TO 430
      IF(SMT(I,J)-ASM5)412,430,430
  412 IF(SMT(I,1)-ASM3)422,414,414
  414 IF(SMT(1,2)-ASM3)422,416,416
  416 IF(SMT(1,3)-ASM3)422,423,423
  418 IF(TW4(9).GT.2.95)GO TO 430
      IF(SMT(I,J)-ASM5)423,430,430
  419 IF(TW4(10).GT.2.95)GO TO 430
      IF(SMT(1,J)-ASM5)420,430,430
  420 IF(SMT(I,9)-ASM3)422,423,423
  422 W4=1.5
  423 WR4(J)=AC(J)*W4
      IF(WR4(J)-AIPC4)424,424,428
  424 DREQ=WR4(J)/AIPD
      NDREQ=DREQ+.5
      IF(NDREQ.GT.0)GO TO 4240
      NDREQ=1
 4240 NDA=ND+NDREQ
      NDAA=NDA-1
      DAP=NDREQ
      AIAPD=(W4/1.5)/DAP
  425 IF(NDAA.LE.138)GO TO 426
      NDAA=138
      NDA=138
  426 ND4=ND
      DO 427 L=ND4,NDAA
      R(L,J)=R(L,J)+AIAPD
      TWA(L,J)=TWA(L,J)+AIAPD
      TW4(J)=TW4(J)+TWA(L,J)
      AIPC4=AIPC4-((TWA(L,J)*1.5)*AC(J))
      TWPDCY=TWPDCY+((TWA(L,J)*1.5)*AC(J))
      IF(TWPDCY.LT.5670.0)GO TO 4269
      ITAG=ITAG+1
      IF(ITAG-1)4267,4267,4269
 4267 DO 4268 M=1,10
      TAX(M)=((TWCA(M)+TW1(M)+TW2(M)+TW3(M)+TW4(M))*1.5)
 4268 CONTINUE
 4269 IF(AIPC4-0.0001)4270,427,427
 4270 AIPC4=0.0
  427 CONTINUE
      GO TO 430
  428 RAI4=AIPC4/AC(J)
      IF(1.5-RAI4)429,429,430
  429 DREQ=AIPC4/AIPD
      NDREQ=DREQ+.5
      IF(NDREQ.GT.0)GO TO 4290
      NDREQ=1
 4290 NDA=ND+NDREQ
      NDAA=NDA-1
      DAP=NDREQ
      W4=RAI4/1.5
```

TABLE XLIII (Continued)

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      AIAPD=W4/DAP
      GO TO 425
  430 CALL SMBAL
  431 CONTINUE
      IF(I.GE.138)GO TO 435
  434 ND=ND+1
      GO TO 400
  435 CONTINUE
C***********************************************************************
C     PERIOD 5: IRRIGATION PRIORITIES= (1)GRAIN SORGHUM AND (2) WHEAT
C***********************************************************************
      ND=139
      NC5=1
  500 CONTINUE
      I=ND
  501 DO 531 J=NC5,10
      W5=4.5
      IF(I.LT.NDA)GO TO 530
      IF(AC(J).EQ.0.0)GO TO 531
      IF(J-5)530,5002,5002
 5002 CONTINUE
      GO TO (502,503,506,511,530,518,519,530,530,530),J
  502 IF(SMT(I,J)-ASM3)523,530,530
  503 IF(SMT(I,J)-ASM3)504,530,530
  504 IF(SMT(I,1)-ASM1)522,523,523
  506 IF(SMT(I,J)-ASM3)507,530,530
  507 IF(SMT(I,1)-ASM1)522,509,509
  509 IF(SMT(I,2)-ASM1)522,523,523
  511 IF(SMT(I,J)-ASM3)512,530,530
  512 IF(SMT(I,1)-ASM1)522,514,514
  514 IF(SMT(I,2)-ASM1)522,516,516
  516 IF(SMT(I,3)-ASM1)522,523,523
  518 IF(TW5(6).GT.2.95)GC TO 530
      IF(SMT(I,J)-ASM5)523,530,530
  519 IF(TW5(7).GT.2.95)GO TO 530
      IF(SMT(I,J)-ASM5)520,530,530
  520 IF(SMT(I,6)-ASMI)522,523,523
  522 W5=1.5
  523 WR5(J)=AC(J)*W5
      IF(WR5(J)-AIPC5)524,524,528
  524 DREQ=WR5(J)/AIPD
      NDREQ=DREQ+.5
      IF(NDREQ.GT.0)GO TO 5240
      NDREQ=1
 5240 NDA=ND+NDREQ
      NDAA=NDA-1
      DAP=NDREQ
      AIAPD=(W5/1.5)/DAP
  525 IF(NDAA.LE.153)GC TO 526
      NDAA=153
      NDA=153
  526 ND5=ND
      DO 527 L=NC5,NDAA
      R(L,J)=R(L,J)+AIAPD
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      TWA(L,J)=TWA(L,J)+AIAPD
      TW5(J)=TW5(J)+TWA(L,J)
      AIPC5=AIPC5-((TWA(L,J)*1.5)*AC(J))
      TWPDCY=TWPDCY+((TWA(L,J)*1.5)*AC(J))
      IF(TWPDCY.LT.5670.0)GO TO 5269
      ITAG=ITAG+1
      IF(ITAG-1)5267,5267,5269
 5267 DO 5268 M=1,10
      TAX(M)=((TWCA(M)+TW1(M)+TW2(M)+TW3(M)+TW4(M)+TW5(M))*1.5)
 5268 CONTINUE
 5269 IF(AIPC5-.00001)5270,527,527
 5270 AIPC5=0.0
  527 CONTINUE
      GO TO 530
  528 RAI5=AIPC5/AC(J)
      IF(1.5-RAI5)529,529,530
  529 DREQ=AIPC5/AIPD
      NDREQ=DREQ+.5
      IF(NDREQ.GT.0)GO TO 5290
      NDREQ=1
 5290 NDA=ND+NDREQ
      NDAA=NDA-1
      DAP=NDREQ
      W5=RAI5/1.5
      AIAPD=W5/DAP
      GO TO 525
  530 CALL SMBAL
  531 CONTINUE
      IF(I.GE.153)GO TO 535
  534 ND=ND+1
      GO TO 500
  535 CONTINUE
  600 DO 601 I=154,184
      DO 601 J=1,10
      CALL SMBAL
  601 CONTINUE
C***********************************************************************
C     COMPUTE GRAIN SORGHUM YIELD REDUCTIONS AND FINAL YIELD
C***********************************************************************
      DO 260 J=1,5
      IF(AC(J).EQ.0.0)GO TO 260
      DO 2600 I=76,145
      IF(SMT(I,J)-13.8)253,256,256
  253 IF(SMT(I,J)-8.69)254,254,255
  254 SMD(I,J)=1.0
      GO TO 257
  255 SMD(I,J)=(13.8-SMT(I,J))/5.11
      GO TO 257
  256 SMD(I,J)=0.0
  257 IF(E(I,J)-GEF3)258,258,259
  258 ATM(I,J)=0.0
      GO TO 2600
  259 ATM(I,J)=E(I,J)-GEF3
 2600 CONTINUE
```

TABLE XLIII (Continued)

```
                                  80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
  260 CONTINUE
      DO 261 J=1,5
      DO 261 I=76,96
      YR1M(I,J)=GRFPM*SMD(I,J)
      R1M(J)=R1M(J)+YR1M(I,J)
      YR1A(I,J)=GRFPA*ATM(I,J)
      R1A(J)=R1A(J)+YR1A(I,J)
  261 CONTINUE
      DO 262 J=1,5
      DO 262 I=97,124
      YR2M(I,J)=GRFBM*SMD(I,J)
      R2M(J)=R2M(J)+YR2M(I,J)
      YR2A(I,J)=GRFBA*ATM(I,J)
      R2A(J)=R2A(J)+YR2A(I,J)
  262 CONTINUE
      DO 263 J=1,5
      DO 263 I=125,145
      YR3M(I,J)=GRFGM*SMD(I,J)
      R3M(J)=R3M(J)+YR3M(I,J)
      YR3A(I,J)=GRFGA*ATM(I,J)
      R3A(J)=R3A(J)+YR3A(I,J)
  263 CONTINUE
      DO 264 J=1,4
      IF(AC(J).EQ.0.0)GO TO 264
      TRM(J)=R1M(J)+R2M(J)+R3M(J)
      TRA(J)=R1A(J)+R2A(J)+R3A(J)
      TR(J)=TRM(J)+TRA(J)
      IF(TW1(J)-0.0)2630,2630,2631
 2630 YLD(J)=120.0-TR(J)
      GO TO 264
 2631 YLD(J)=145.0-TR(J)
  264 CONTINUE
      TRM(5)=R1M(5)+R2M(5)+R3M(5)
      TRA(5)=R1A(5)+R2A(5)+R3A(5)
      TR(5)=TRM(5)+TRA(5)
      YLD(5)=100.0-TR(5)
      DO 2641 I=15,56
      IF(SMU(I,5)-2.21)2640,2642,2642
 2640 IF(R(I,5)-.68)2641,2642,2642
 2641 CONTINUE
      YLD(5)=0.0
C************************************************************************
C     COMPUTE WHEAT YIELD REDUCTIONS AND FINAL YIELD
C************************************************************************
 2642 DO 272 J=6,8
      IF(AC(J).EQ.0.0)GO TO 272
      DO 2720 I=2,45
      IF(SMT(I,J)-13.8)265,268,268
  265 IF(SMT(I,J)-8.69)266,266,267
  266 SMD(I,J)=1.0
      GO TO 269
  267 SMD(I,J)=(13.8-SMT(I,J))/5.11
      GO TO 269
  268 SMD(I,J)=0.0
```

```
                                  80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
  269 IF(E(I,J)-.25)270,270,271
  270 ATM(I,J)=0.0
      GO TO 2720
  271 ATM(I,J)=E(I,J)-.25
 2720 CONTINUE
  272 CONTINUE
      DO 273 J=6,8
      DO 273 I=2,16
      YR1M(I,J)=WRFPM*SMD(I,J)
      R1M(J)=R1M(J)+YR1M(I,J)
      YR1A(I,J)=WRFPA*ATM(I,J)
      R1A(J)=R1A(J)+YR1A(I,J)
  273 CONTINUE
      DO 274 J=6,8
      DO 274 I=17,29
      YR2M(I,J)=WRFBM*SMD(I,J)
      R2M(J)=R2M(J)+YR2M(I,J)
      YR2A(I,J)=WRFBA*ATM(I,J)
      R2A(J)=R2A(J)+YR2A(I,J)
  274 CONTINUE
      DO 275 J=6,8
      DO 275 I=30,37
      YR3M(I,J)=WRFFM*SMD(I,J)
      R3M(J)=R3M(J)+YR3M(I,J)
      YR3A(I,J)=WRFFA*ATM(I,J)
      R3A(J)=R3A(J)+YR3A(I,J)
  275 CONTINUE
      DO 276 J=6,8
      DO 276 I=38,44
      YR4M(I,J)=WRFMM*SMD(I,J)
      R4M(J)=R4M(J)+YR4M(I,J)
      YR4A(I,J)=WRFMA*ATM(I,J)
      R4A(J)=R4A(J)+YR4A(I,J)
  276 CONTINUE
      DO 277 J=6,7
      IF(AC(J).EQ.0.0)GO TO 277
      TRM(J)=R1M(J)+R2M(J)+R3M(J)+R4M(J)
      TRA(J)=R1A(J)+R2A(J)+R3A(J)+R4A(J)
      TR(J)=TRM(J)+TRA(J)
      IF(TW5(J)-0.0)2760,2760,2761
 2760 YLD(J)=60.0-TR(J)
      GO TO 277
 2761 YLD(J)=75.0-TR(J)
  277 CONTINUE
      TRM(8)=R1M(8)+R2M(8)+R3M(8)+R4M(8)
      TRA(8)=R1A(8)+R2A(8)+R3A(8)+R4A(8)
      TR(8)=TRM(8)+TRA(8)
      YLD(8)=55.0-TR(8)
      DO 2771 I=124,184
      IF(SMU(I,8)-2.21)2770,2772,2772
 2770 IF(R(I,8)-.68)2771,2772,2772
 2771 CONTINUE
      YLD(8)=0.0
C***********************************************************************
```

TABLE XLIII (Continued)

```
                                   80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
C     COMPUTE IRRIGATED CORN YIELD REDUCTIONS AND FINAL YIELD
C***********************************************************************
 2772 DO 285 J=9,10
      IF(AC(J).EQ.0.0)GO TO 285
      DO 2850 I=7,116
      IF(SMT(I,J)-13.8)278,281,281
  278 IF(SMT(I,J)-8.69)279,279,280
  279 SMD(I,J)=1.0
      GO TO 282
  280 SMD(I,J)=(13.8-SMT(I,J))/5.11
      GO TO 282
  281 SMD(I,J)=0.0
  282 IF(E(I,J)-CEF3)283,283,284
  283 ATM(1,J)=0.0
      GO TO 2850
  284 ATM(I,J)=E(I,J)-CEF3
 2850 CONTINUE
  285 CONTINUE
      DO 286 J=9,10
      DO 286 I=7,36
      YR1M(I,J)=CRV1M*SMD(I,J)
      R1M(J)=R1M(J)+YR1M(I,J)
      YR1A(I,J)=CRV1A*ATM(I,J)
      R1A(J)=R1A(J)+YR1A(I,J)
  286 CONTINUE
      DO 287 J=9,10
      DO 287 I=37,63
      YR2M(I,J)=CRV2M*SMD(I,J)
      R2M(J)=R2M(J)+YR2M(I,J)
      YR2A(I,J)=CRV2A*ATM(I,J)
      R2A(J)=R2A(J)+YR2A(I,J)
  287 CONTINUE
      DO 288 J=9,10
      DO 288 I=64,79
      YR3M(I,J)=CRFSM*SMD(I,J)
      R3M(J)=R3M(J)+YR3M(I,J)
      YR3A(I,J)=CRFSA*ATM(I,J)
      R3A(J)=R3A(J)+YR3A(I,J)
  288 CONTINUE
      DO 289 J=9,10
      DO 289 I=80,101
      YR4M(I,J)=CRFMM*SMD(I,J)
      R4M(J)=R4M(J)+YR4M(I,J)
      YR4A(I,J)=CRFMA*ATM(I,J)
      R4A(J)=R4A(J)+YR4A(I,J)
  289 CONTINUE
      DO 290 J=9,10
      DO 290 I=102,116
      YR5M(I,J)=CRFDM*SMD(I,J)
      R5M(J)=R5M(J)+YR5M(I,J)
      YR5A(I,J)=CRFDA*ATM(I,J)
      R5A(J)=R5A(J)+YR5A(I,J)
  290 CONTINUE
      DO 291 J=9,10
```

```
                                   80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      IF(AC(J).EQ.0.0)GO TO 291
      TRM(J)=R1M(J)+R2M(J)+R3M(J)+R4M(J)+R5M(J)
      TRA(J)=R1A(J)+R2A(J)+R3A(J)+R4A(J)+R5A(J)
      TR(J)=TRM(J)+TRA(J)
      YLD(J)=150.0-TR(J)
  291 CONTINUE
C***********************************************************************
C     COMPUTE CORN SILAGE AND SMALL GRAIN PASTURE YIELDS
C***********************************************************************
      CS1=CSYP*YLD(9)
      CS2=CSYP*YLD(10)
      SGPY1=(.12857*YLD(8))*.33333
      SGPY2=(.12857*YLD(8))*.66667
C***********************************************************************
C     IRRIGATION WATER APPLICATIONS BY CROPS AND TOTAL PUMPING FOR THE
C     CROP YEAR IN ACRE INCHES AND ACRE FEET
C***********************************************************************
      TP=0.0
      TAP=0.0
      GTWA=0.0
      GTW1=0.0
      GTW2=0.0
      GTW3=0.0
      GTW4=0.0
      GTW5=0.0
      GTPA=0.0
      GTP1=0.0
      GTP2=0.0
      GTP3=0.0
      GTP4=0.0
      GTP5=0.0
      YGTPA=0.0
      YGTP1=0.0
      YGTP2=0.0
      YGTP3=0.0
      YGTP4=0.0
      YGTP5=0.0
      FGTP=0.0
      AFW=0.0
      DECL=0.0
      CCCS1=0.0
      CCCS2=0.0
      DO 292 J=1,10
      GTWA=GTWA+TWCA(J)
      GTW1=GTW1+TW1(J)
      GTW2=GTW2+TW2(J)
      GTW3=GTW3+TW3(J)
      GTW4=GTW4+TW4(J)
      GTW5=GTW5+TW5(J)
      TPA(J)=TWCA(J)*1.5
      TP1(J)=TW1(J)*1.5
      TP2(J)=TW2(J)*1.5
      TP3(J)=TW3(J)*1.5
      TP4(J)=TW4(J)*1.5
```

TABLE XLIII (Continued)

```
                              80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      TP5(J)=TW5(J)*1.5
      GTPA=GTWA*1.5
      GTP1=GTW1*1.5
      GTP2=GTW2*1.5
      GTP3=GTW3*1.5
      GTP4=GTW4*1.5
      GTP5=GTW5*1.5
      TW(J)=TW1(J)+TW2(J)+TW3(J)+TW4(J)+TW5(J)+TWCA(J)
      TWP(J)=TW(J)*1.5
      TP=TP+TW(J)
      YTPA(J)=TPA(J)*AC(J)
      YTP1(J)=TP1(J)*AC(J)
      YTP2(J)=TP2(J)*AC(J)
      YTP3(J)=TP3(J)*AC(J)
      YTP4(J)=TP4(J)*AC(J)
      YTP5(J)=TP5(J)*AC(J)
      YGTPA=YGTPA+YTPA(J)
      YGTP1=YGTP1+YTP1(J)
      YGTP2=YGTP2+YTP2(J)
      YGTP3=YGTP3+YTP3(J)
      YGTP4=YGTP4+YTP4(J)
      YGTP5=YGTP5+YTP5(J)
      YGTP(J)=YTPA(J)+YTP1(J)+YTP2(J)+YTP3(J)+YTP4(J)+YTP5(J)
      FGTP=FGTP+YGTP(J)
  292 CONTINUE
      TAP=TP*1.5
      AFW=FGTP/12.0
      DO 5997 J=1,4
      IF(AC(J).EQ.0.0)GO TO 5997
      IF(TWP(J).GT.0.0)GO TO 5997
      YLD(J)=YLD(5)
 5997 CONTINUE
      DO 5998 J=6,7
      IF(AC(J).EQ.0.0)GO TO 5998
      IF(TWP(J).GT.0.0)GO TO 5998
      YLD(J)=YLD(8)
 5998 CONTINUE
C***********************************************************************
C     COMPUTE DAYS OF ANNUAL USE, HOURS OF ANNUAL USE AND HOURS OF
C     IRRIGATION PUMPING PER ACRE BY CROPS
C***********************************************************************
      DAU=FGTP/AIPD
      HAU=DAU*24.0
      WELL=NWELL
      HAUPW=HAU
      DO 5999 J=1,10
      HIPA(J)=(TWP(J)/AIPD)*24.0
      HPPW(J)=HIPA(J)/WELL
 5999 CONTINUE
      HICS1=HIPA(9)
      HICS2=HIPA(10)
      HWCS1=HICS1/WELL
      HWCS2=HICS2/WELL
C***********************************************************************
```

```
                              80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
C     COMPUTE HOURS OF IRRIGATION LABOR REQUIRED PER ACRE BY CROP AND
C     PERIOD
C*********************************************************************
      TCLA=0.0
      TCLI=0.0
      TLA=0.0
      TL1=0.0
      TL2=0.0
      TL3=0.0
      TL4=0.0
      TL5=0.0
      TL=0.0
      DO 6000 J=1,10
      NIA(J)=(TPA(J)/4.5)
      NI1(J)=(TP1(J)/4.5)+.75
      NI2(J)=(TP2(J)/4.5)+.75
      NI3(J)=(TP3(J)/4.5)+.75
      NI4(J)=(TP4(J)/4.5)+.75
      NI5(J)=(TP5(J)/4.5)+.75
      NI(J)=(TWP(J)/4.5)+.75
      TNIA(J)=NIA(J)
      TNI1(J)=NI1(J)
      TNI2(J)=NI2(J)
      TNI3(J)=NI3(J)
      TNI4(J)=NI4(J)
      TNI5(J)=NI5(J)
      TNI(J)=NI(J)
 6000 CONTINUE
      DO 6001 J=1,10
      TNIA(J)=TNIA(J)*.75
      TNI1(J)=TNI1(J)*.75
      TNI2(J)=TNI2(J)*.75
      TNI3(J)=TNI3(J)*.75
      TNI4(J)=TNI4(J)*.75
      TNI5(J)=TNI5(J)*.75
      TNI(J)=TNI(J)*.75
 6001 CONTINUE
      DO 6002 J=1,10
      TLA=TLA+TNIA(J)
      TL1=TL1+TNI1(J)
      TL2=TL2+TNI2(J)
      TL3=TL3+TNI3(J)
      TL4=TL4+TNI4(J)
      TL5=TL5+TNI5(J)
      TL=TL+TNI(J)
 6002 CONTINUE
C***********************************************************************
C     COMPUTE COST OF IRRIGATION LABOR PER ACRE BY CROPS
C***********************************************************************
      DO 6003 J=1,10
      CLA(J)=TNI(J)*2.0
      TCLA=TCLA+CLA(J)
 6003 CONTINUE
C***********************************************************************
```

TABLE XLIII (Continued)

```
                                 80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
C     COMPUTE COS7 CF IRRIGATION LABOR PER ACRE INCH BY CROPS
C***********************************************************************
      DO 6004 J=1,10
      IF(TWP(J).EQ.0.0)GO TO 6004
      CLI(J)=CLA(J)/TWP(J)
      TCLI=TCLI+CLI(J)
 6004 CONTINUE
C***********************************************************************
C     COMPUTE VARIABLE PUMPING COSTS PER ACRE 8Y CROPS
C***********************************************************************
      IF(NWELL.GT.1)GO TO 6015
      IW1=(GPM/25.0)+.5
      VPC=VC1(IW1)
      GO TO 6017
 6015 IF(NWELL.GT.2)GO TO 6016
      IW1=(GPM1/25.0)+.5
      IW2=(GPM2/25.0)+.5
      VPC=VC1(IW1)+VC2(IW2)
      GO TO 6017
 6016 IF(NWELL.GT.3)GO TO 6017
      IW1=(GPM1/25.0)+.5
      IW2=(GPM2/25.0)+.5
      IW3=(GPM3/25.0)+.5
      VPC=VC1(IW1)+VC2(IW2)+VC3(IW3)
 6017 VPCAI=VPC/WELL
C***********************************************************************
C     COMPUTE ANNUAL IRRIGATION CAPITAL AND INTEREST CN ANNUAL CAPITAL
C     PER ACRE BY CRGPS
C***********************************************************************
      DO 6023 J=1,10
      IF(J.GT.5)GO TO 6020
      PYA=.5
      PY1=.41667
      PY2=.41667
      PY3=.25
      PY4=.08333
      PY5=.08333
      GO TO 6022
 6020 IF(J.GT.8)GO TO 6021
      PYA=.16667
      PY1=.08333
      PY2=.08333
      PY3=.08333
      PY4=.83333
      PY5=.75
      GO TO 6022
 6021 PYA=.41667
      PY1=.33333
      PY2=.33333
      PY3=.16667
      PY4=.08333
      PY5=.08333
 6022 ACA(J)=TPA(J)*VPCAI*PYA
      AC1(J)=TP1(J)*VPCAI*PY1
```

```
                                 80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      AC2(J)=TP2(J)*VPCAI*PY2
      AC3(J)=TP3(J)*VPCAI*PY3
      AC4(J)=TP4(J)*VPCAI*PY4
      AC5(J)=TP5(J)*VPCAI*PY5
      TAC(J)=ACA(J)+AC1(J)+AC2(J)+AC3(J)+AC4(J)+AC5(J)
      TACI(J)=TAC(J)*.08
 6023 CONTINUE
C***********************************************************************
C     COMPUTE CASH COSTS PER ACRE
C***********************************************************************
      DO 6007 J=1,5
      IF(AC(J).EQ.0.0)GO TO 6007
      IF(TWP(J).GT.0.0)GO TO 6005
      CC(J)=7.51+(.11*YLD(J))+CLA(J)+TACI(J)
      CEI(J)=CC(J)+GFC1
      GO TO 6007
 6005 IF(TWP(J).GT.13.0)GO TO 6006
      CC(J)=23.20+(.11*YLD(J))+CLA(J)+(VPCAI*TWP(J))+TAC1(J)
      CEI(J)=CC(J)+GFC2
      GO TO 6007
 6006 CC(J)=29.81+(.11*YLD(J))+CLA(J)+(VPCAI*TWP(J))+TACI(J)
      CEI(J)=CC(J)+GFC3
 6007 CONTINUE
      DO 6010 J=6,8
      IF(AC(J).EQ.0.0)GO TO 6010
      IF(TWP(J).GT.0.0)GO TO 6008
      CC(J)= 9.68+(.05*YLO(J))+CLA(J)+TACI(J)
      CEI(J)=CC(J)+WFC1
      GO TO 6010
 6008 IF(TWP(J).GT.13.0)GO TO 6009
      CC(J)=16.13+(.08*YLD(J))+CLA(J)+(VPCAI*TWP(J))+TACI(J)
      CEI(J)=CC(J)+WFC2
      GO TO 6010
 6009 CC(J)=18.79+(.08*YLD(J))+CLA(J)+(VPCAI*TWP(J))+TACI(J)
      CEI(J)=CC(J)+WFC3
 6010 CONTINUE
      DO 6011 J=9,10
      IF(AC(J).EQ.0.0)GO TO 6011
      CC(J)=50.89+(.17*YLD(J))+CLA(J)+(VPCAI*TWP(J))+TACI(J)
      CEI(J)=CC(J)+CFC1
 6011 CONTINUE
      IF(AC(9).EQ.0.0)GO TO 6012
      CCCS1=50.05+CLA(9)+(VPCAI*TWP(9))+TACI(9)
      CEICS1=CCCS1+CFC2
 6012 IF(AC(10).EQ.0.0)GO TO 6013
      CCCS2=50.05+CLA(10)+(VPCAI*TWP(10))+TACI(10)
      CEICS2=CCCS2+CFC2
 6013 CCSGP1=2.40
      CCSGP2=4.81
      CCSGP=CCSGP1+CCSGP2
      CEIP1=CCSGP1+PFC1
      CEIP2=CCSGP2+PFC2
      CEIP=CEIP1+CEIP2
      DO 6091 J=1,10
```

TABLE XLIII (Continued)

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      IF(TAX(J)-0.0)6091,6091,6090
 6090 CC(J)=CC(J)+((TWP(J)-TAX(J))*.50)
 6091 CONTINUE
      IF(TAX(9)-0.0)6093,6093,6092
 6092 CCCS1=CCCS1+((TWP(9)-TAX(9))*.50)
 6093 IF(TAX(10)-0.0)6095,6095,6094
 6094 CCCS2=CCCS2+((TWP(10)-TAX(10))*.50)
 6095 CONTINUE
C***********************************************************************
C     COMPUTE TOTAL LABOR REQUIREMENTS BY PERIOD AND CROP
C***********************************************************************
      DO 6027 J=1,5
      IF(AC(J).EQ.0.0)GO TO 6027
      IF(TWP(J).GT.0.0)GO TO 6025
      GTL1(J)=GNIL1(1)
      GTL2(J)=GNIL1(2)
      GTL3(J)=GNIL1(3)
      GTL4(J)=GNIL1(4)
      GTL5(J)=GNIL1(5)
      GTL6(J)=GNIL1(6)
      GTL7(J)=GNIL1(7)
      GTL8(J)=GNIL1(8)
      GO TO 6027
 6025 IF(TWP(J).GT.13.0)GO TO 6026
      GTL1(J)=GNIL2(1)
      GTL2(J)=TNIA(J)+GNIL2(2)
      GTL3(J)=TNI1(J)+GNIL2(3)
      GTL4(J)=TNI2(J)+GNIL2(4)
      GTL5(J)=TNI3(J)+GNIL2(5)
      GTL6(J)=TNI4(J)+GNIL2(6)
      GTL7(J)=TNI5(J)+GNIL2(7)
      GTL8(J)=GNIL2(8)
      GO TO 6027
 6026 GTL1(J)=GNIL3(1)
      GTL2(J)=TNIA(J)+GNIL3(2)
      GTL3(J)=TNI1(J)+GNIL3(3)
      GTL4(J)=TNI2(J)+GNIL3(4)
      GTL5(J)=TNI3(J)+GNIL3(5)
      GTL6(J)=TNI4(J)+GNIL3(6)
      GTL7(J)=TNI5(J)+GNIL3(7)
      GTL8(J)=GNIL3(8)
 6027 CONTINUE
      DO 6030 J=6,8
      IF(AC(J).EQ.0.0)GO TO 6030
      IF(TWP(J).GT.0.0)GO TO 6028
      GTL1(J)=WNIL1(1)
      GTL2(J)=WNIL1(2)
      GTL3(J)=WNIL1(3)
      GTL4(J)=WNIL1(4)
      GTL5(J)=WNIL1(5)
      GTL6(J)=WNIL1(6)
      GTL7(J)=WNIL1(7)
      GTL8(J)=WNIL1(8)
      GO TO 6030
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
 6028 IF(TWP(J).GT.13.0)GO TO 6029
      GTL1(J)=WNIL2(1)
      GTL2(J)=TNIA(J)+WNIL2(2)
      GTL3(J)=TNI1(J)+WNIL2(3)
      GTL4(J)=TNI2(J)+WNIL2(4)
      GTL5(J)=TNI3(J)+WNIL2(5)
      GTL6(J)=TNI4(J)+WNIL2(6)
      GTL7(J)=TNI5(J)+WNIL2(7)
      GTL8(J)=WNIL2(8)
      GO TO 6030
 6029 GTL1(J)=WNIL3(1)
      GTL2(J)=TNIA(J)+WNIL3(2)
      GTL3(J)=TNI1(J)+WNIL3(3)
      GTL4(J)=TNI2(J)+WNIL3(4)
      GTL5(J)=TNI3(J)+WNIL3(5)
      GTL6(J)=TNI4(J)+WNIL3(6)
      GTL7(J)=TNI5(J)+WNIL3(7)
      GTL8(J)=WNIL3(8)
 6030 CONTINUE
      DO 6031 J=9,10
      IF(AC(J).EQ.0.0)GO TO 6031
      GTL1(J)=CGNIL(1)
      GTL2(J)=TNIA(J)+CGNIL(2)
      GTL3(J)=TNI1(J)+CGNIL(3)
      GTL4(J)=TNI2(J)+CGNIL(4)
      GTL5(J)=TNI3(J)+CGNIL(5)
      GTL6(J)=TNI4(J)+CGNIL(6)
      GTL7(J)=TNI5(J)+CGNIL(7)
      GTL8(J)=CGNIL(8)
 6031 CONTINUE
C***********************************************************************
C     COMPUTE NET RETURNS PER ACRE ABOVE ALL COSTS EXCEPT OWNERSHIP
C     COSTS ON IRRIGATION EQUIPMENT.
C***********************************************************************
      DO 6038 J=1,4
      IF(YLD(J)-0.0)6036,6036,6037
 6036 TNRA(J)=0.0
      GO TO 6038
 6037 TNRA(J)=(YLD(J)*0.94)-CEI(J)
 6038 CONTINUE
      TNRA(5)=(YLD(5)*.94)-CEI(5)
      DO 6041 J=6,7
      IF(YLD(J)-0.0)6039,6039,6040
 6039 TNRA(J)=0.0
      GO TO 6041
 6040 TNRA(J)=(YLD(J)*1.29)-CEI(J)
 6041 CONTINUE
      TNRA(8)=(YLD(8)*1.29)-CEI(8)
      DO 6042 J=9,10
      TNRA(J)=(YLD(J)*1.11)-CEI(J)
 6042 CONTINUE
      TNRS1=(CS1*5.50)-CEICS1
      IF(YLD(9)-0.0)6043,6043,6044
 6043 TNRS1=0.0
```

TABLE XLIII (Continued)

```
                          80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
 6044 TNRS2=(CS2*5.50)-CEICS2
      IF(YLD(10)-0.0)6045,6045,6046
 6045 TNRS2=0.0
 6046 TNRAP1=(SGPY1*8.00)-CEIP1
      TNRAP2=(SGPY2*8.00)-CEIP2
      TNRAP=TNRAP1+TNRAP2
C***********************************************************************
C     COMPUTE MACHINE USE HOURS PER ACRE BY CROPS
C***********************************************************************
      DO 6082 I=1,12
      IF(TWP(1)-0.0) 6050,6050,6051
 6050 AMU(I,1)=HAMU(I,1)
      GO TO 6054
 6051 IF(TWP(1)-13.0) 6052,6052,6053
 6052 AMU(I,1)=HAMU(I,2)
      GO TO 6054
 6053 AMU(I,1)=HAMU(I,3)
 6054 IF(TWP(2)-0.0) 6055,6055,6056
 6055 AMU(I,2)=HAMU(I,1)
      GO TO 6059
 6056 IF(TWP(2)-13.0) 6057,6057,6058
 6057 AMU(I,2)=HAMU(I,2)
      GO TO 6059
 6058 AMU(I,2)=HAMU(I,3)
 6059 IF(TWP(3)-0.0) 6060,6060,6061
 6060 AMU(I,3)=HAMU(I,1)
      GO TO 6064
 6061 IF(TWP(3)-13.0) 6062,6062,6063
 6062 AMU(I,3)=HAMU(I,2)
      GO TO 6064
 6063 AMU(I,3)=HAMU(I,3)
 6064 IF(TWP(4)-0.0) 6065,6065,6066
 6065 AMU(I,4)=HAMU(I,1)
      GO TO 6069
 6066 IF(TWP(4)-13.0) 6067,6067,6068
 6067 AMU(I,4)=HAMU(I,2)
      GO TO 6069
 6068 AMU(I,4)=HAMU(I,3)
 6069 AMU(I,5)=HAMU(I,1)
      IF(TWP(6)-0.0) 6070,6070,6071
 6070 AMU(I,6)=HAMU(I,4)
      GO TO 6074
 6071 IF(TWP(6)-13.0) 6072,6072,6073
 6072 AMU(I,6)=HAMU(I,5)
      GO TO 6074
 6073 AMU(I,6)=HAMU(I,6)
 6074 IF(TWP(7)-0.0) 6075,6075,6076
 6075 AMU(I,7)=HAMU(I,4)
      GO TO 6079
 6076 IF(TWP(7)-13.0) 6077,6077,6078
 6077 AMU(I,7)=HAMU(I,5)
      GO TO 6079
 6078 AMU(I,7)=HAMU(I,6)
 6079 AMU(I,8)=HAMU(I,4)
```

```
                          80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      IF(TWP(9).EQ.0.0) GO TO 6080
      AMU(I,9)=HAMU(I,7)
      AMU(I,11)=HAMU(I,8)
 6080 IF(TWP(10).EQ.0.0) GO TO 6081
      AMU(I,10)=HAMU(I,7)
      AMU(I,12)=HAMU(I,8)
 6081 AMU(I,13)=HAMU(I,9)
 6082 CONTINUE
      DO 6084 J=1,10
      DO 6084 I=1,12
      IF(AC(J)-0.0)6083,6083,6084
 6083 AMU(I,J)=0.0
 6084 CONTINUE
      DO 6088 I=1,12
      IF(AC(9)-0.0)6085,6085,6086
 6085 AMU(I,11)=0.0
 6086 IF(AC(10)-0.0)6087,6087,6088
 6087 AMU(I,12)=0.0
 6088 CONTINUE
C***********************************************************************
C     COMPUTE VALUE OF GOVERMENT PAYMENTS PER ACRE
C***********************************************************************
      IF(K-1)5000,5000,5001
 5000 GYLD5=120.0
      GYLD4=115.0
      GYLD3=110.0
      GYLD2=105.0
      WYLD5=42.0
      WYLD4=38.0
      WYLD3=35.0
      WYLD2=32.0
      CYLD5=130.0
      CYLD4=126.0
      CYLD3=124.0
      CYLD2=122.0
      GO TO 5006
 5001 WYLD5=WYLD4
      WYLD4=WYLD3
      WYLD3=WYLD2
      WYLD2=WYLD1
      GYLD5=GYLD4
      GYLD4=GYLD3
      GYLD3=GYLD2
      GYLD2=GYLD1
      CYLD5=CYLD4
      CYLD4=CYLD3
      CYLD3=CYLD2
      CYLD2=CYLD1
 5006 SUMGY=0.0
      PGYLD1=0.0
      DO 5007 J=1,5
      SUMGY=SUMGY+AC(J)
      IF(SUMGY.EQ.0.0)GO TO 5007
      VYLD(J)=(AC(J)*YLD(J))/SUMGY
```

TABLE XLIII (Continued)

```
                                   80/80 LIST

       00000000011111111112222222222333333333344444444445555555555666666666677777777778
       12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
0271            PGYLD1=PGYLD1+VYLD(J)
0272            GYLD1=PGYLD1
0273       5007 CONTINUE
0274            SUMWY=0.0
0275            PWYLD1=0.0
0276            DO 5008 J=6,8
0277            SUMWY=SUMWY+AC(J)
0278            IF(SUMWY.EQ.0.0)GO TO 5008
0279            VYLD(J)=(AC(J)*YLD(J))/SUMWY
0280            PWYLD1=PWYLD1+VYLD(J)
0281            WYLD1=PWYLD1
0282       5008 CONTINUE
0283            SUMCY=0.0
0284            PCYLD1=0.0
0285            DO 5009 J=9,10
0286            SUMCY=SUMCY+AC(J)
0287            IF(SUMCY.EQ.0.0)GO TO 5009
0288            VYLD(J)=(AC(J)*YLD(J))/SUMCY
0289            PCYLD1=PCYLD1+VYLD(J)
0290            CYLD1=PCYLD1
0291       5009 CONTINUE
0292            GYLD=(GYLD1+GYLD2+GYLD3+GYLD4+GYLD5)/5.0
0293            WYLD=(WYLD1+WYLD2+WYLD3+WYLD4+WYLD5)/5.0
0294            CYLD=(CYLD1+CYLD2+CYLD3+CYLD4+CYLD5)/5.0
0295            DO 5012 J=1,5
0296            IF(SUMGY.EQ.0.0)GO TO 5012
0297            GPA(J)=(46.0*GYLD*.29)/SUMGY
0298       5012 CONTINUE
0299            DO 5013 J=6,8
0300            IF(SUMWY.EQ.0.0)GO TO 5013
0301            GPA(J)=(80.0*WYLD*1.61)/SUMWY
0302       5013 CONTINUE
0303            DO 5014 J=9,10
0304            IF(SUMCY.EQ.0.0)GO TO 5014
0305            GPA(J)=(14.0*CYLD*.32)/SUMCY
0306       5014 CONTINUE
0307            GPACS1=GPA(9)
0308            GPACS2=GPA(10)
0309   C***********************************************************************
0310   C        DECISION RULE FOR ADJUSTING PRODUCTION ORGANIZATION:
0311   C        IF OPPORTUNITY COST NET RETURNS PER ACRE ON DRYLAND WHEAT EXCEED
0312   C        IRRIGATED NET RETURNS PER ACRE ABOVE TOTAL VARIABLE COSTS, CONVERT
0313   C        THE BLOCK OF IRRIGATED CROP TO DRYLAND WHEAT.
0314   C***********************************************************************
0315            IF(NWELL-3)2930,5015,5015
0316       5015 IF(TNRA(1)-5.24)5016,5017,5017
0317       5016 KG1=1
0318       5017 IF(TNRA(2)-5.24)5018,5019,5019
0319       5018 KG2=1
0320       5019 IF(TNRA(3)-5.24)5020,5021,5021
0321       5020 KG3=1
0322       5021 IF(TNRA(4)-5.24)5022,5023,5023
0323       5022 KG4=1
0324       5023 IF(TNRA(6)-5.24)5024,5025,5025
```

```
                                   80/80 LIST

       00000000011111111112222222222333333333344444444445555555555666666666677777777778
       12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
0325       5024 KW1=1
0326       5025 IF(TNRA(7)-5.24)5026,5027,5027
0327       5026 KW2=1
0328       5027 IF(TNRA(9)-5.24)5028,5029,5029
0329       5028 KC1=1
0330       5029 IF(TNRA(10)-5.24)5030,2930,2930
0331       5030 KC2=1
0332       2930 DO 5050 J=1,12
0333            IROD=J
0334            IF(J.EQ.11)IROD=9
0335            IF(J.EQ.12)IROD=10
0336            T1(17,J)=GTL1(IROD)
0337            T1(18,J)=GTL2(IROD)
0338            T1(19,J)=GTL3(IROD)
0339            T1(20,J)=GTL4(IROD)
0340            T1(21,J)=GTL5(IROD)
0341            T1(22,J)=GTL6(IROD)
0342            T1(23,J)=GTL7(IROD)
0343       5050 CONTINUE
0344            DO 5051 J=1,10
0345            T1(24,J)=GTL8(J)
0346       5051 CONTINUE
0347            T1(24,11)=CSNIL(8)
0348            T1(24,12)=CSNIL(8)
0349            DO 5052 J=1,8
0350            IROD=J+16
0351            T1(IROD,13)=GONIL(J)
0352       5052 CONTINUE
0353            DO 5053 J=1,12
0354            IROD=J
0355            IF(J.EQ.11)IROD=9
0356            IF(J.EQ.12)IROD=10
0357            T1(25,J)=TPA(IROD)
0358            T1(26,J)=TP1(IROD)
0359            T1(27,J)=TP2(IROD)
0360            T1(28,J)=TP3(IROD)
0361            T1(29,J)=TP4(IROD)
0362            T1(30,J)=TP5(IROD)
0363       5053 CONTINUE
0364            DO 5054 J=1,10
0365            T1(31,J)=CC(J)
0366       5054 CONTINUE
0367            T1(31,11)=CCCS1
0368            T1(31,12)=CCCS2
0369            T1(31,13)=CCSGP
0370            DO 5055 I=33,44
0371            DO 5055 J=1,10
0372            T1(1,J)=HPPW(J)
0373       5055 CONTINUE
0374            DO 5056 J=33,44
0375            T1(J,11)=HWCS1
0376            T1(J,12)=HWCS2
0377       5056 CONTINUE
0378            DO 5057 J=1,10
```

TABLE XLIII (Continued)

80/80 LIST

```
000000000111111111122222222223333333333444444444455555555556666666666777777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890C

      TY2(J)=YLD(J)
 5057 CONTINUE
      TY2(11)=CS1
      TY2(12)=CS2
      TY2(13)=SGPY1
C***********************************************************************
C     COMPUTE DECLINE IN THE STATIC WATER LEVEL AND REMAINING SATURATED
C     THICKNESS FOR THE COMING YEAR
C***********************************************************************
      IF(RGPM-1.0)293,293,294
  293 DECL=(AFW/(ACRES*.20))
      RSAT=BSAT-DECL
      GO TO 699
  294 IF(RGPM-2.0)295,295,297
  295 IF(K.EQ.1)GO TO 296
      BSAT=RSAT
  296 DECL=(AFW/(ACRES*.20))
      RSAT=BSAT-DECL
      GO TO 699
C***********************************************************************
C     DECISION RULE FOR DRILLING AN ADDITIONAL IRRIGATION WELL :
C     IF THE CAPACITY OF THE CURRENT SYSTEM FALLS BELOW 750 GPM, AN
C     ADDITIONAL WELL IS SUNK.
C***********************************************************************
  297 IF(RGPM-3.0)298,298,699
  298 IF(K.EQ.1)GO TC 299
      BSAT=RSAT
  299 DECL=(AFW/(ACRES*.20))
      RSAT=BSAT-DECL
      IF(GPM.GE.750.0) GO TO 699
      IF(NWELL.EQ.3)GO TO 699
      KOUNT=KOUNT+1
C***********************************************************************
C     SUBROUTINE OUTPUT PRINTS THE RESULTS OF THE SIMULATION RUN AND
C     PUNCHES CARD INPUT DATA FOR THE FARM FIRM SIMULATION MODEL
C***********************************************************************
  699 CALL OUTPUT
 1000 CONTINUE
      STOP
      END
```

80/80 LIST

```
000000000111111111122222222223333333333444444444455555555556666666666777777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

      SUBROUTINE RAIN
      COMMON/RF/RAP1(1000),RAP2(1000),RM1(1000),RM2(1000),RJU1(1000),RJU
     12(1000),RJL1(1000),RJL2(1000),RA1(1000),RA2(1000),RS1(1000),RS2(10
     100),RO1(1000),RO2(1000),IX1,IX2,UD(215),N(215),RN(215),EP(185),D(1
     185),KNT1,KNT2,IY
C***********************************************************************
C     GENERATE DAILY RAINFALL
C***********************************************************************
      KNT1=KNT1+1
      IF(KNT1.GT.1)GO TO 17
      IX=IX1
      GO TO 18
   17 IX=IY
   18 DO 19 I=1,214
      CALL RANDU (IX,1Y,UDEV)
      UD(I)=UDEV
      IX=IY
      N(1)=UD(I)*1000
   19 CONTINUE
      OO 23 I=1,15
      IF(N(I)-0)20,20,21
   20 J=1
      GO TO 22
   21 J=N(I)
   22 RN(I)=RM1(J)
   23 CONTINUE
      DO 27  I=16,31
      IF(N(I)-0)24,24,25
   24 J=1
      GO TO 26
   25 J=N(I)
   26 RN(I)=RM2(J)
   27 CONTINUE
      DO 31 I=32,46
      IF (N(I)-0)28,28,29
   28 J=1
      GO TO 30
   29 J=N(I)
   30 RN(I)=RJU1(J)
   31 CONTINUE
      OO 35  I=47,61
      IF (N(I)-0)32,32,33
   32 J=1
      GO TO 34
   33 J=N(I)
   34 RN(I)=RJU2(J)
   35 CONTINUE
      DO 39  I=62,76
      IF(N(I)-0)36,36,37
   36 J=1
      GO TO 38
   37 J=N(I)
   38 RN(I)=RJL1(J)
   39 CONTINUE
```

TABLE XLIII (Continued)

```
                                  80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

      DO 43  I=77,92
      IF (N(I)-0)40,40,41
   40 J=1
      GO TO 42
   41 J=N(I)
   42 RN(1)=RJL2(J)
   43 CONTINUE
      DO 47  I=93,107
      IF(N(I)-0)44,44,45
   44 J=1
      GO TO 46
   45 J=N(I)
   46 RN(I)=RA1(J)
   47 CONTINUE
      DO 51  I=108,123
      IF(N(1)-0)48,48,49
   48 J=1
      GO TO 50
   49 J=N(I)
   50 RN(I)=RA2(J)
   51 CONTINUE
      DO 55  I=124,138
      IF(N(I)-0)52,52,53
   52 J=1
      GO TO 54
   53 J=N(I)
   54 RN(I)=RS1(J)
   55 CONTINUE
      DO 59  I=139,153
      IF(N(I)-0)56,56,57
   56 J=1
      GO TO 58
   57 J=N(I)
   58 RN(I)=RS2(J)
   59 CONTINUE
      DO 63  I=154,168
      IF(N(I)-0)60,60,61
   60 J=1
      GO TO 62
   61 J=N(I)
   62 RN(I)=RO1(J)
   63 CONTINUE
      DO 67  I=169,184
      IF(N(I)-0)64,64,65
   64 J=1
      GO TO 66
   65 J=N(I)
   66 RN(I)=RO2(J)
   67 CONTINUE
      DO 71  I=185,199
      IF(N(I)-0)68,68,69
   68 J=1
      GO TO 70
   69 J=N(I)
```

```
                                  80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

   70 RN(I)=RAP1(J)
   71 CONTINUE
      DO 75  I=200,214
      IF(N(I)-0)72,72,73
   72 J=1
      GO TO 74
   73 J=N(I)
   74 RN(I)=RAP2(J)
   75 CONTINUE
C***********************************************************************
C     GENERATE LOGNORMALLY DISTRIBUTED PAN EVAPORATION
C***********************************************************************
      EX=2.718282
      KNT2=KNT2+1
      IF(KNT2.GT.1)GO TO 76
      IX=IX2
      GO TO 77
   76 IX=IY
   77 DO 78 I=1,184
      CALL GAUSS (IX,1.0,0.0,DEV)
      D(I)=DEV
   78 CONTINUE
      DO 79  I=1,15
      EP(I)=EX**(-1.11687+.55696*D(I))
   79 CONTINUE
      DO 80 I=16,31
      EP(I)=EX**(-1.21614+.66913*D(I))
   80 CONTINUE
      DO 81  I=32,46
      EP(I)=EX**(-1.02709+.55769*D(I))
   81 CONTINUE
      DO 82  I=47,61
      EP(I)=EX**(-.83398+.47902*D(I))
   82 CONTINUE
      DO 83  I=62,76
      EP(I)=EX**(-.95027+.70695*D(I))
   83 CONTINUE
      DO 84  I=77,92
      EP(I)=EX**(-.89505+.60121*D(I))
   84 CONTINUE
      DO 85  I=93,107
      EP(I)=EX**(-1.22882+.50944*D(I))
   85 CONTINUE
      DO 86  I=108,123
      EP(I)=EX**(-1.10846+.55459*D(I))
   86 CONTINUE
      DO 87 I=124,138
      EP(I)=EX**(-1.27964+.63444*D(I))
   87 CONTINUE
      DO 88  I=139,153
      EP(I)=EX**(-1.43233+.59825*D(I))
   88 CONTINUE
      DO 89  I=154,168
      EP(I)=EX**(-1.33889+.61468*D(I))
```

TABLE XLIII (Continued)

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
   89 CONTINUE
      DO 90  I=169,184
      EP(I)=EX**(-1.71473+.58168*D(I))
   90 CONTINUE
      RETURN
      END
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      SUBROUTINE SMBAL
C***************************************************************************
C     COMPUTE DAILY SOIL MOISTURE THROUGHOUT THE GROWING SEASON
C***************************************************************************
      COMMON SMT(185,10),SMU(185,10),SML(185,10),R(185,10),E(185,10),I,J
     1,AE(185,10),CM(185,10),C(185,10)
  200 IF(SMU(I,J)-1.53)201,201,224
  201 IF(SML(I,J)-7.16)202,202,207
  202 AE(I,J)=E(I,J)*(SML(I,J)/13.44)
      CM(I,J)=R(I,J)-AE(I,J)
      IF(CM(I,J)-0.0)203,203,204
  203 AE(I,J)=0.0
      CM(I,J)=0.0
      SMU(I+1,J)=1.53
      SML(1+1,J)=7.16
      SMT(I+1,J)=8.69
      GO TO 251
  204 SMU(I+1,J)=SMU(I,J)+CM(I,J)
      IF(SMU(1+1,J)-2.88)205,205,206
  205 SML(I+1,J)=SML(I,J)
      SMT(I+1,J)=SMU(I+1,J)+SML(I+1,J)
      GO TO 251
  206 C(I,J)=SMU(I+1,J)-2.88
      SMU(I+1,J)=2.88-.05*SMU(I,J)
      SML(I+1,J)=SML(I,J)+C(I,J)+.05*SMU(I,J)
      SMT(I+1,J)=SML(I+1,J)+SMU(I+1,J)
      GO TO 251
  207 IF(13.44-SML(I,J))208,213,213
  208 SML(I,J)=13.44
      AE(I,J)=E(I,J)
      CM(I,J)=R(I,J)-AE(I,J)
      IF(CM(I,J)-0.0)209,209,210
  209 SMU(I+1,J)=1.53
      SML(I+1,J)=SML(I,J)+CM(I,J)
      SMT(I+1,J)=SML(I+1,J)+SMU(I+1,J)
      GO TO 251
  210 SMU(I+1,J)=SMU(I,J)+CM(I,J)
      SML(I+1,J)=SML(I,J)
      IF(2.88-SMU(I+1,J))211,212,212
  211 SMU(I+1,J)=2.88
  212 SMT(I+1,J)=SMU(I+1,J)+SML(I+1,J)
      GO TO 251
  213 AE(I,J)=E(I,J)*(SML(I,J)/13.44)
      CM(I,J)=R(I,J)-AE(I,J)
      IF(CM(I,J)-0.0)214,214,217
  214 SMU(1+1,J)=1.53
      SML(I+1,J)=SML(I,J)+CM(I,J)
      IF(SML(I+1,J)-7.16)215,216,216
  215 SML(I+I,J)=7.16
  216 SMT(I+1,J)=SMU(1+1,J)+SML(I+1,J)
      GO TO 251
  217 SMU(I+1,J)=SMU(I,J)+CM(1,J)
      IF(2.88-SMU(I+1,J))218,221,221
  218 C(I,J)=SMU(I+1,J)-2.88
```

TABLE XLIII (Continued)

```
                                   80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      SMU(I+1,J)=2.88-.05*SMU(I,J)
      SML(I+1,J)=SML(I,J)+C(I,J)+.05*SMU(I,J)
      IF(13.44-SML(I+1,J))219,220,220
  219 SML(I+1,J)=13.44
      SMU(I+1,J)=2.88
  220 SMT(I+1,J)=SMU(I+1,J)+SML(I+1,J)
      GO TO 251
  221 SMU(I+1,J)=SMU(I+1,J)-.05*SMU(I,J)
      SML(I+1,J)=SML(I,J)+.05*SMU(I,J)
      IF(SMU(I+1,J)-1.53)222,223,223
  222 SMU(I+1,J)=1.53
      SML(I+1,J)=SML(I,J)
  223 SMT(I+1,J)=SML(I+1,J)+SMU(I+1,J)
      GO TO 251
  224 IF(2.88-SMU(I,J))225,225,234
  225 C(I,J)=SMU(I,J)-2.88
      SML(I,J)=SML(I,J)+C(I,J)
      SMU(I,J)=2.88
      IF(13.44-SML(I,J))226,226,229
  226 SML(I,J)=13.44
      AE(I,J)=E(I,J)
      CM(I,J)=R(1,J)-AE(I,J)
      IF(CM(I,J)-0.0)227,227,228
  227 SMU(I+1,J)=SMU(I,J)+CM(I,J)
      SML(I+1,J)=SML(I,J)
      SMT(I+1,J)=SMU(I+1,J)+SML(I+1,J)
      GO TO 251
  228 SMU(I+1,J)=SMU(I,J)
      SML(I+1,J)=SML(I,J)
      SMT(I+1,J)=SML(I+1,J)+SMU(I+1,J)
      GO TO 251
  229 AE(I,J)=E(I,J)
      CM(I,J)=R(I,J)-AE(I,J)
      IF(CM(I,J)-0.0)230,230,231
  230 SMU(I+1,J)=SMU(I,J)+CM(I,J)-.05*SMU(I,J)
      SML(I+1,J)=SML(1,J)+.05*SMU(I,J)
      SMT(I+1,J)=SMU(I+1,J)+SML(I+1,J)
      GO TO 251
  231 SML(I+1,J)=SML(I,J)+CM(I,J)
      IF(13.44-SML(I+1,J))232,232,233
  232 SML(1+1,J)=13.44
      SMT(I+1,J)=SMU(I+1,J)+SML(I+1,J)
      GO TO 251
  233 SMU(I+1,J)=SMU(I,J)-.05*SMU(I,J)
      SML(I+1,J)=SML(I,J)+.05*SMU(I,J)
      SMT(I+1,J)=SML(I+1,J)+SMU(I+1,J)
      GO TO 251
  234 IF(13.44-SML(I,J))235,235,242
  235 SML(I,J)=13.44
      AE(I,J)=E(I,J)*(SMU(1,J)/2.88)
      CM(I,J)=R(I,J)-AE(I,J)
      IF(CM(I,J)-0.0)236,239,239
  236 SMU(I+1,J)=SMU(1,J)+CM(I,J)
      IF(SMU(I+1,J)-1.53)237,238,238
```

```
                                   80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
  237 SMU(I+1,J)=1.53
  238 SML(I+1,J)=SML(I,J)
      SMT(I+1,J)=SMU(1+1,J)+SML(I+1,J)
      GO TO 251
  239 SMU(I+1,J)=SMU(I,J)+CM(I,J)
      IF(2.88-SMU(I+1,J))240,241,241
  240 SMU(1+1,J)=2.88
  241 SML(I+1,J)=SML(I,J)
      SMT(1+1,J)=SML(I+1,J)+SMU(I+1,J)
      GO TO 251
  242 AE(I,J)=E(I,J)*(SMU(I,J)/2.88)
      CM(I,J)=R(I,J)-AE(I,J)
      SMU(I+1,J)=SMU(I,J)+CM(I,J)-.05*SMU(I,J)
      IF(SMU(I+1,J)-1.53)243,246,246
  243 C(I,J)=1.53-SMU(I+1,J)
      SMU(I+1,J)=1.53
      SML(I+1,J)=SML(1,J)-C(I,J)+.05*SMU(I,J)
      IF(SML(I+1,J)-7.16)244,245,245
  244 SML(I+1,J)=7.16
  245 SMT(I+1,J)=SMU(I+1,J)+SML(I+1,J)
      GO TO 251
  246 IF(2.88-SMU(I+1,J))247,250,250
  247 C(I,J)=SMU(I+1,J)-2.88
      SMU(I+1,J)=2.88-.05*SMU(I,J)
      SML(I+1,J)=SML(I,J)+C(I,J)+.05*SMU(1,J)
      IF(13.44-SML(I+1,J))248,249,249
  248 SMU(I+1,J)=2.88
      SML(I+1,J)=13.44
  249 SMT(I+1,J)=SML(I+1,J)+SMU(I+1,J)
      GO TO 251
  250 SML(I+1,J)=SML(I,J)+.05*SMU(I,J)
      SMT(I+1,J)=SML(I+1,J)+SMU(I+1,J)
  251 CONTINUE
      RETURN
      END
```

TABLE XLIII (Continued)

```
80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

      SUBROUTINE OUTPUT
C***********************************************************************
C     WRITE RESULTS OF PRODUCTION SUBSET
C***********************************************************************
      COMMON/OUTPT/K,YGTPA,YGTP1,YGTP2,YGTP3,YGTP4,YGTP5,FGTP,CCCS1,CCCS
     12,CCSGP,HWCS1,HWCS2,CS1,CS2,SGPY1,SGPY2,GPACS1,GPACS2,TNRS1,TNRS2,
     1TNRAP,BIPCA,BIPC1,BIPC2,BIPC3,BIPC4,BIPC5,BIPD,AIPCA,AIPC1,AIPC2,A
     1IPC3,AIPC4,AIPC5,AIPD,AFW,BSAT,OECL,RSAT,GPM,NWELL,DAU,HAU,HAUPW,G
     1PM1,GPM2,GPM3,VPCAI,KMAP,AMU(12,13),GTL1(10),GONIL(8),GTL2(10),GTL
     13(10),GTL4(10),GTL5(10),GTL6(10),GTL7(10),GTL8(10),TPA(10),TP1(10)
     1,TP2(10),TP3(10),TP4(10),TP5(10),TWP(10),CC(10),HPPW(10),YLD(10),G
     1PA(10),TNRA(10),AC(10),R1M(10),R2M(10),R3M(10),R4M(10),R5M(10),R1A
     1(10),R2A(10),R3A(10),R4A(10),R5A(10),TR(10),T1(44,13),TY2(13),CSNI
     1L(8)
      IF(KMAP-1)7000,7121,7000
 7000 WRITE(6,700)K
  700 FORMAT(1H1,55X,'YEAR=',I2)
      WRITE(6,780)
  780 FORMAT(1H0,40X,'MACHINE HOURS BY CROP')
      WRITE(6,7504)
      WRITE(6,782)(AMU(1,J),J=1,13)
  782 FORMAT(1H0,3X,'T1',13F9.2)
      WRITE(6,784)(AMU(2,J),J=1,13)
  784 FORMAT(1H0,3X,'T2',13F9.2)
      WRITE(6,786)(AMU(3,J),J=1,13)
  786 FORMAT(1H0,3X,'OW',13F9.2)
      WRITE(6,788)(AMU(4,J),J=1,13)
  788 FORMAT(1H0,3X,'CH',13F9.2)
      WRITE(6,790)(AMU(5,J),J=1,13)
  790 FORMAT(1H0,3X,'OD',13F9.2)
      WRITE(6,792)(AMU(6,J),J=1,13)
  792 FORMAT(1H0,3X,'CB',13F9.2)
      WRITE(6,794)(AMU(7,J),J=1,13)
  794 FORMAT(1H0,3X,'CV',13F9.2)
      WRITE(6,796)(AMU(8,J),J=1,13)
  796 FORMAT(1H0,3X,'SW',13F9.2)
      WRITE(6,798)(AMU(9,J),J=1,13)
  798 FORMAT(1H0,3X,'OR',13F9.2)
      WRITE(6,800)(AMU(10,J),J=1,13)
  800 FORMAT(1H0,3X,'FL',13F9.2)
      WRITE(6,802)(AMU(11,J),J=1,13)
  802 FORMAT(1H0,3X,'SR',13F9.2)
      WRITE(6,804)(AMU(12,J),J=1,13)
  804 FORMAT(1H0,3X,'SH',13F9.2)
      WRITE(6,770)
  770 FORMAT(1H0,40X,'TOTAL HOURS OF LABOR REQUIRED PER ACRE')
      WRITE(6,7504)
      WRITE(6,772)(GTL1(J),J=1,10),GTL1(9),GTL1(10),GONIL(1)
  772 FORMAT(1H0,3X,'L1',13F9.2)
      WRITE(6,773)(GTL2(J),J=1,10),GTL2(9),GTL2(10),GONIL(2)
  773 FORMAT(1H0,3X,'L2',13F9.2)
      WRITE(6,774)(GTL3(J),J=1,10),GTL3(9),GTL3(10),GONIL(3)
  774 FORMAT(1H0,3X,'L3',13F9.2)
      WRITE(6,775)(GTL4(J),J=1,10),GTL4(9),GTL4(10),GONIL(4)
```

```
80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  775 FORMAT(1H0,3X,'L4',13F9.2)
      WRITE(6,776)(GTL5(J),J=1,10),GTL5(9),GTL5(10),GONIL(5)
  776 FORMAT(1H0,3X,'L5',13F9.2)
      WRITE(6,777)(GTL6(J),J=1,10),GTL6(9),GTL6(10),GONIL(6)
  777 FORMAT(1H0,3X,'L6',13F9.2)
      WRITE(6,778)(GTL7(J),J=1,10),GTL7(9),GTL7(10),GONIL(7)
  778 FORMAT(1H0,3X,'L7',13F9.2)
      WRITE(6,779)(GTL8(J),J=1,10),CSNIL(8),CSNIL(8),GONIL(8)
  779 FORMAT(1H0,3X,'L8',13F9.2)
      WRITE(6,721)
  721 FORMAT(1H0,40X,'WATER PUMPED FOR EACH CROP BY PERIODS')
      WRITE(6,75040)
75040 FORMAT(1H0,11X,'G1',7X,'G2',7X,'G3',7X,'G4',7X,'G5',7X,'W1',7X,'W2
     1',7X,'W3',7X,'C1',7X,'C2',6X,'CS1',6X,'CS2',4X,'TOTAL')
      WRITE(6,723)(TPA(J),J=1,10),TPA(9),TPA(10),YGTPA
  723 FORMAT(1H0,3X,'IA',13F9.2)
      WRITE(6,724)(TP1(J),J=1,10),TP1(9),TP1(10),YGTP1
  724 FORMAT(1H0,3X,'I1',13F9.2)
      WRITE(6,725)(TP2(J),J=1,10),TP2(9),TP2(10),YGTP2
  725 FORMAT(1H0,3X,'I2',13F9.2)
      WRITE(6,726)(TP3(J),J=1,10),TP3(9),TP3(10),YGTP3
  726 FORMAT(1H0,3X,'I3',13F9.2)
      WRITE(6,727)(TP4(J),J=1,10),TP4(9),TP4(10),YGTP4
  727 FORMAT(1H0,3X,'I4',13F9.2)
      WRITE(6,728)(TP5(J),J=1,10),TP5(9),TP5(10),YGTP5
  728 FORMAT(1H0,3X,'I5',13F9.2)
      WRITE(6,7728)(TWP(J),J=1,10),TWP(9),TWP(10),FGTP
 7728 FORMAT(1H0,2X,'TOT',13F9.2)
      WRITE(6,7200)
 7200 FORMAT(1H0,40X,'TOTAL VARIABLE COSTS PER ACRE BY CROPS')
      WRITE(6,7504)
      WRITE(6,7202)(CC(J),J=1,10),CCCS1,CCCS2,CCSGP
 7202 FORMAT(3X,'CC',13F9.2)
      WRITE(6,72030)
72030 FORMAT(1H0,10X,'HOURS PUMPED PER WELL. THESE FIGURES APPLY TO EACH
     1 WELL, PUMP, MOTOR AND DISTRIBUTION SYSTEM.')
      WRITE(6,7504)
      WRITE(6,7204)(HPPW(J),J=1,10),HWCS1,HWCS2
 7204 FORMAT(3X,'H/W',13F9.2)
      WRITE(6,705)
  705 FORMAT(1H0,50X,'FINAL CROP YIELD')
      WRITE(6,7504)
      WRITE(6,707)(YLD(J),J=1,10),CS1,CS2,SGPY1
  707 FORMAT(2X,'YLD',13F9.2)
      WRITE(6,7061)SGPY2
 7061 FORMAT(2X,'YLD',108X,F9.2)
      WRITE(6,7500)
 7500 FORMAT(1H0,40X,'GOVERNMENT SUPPORT PAYMENTS PER ACRE')
      WRITE(6,7504)
      WRITE(6,7502)(GPA(J),J=1,10),GPACS1,GPACS2
 7502 FORMAT(3X,'GP',12F9.2)
      WRITE(6,7503)
 7503 FORMAT(1H0,30X,'NET RETURNS PER ACRE ABOVE TOTAL VARIABLE COSTS')
      WRITE(6,7504)
```

TABLE XLIII (Continued)

```
                         80/80 LIST

     00000000011111111112222222222333333333344444444445555555555666666666677777777778
     12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
0109  7504 FORMAT(1H0,11X,'G1',7X,'G2',7X,'G3',7X,'G4',7X,'G5',7X,'W1',7X,'W2
0110      1',7X,'W3',7X,'C1',7X,'C2',6X,'CS1',6X,'CS2',6X,'SGP')
0111       WRITE(6,7505)(TNRA(J),J=1,10),TNRS1,TNRS2,TNRAP
0112  7505 FORMAT(2X,'NRA',13F9.2)
0113       WRITE(6,7006)
0114  7006 FORMAT(1H0,50X,'ACRES PLANTED, BY CROPS')
0115       WRITE(6,7007)
0116  7007 FORMAT(1H0,14X,'G1',8X,'G2',8X,'G3',8X,'G4',8X,'G5',8X,'W1',8X,'W2
0117      1',8X,'W3',8X,'C1',8X,'C2',6X,'TOTAL')
0118       WRITE(6,7008)(AC(J),J=1,10)
0119  7008 FORMAT(10X,10F10.4)
0120       WRITE(6,701)
0121   701 FORMAT(1H0,45X,'CROP YIELD REDUCTION DUE TO:')
0122       WRITE(6,702)
0123   702 FORMAT(1H0,20X,'SOIL MOISTURE BY PERIODS',33X,'ATMOSPHERIC CONDITI
0124      1ONS BY PERIODS')
0125       WRITE(6,703)
0126   703 FORMAT(1H0,14X,'1',9X,'2',9X,'3',9X,'4',9X,'5',19X,'1',9X,'2',9X,'
0127      13',9X,'4',9X,'5',7X,'TOTAL')
0128       WRITE(6,704)(R1M(J),R2M(J),R3M(J),R4M(J),R5M(J),R1A(J),R2A(J),R3A(
0129      1J),R4A(J),R5A(J),TR(J),J=1,10)
0130   704 FORMAT(10X,5F10.4,10X,6F10.4)
0131       WRITE(6,7115)
0132  7115 FORMAT(1H0,50X,'PUMPING CAPACITY, BEGINNING OF YEAR')
0133       WRITE(6,7116)
0134  7116 FORMAT(1H0,33X,'BIPCA',5X,'BIPC1',5X,'BIPC2',5X,'BIPC3',5X,'BIPC4'
0135      1,5X,'BIPC5',5X,'BIPD')
0136       WRITE(6,7117)BIPCA,BIPC1,BIPC2,BIPC3,BIPC4,BIPC5,BIPD
0137  7117 FORMAT(30X,7F10.3)
0138       WRITE(6,730)
0139   730 FORMAT(1H0,50X,'PUMPING CAPACITY, END OF CURRENT YEAR')
0140       WRITE(6,731)
0141   731 FORMAT(1H0,33X,'AIPCA',5X,'AIPC1',5X,'AIPC2',5X,'AIPC3',5X,'AIPC4'
0142      1,5X,'AIPC5',5X,'AIPD')
0143       WRITE(6,717)AIPCA,AIPC1,AIPC2,AIPC3,AIPC4,AIPC5,AIPD
0144   717 FORMAT(30X,7F10.3)
0145       WRITE(6,718)
0146   718 FORMAT(1H0,50X,'WATER PUMPED AND CHANGES IN WATER SITUATION')
0147       WRITE(6,719)
0148   719 FORMAT(1H0,33X,'FGTP',7X,'AFW',7X,'BSAT',6X,'DECL',6X,'RSAT',6X,'G
0149      1PM',6X,'NWELL')
0150       WRITE(6,720)FGTP,AFW,BSAT,DECL,RSAT,GPM,NWELL
0151   720 FORMAT(30X,6F10.3,I7)
0152       WRITE(6,7118)
0153  7118 FORMAT(1H0,30X,'ANNUAL USE, INDIVIDUAL WELL CAPACITY AND VARIABLE
0154      1PUMPING COST PER ACRE INCH')
0155       WRITE(6,7119)
0156  7119 FORMAT(1H0,34X,'DAU',7X,'HAU',6X,'HAUPW',6X,'GPM1',6X,'GPM2',6X,'G
0157      1PM3',6X,'VPCAI')
0158       WRITE(6,7120)DAU,HAU,HAUPW,GPM1,GPM2,GPM3,VPCAI
0159  7120 FORMAT(30X,7F10.2)
0160 C***********************************************************************
0161 C     PUNCH CARDS FOR SIMULATOR
0162 C***********************************************************************
```

```
                         80/80 LIST

     00000000011111111112222222222333333333344444444445555555555666666666677777777778
     12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
0163  7121 KROD=1
0164       IF(KMAP-1)1000,7122,7122
0165  7122 IF(K-1)7125,7125,7141
0166  7125 WRITE(7,71410)
0167       DO 7126 I=1,12
0168       DO 7126 J=1,13
0169       WRITE(7,7127)KROD,I,J,AMU(I,J)
0170  7126 CONTINUE
0171  7127 FORMAT(I1,2I2,F8.2)
0172       DO 7128 I=17,24
0173       DO 7128 J=1,13
0174       WRITE(7,7127)KROD,I,J,T1(I,J)
0175  7128 CONTINUE
0176       GO TO 71290
0177  7141 WRITE(7,71410)
0178 71410 FORMAT(70X,'AAAAAAAAAA')
0179       DO 7142 I=1,12
0180       DO 7142 J=1,4
0181       WRITE(7,7127)KROD,I,J,AMU(I,J)
0182  7142 CONTINUE
0183       DO 7143 I=1,12
0184       DO 7143 J=6,7
0185       WRITE(7,7127)KROD,I,J,AMU(I,J)
0186  7143 CONTINUE
0187       DO 7144 I=1,12
0188       DO 7144 J=9,12
0189       WRITE(7,7127)KROD,I,J,AMU(I,J)
0190  7144 CONTINUE
0191       DO 7145 I=17,24
0192       DO 7145 J=1,4
0193       WRITE(7,7127)KROD,I,J,T1(I,J)
0194  7145 CONTINUE
0195       DO 7146 I=17,24
0196       DO 7146 J=6,7
0197       WRITE(7,7127)KROD,I,J,T1(I,J)
0198  7146 CONTINUE
0199       DO 7147 I=17,24
0200       DO 7147 J=9,12
0201       WRITE(7,7127)KROD,I,J,T1(I,J)
0202  7147 CONTINUE
0203 71290 DO 7129 I=25,30
0204       DO 7129 J=1,4
0205       WRITE(7,7127)KROD,I,J,T1(I,J)
0206  7129 CONTINUE
0207       DO 7130 I=25,30
0208       DO 7130 J=6,7
0209       WRITE(7,7127)KROD,I,J,T1(I,J)
0210  7130 CONTINUE
0211       DO 7131 I=25,30
0212       DO 7131 J=9,12
0213       WRITE(7,7127)KROD,I,J,T1(I,J)
0214  7131 CONTINUE
0215       DO 7132 J=1,13
0216       I=31
```

TABLE XLIII (Continued)

```
                                80/80 LIST

       00000000011111111112222222222333333333344444444445555555555666666666677777777778
       12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
0217         WRITE(7,7127)KROD,I,J,T1(I,J)
0218    7132 CONTINUE
0219         IF(NWELL-1)7133,7133,7135
0220    7133 DO 7134 I=33,36
0221         DO 7134 J=1,4
0222         WRITE(7,7127)KROO,I,J,T1(I,J)
0223    7134 CONTINUE
0224         DO 7300 I=33,36
0225         DO 7300 J=6,7
0226         WRITE(7,7127)KROD,I,J,T1(I,J)
0227    7300 CONTINUE
0228         DO 7301 I=33,36
0229         OO 7301 J=9,12
0230         WRITE(7,7127)KROD,I,J,T1(1,J)
0231    7301 CONTINUE
0232         GO TO 7148
0233    7135 IF(NWELL-2)7136,7136,7138
0234    7136 DO 7137 I=33,40
0235         DO 7137 J=1,4
0236         WRITE(7,7127)KROD,I,J,T1(I,J)
0237    7137 CONTINUE
0238         DO 7302 I=33,40
0239         DO 7302 J=6,7
0240         WRITE(7,7127)KROD,I,J,T1(I,J)
0241    7302 CONTINUE
0242         DO 7303 I=33,40
0243         DO 7303 J=9,12
0244         WRITE(7,7127)KROD,I,J,T1(I,J)
0245    7303 CONTINUE
0246         GO TO 7148
0247    7138 DO 7139 I=33,44
0248         DO 7139 J=1,4
0249         WRITE(7,7127)KROD,I,J,T1(I,J)
0250    7139 CONTINUE
0251         DO 7304 I=33,44
0252         DO 7304 J=6,7
0253         WRITE(7,7127)KROD,I,J,T1(I,J)
0254    7304 CONTINUE
0255         DO 7305 I=33,44
0256         DO 7305 J=9,12
0257         WRITE(7,7127)KROD,I,J,T1(I,J)
0258    7305 CONTINUE
0259    7148 DO 7140 J=1,13
0260         JROD=2
0261         WRITE(7,7127)JROD,J,J,TY2(J)
0262    7140 CONTINUE
0263         LROD=14
0264         MROD=13
0265         WRITE(7,7127)JROD,LROD,MROO,SGPY2
0266         DO 7041 J=1,5
0267         I=16
0268         WRITE(7,7127)JROD,I,J,GPA(J)
0269    7041 CONTINUE
0270         DO 7042 J=6,8
```

```
                                80/80 LIST

       00000000011111111112222222222333333333344444444445555555555666666666677777777778
       12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
0271         I=17
0272         WRITE(7,7127)JROO,I,J,GPA(J)
0273    7042 CONTINUE
0274         OO 7043 J=9,10
0275         I=16
0276         WRITE(7,7127)JROO,I,J,GPA(J)
0277    7043 CONTINUE
D278         LROD=16
0279         MROO=11
0280         NROD=12
0281         WRITE(7,7127)JROO,LROD,MROO,GPACS1
0282         WRITE(7,7127)JRCO,LROD,NROD,GPACS2
0283    7050 NENO=9
0284         WRITE(7,7044)NEND
0285    7044 FORMAT(I1)
0286         NCOPY=5
0287         WRITE(7,7045)NCOPY
0288    7045 FORMAT(79X,11)
0289    1000 RETURN
0290         END
```

TABLE XLIV

SAMPLE OUTPUT FROM PRODUCTION SUBSET

```
                                    YEAR= 1

                          MACHINE HOURS BY CROP

        G1      G2      G3      G4      G5      W1      W2      W3      C1      C2      CS1     CS2     SGP

 T1     1.22    1.22    1.22    1.16    1.09    0.70    0.70    0.52    1.35    1.35    1.66    1.66    0.65

 T2     1.31    1.31    1.31    0.91    0.44    0.81    0.81    0.44    1.54    1.54    1.04    1.04    0.48

 CW     0.0     0.0     0.0     0.0     0.28    0.0     0.0     0.14    0.0     0.0     0.0     0.0     0.28

 CH     0.21    0.21    0.21    0.21    0.0     0.0     0.0     0.0     0.21    0.21    0.21    0.21    0.21

 CD     0.25    0.25    0.25    0.25    0.12    0.25    0.25    0.0     0.25    0.25    0.25    0.25    0.0

 CB     0.42    0.42    0.42    0.42    0.28    0.21    0.21    0.0     0.42    0.42    0.42    0.42    0.0

 CV     0.48    0.48    0.48    0.24    0.71    0.24    0.24    0.0     0.48    0.48    0.48    0.48    0.0

 SW     0.0     0.0     0.0     0.0     0.0     0.20    0.20    0.40    0.0     0.0     0.0     0.0     0.20

 DR     0.0     0.0     0.0     0.0     0.0     0.18    0.18    0.18    0.0     0.0     0.0     0.0     0.18

 FL     0.14    0.14    0.14    0.14    0.0     0.14    0.14    0.0     0.14    0.14    0.14    0.14    0.0

 SR     0.33    0.33    0.33    0.33    0.0     0.0     0.0     0.0     0.66    0.66    0.66    0.66    0.0

 SH     0.18    0.18    0.18    0.0     0.0     0.0     0.0     0.0     0.18    0.18    0.0     0.0     0.0

                          TOTAL HOURS OF LABOR REQUIRED PER ACRE

        G1      G2      G3      G4      G5      W1      W2      W3      C1      C2      CS1     CS2     SGP

 L1     0.0     0.0     0.0     0.0     0.0     0.19    0.19    0.19    0.0     0.0     0.0     0.0     0.0

 L2     0.76    0.76    0.76    0.72    0.17    0.0     0.0     0.0     1.79    1.79    1.79    1.79    0.0

 L3     0.27    0.27    0.27    0.22    0.23    0.0     0.0     0.0     0.37    0.37    0.37    0.37    0.0

 L4     0.27    0.27    0.27    0.22    0.23    0.75    0.75    0.0     0.37    0.37    0.37    0.37    0.0

 L5     2.37    2.37    1.62    1.88    1.06    0.39    0.39    0.24    3.78    3.03    3.78    3.03    0.53

 L6     1.50    0.75    1.50    0.75    0.0     0.70    0.70    0.40    0.0     0.0     0.0     0.0     0.20

 L7     0.0     0.0     0.0     0.0     0.0     1.13    1.13    0.23    0.0     0.0     0.0     0.0     0.0

 L8     0.62    0.62    0.62    0.0     0.0     0.0     0.0     0.0     0.62    0.62    0.40    0.40    0.0

                          WATER PUMPED FOR EACH CROP BY PERIODS

        G1      G2      G3      G4      G5      W1      W2      W3      C1      C2      CS1     CS2     TOTAL

 IA     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     6.00    6.00    6.00    6.00    360.00

 I1     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0

 I2     0.0     0.0     0.0     0.0     0.0     4.50    4.50    0.0     0.0     0.0     0.0     0.0     382.50

 I3     9.00    9.00    4.50    4.50    0.0     0.0     0.0     0.0     18.00   13.50   18.00   13.50  2295.00

 I4     9.00    4.50    9.00    4.50    0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0    1260.00

 I5     0.0     0.0     0.0     0.0     0.0     4.50    4.50    0.0     0.0     0.0     0.0     0.0     382.50

TCT    18.00   13.50   13.50    9.00    0.0     9.00    9.00    0.0     24.00   19.50   24.00   19.50  4680.00
```

TABLE XLIV (Continued)

```
                                      TOTAL VARIABLE COSTS PER ACRE BY CROPS

          G1       G2       G3       G4       G5       W1       W2       W3       C1       C2      CS1      CS2      SGP
 CC    55.15    52.42    51.37    41.45    10.05    28.67    28.53    11.33    91.80    87.33    69.80    66.30     7.21

        HOURS PUMPED PER WELL. THESE FIGURES APPLY TO EACH WELL, PUMP, MOTOR AND DISTRIBUTION SYSTEM.

          G1       G2       G3       G4       G5       W1       W2       W3       C1       C2      CS1      CS2      SGP
 H/W    8.15     6.11     6.11     4.07     0.0      4.07     4.07     0.0     10.86     8.83    10.86     8.83

                                               FINAL CROP YIELD

          G1       G2       G3       G4       G5       W1       W2       W3       C1       C2      CS1      CS2      SGP
YLC   102.85   109.82   100.51   102.12    23.07    68.12    66.31    32.91   124.46   118.77    22.40    21.38     1.41
YLC                                                                                                               2.82

                                      GOVERNMENT SUPPORT PAYMENTS PER ACRE

          G1       G2       G3       G4       G5       W1       W2       W3       C1       C2      CS1      CS2      SGP
 GP     8.34     8.34     8.34     8.34     8.34    37.46    37.46    37.46     9.95     9.95     9.95     9.95

                               NET RETURNS PER ACRE ABOVE TOTAL VARIABLE COSTS

          G1       G2       G3       G4       G5       W1       W2       W3       C1       C2      CS1      CS2      SGP
NRA    41.53    50.81    43.11    54.55    11.64    59.21    57.01    31.13    46.35    44.51    53.41    51.28    26.64

                                              ACRES PLANTED, BY CROPS

           G1         G2         G3         G4         G5         W1         W2         W3         C1         C2        TOTAL
        80.0000    40.0000    30.0000    20.0000    30.0000    65.0000    20.0000    85.0000    40.0000    20.0000

                                          CROP YIELD REDUCTION DUE TO:

               SOIL MOISTURE BY PERIODS                                   ATMOSPHERIC CONDITIONS BY PERIODS

           1          2          3          4          5                   1          2          3          4          5          TOTAL
        4.5501    10.7159     1.4442     0.0        0.0                 0.3547     0.0        0.0816     0.0        0.0        17.1465
        4.3193     5.0074     0.4122     0.0        0.0                 0.3547     0.0        0.0816     0.0        0.0        10.1752
        4.8883    13.5609     0.6024     0.0        0.0                 0.3547     0.0        0.0816     0.0        0.0        19.4879
        5.2608     8.1692     4.0153     0.0        0.0                 0.3547     0.0        0.0816     0.0        0.0        17.8815
        3.5657    46.4411    25.5489     0.0        0.0                 1.2832     0.0061     0.0816     0.0        0.0        76.9266
        1.3229     0.3207     0.8006     2.8123     0.0                 0.0        0.6866     0.3849     0.5484     0.0         6.8765
        1.3229     2.0516     0.8529     2.8431     0.0                 0.0        0.6866     0.3849     0.5484     0.0         8.6903
        1.3229     5.0291     6.5712     7.5463     0.0                 0.0        0.6866     0.3849     0.5484     0.0        22.0894
        0.0        5.3404    15.7351     1.3025     0.0                 0.0459     1.8504     1.1669     0.1002     0.0        25.5414
        0.0        6.6272    18.0784     2.4187     0.9190              0.0470     1.8751     1.1669     0.0982     0.0        31.2306

                                        PUMPING CAPACITY, BEGINNING OF YEAR

                      BIPCA      BIPC1      BIPC2      BIPC3      BIPC4      BIPC5      BIPD
                    1590.867    742.405  1060.578   2969.619   2068.127    742.405    53.029

                                        PUMPING CAPACITY, END OF CURRENT YEAR

                      AIPCA      AIPC1      AIPC2      AIPC3      AIPC4      AIPC5      AIPD
                    1230.867    742.405   678.078    674.617    808.125    359.905    53.029

                                        WATER PUMPED AND CHANGES IN WATER SITUATION

                      FGTP        AFW        BSAT       DECL       RSAT       GPM       NWELL
                    4679.996    390.000   325.000      3.047    321.953   1000.000      1

                    ANNUAL USE, INDIVIDUAL WELL CAPACITY AND VARIABLE PUMPING COST PER ACRE INCH

                       DAU        HAU       HAUPW      GPM1       GPM2       GPM3       VPCAI
                      88.25     2118.09   2118.09      0.0        0.0        0.0        0.44
```

APPENDIX D

PUMPING AND INVESTMENT COSTS FOR ALTERNATIVE IRRIGATION SYSTEMS

This appendix discusses investment and pumping costs for the surface irrigation systems assumed in the analysis. The costs are computed using a model developed by Shaffer and Eidman.[1] For a brief but complete summary of the basic characteristics and assumptions of the model, see Bekure.[2]

Assumptions and Pumping Costs

Each Resource Situation is assumed to begin the 20-year simulation period with a specified irrigation system. Resource Situation 1, overlying 100 feet of saturated thickness, is assumed to begin the period with five year old well, pump and distribution system, but with a new motor. The distribution system consists of 2,600 feet of 12-inch underground concrete asbestos pipe, 600 feet of aluminum gated pipe and 600 feet of ungated aluminum pipe. The underground distribution system is assumed to last the length of the analysis. Aluminum pipe, which is handled continuously is assumed to have a life of ten years. The well is assumed to have a 15 year life; pumps, a ten year life; and motors, a four year life.

As the components of the irrigation system wear out, they are replaced. The operator is assumed to replace the motor and pump with one of the appropriate size, given the current capacity of the irrigation well. Changes in variable pumping costs per acre inch associated with 25 gpm declines in pumping capacity for well 1 are shown in the first column of Table XLV. The pumping costs reflect increased efficiency gained by replacing each old motor with a new motor of the appropriate size. A new motor is assumed added at 600 gpm capacity, 375 gpm capacity, 225 gpm capacity and 150 gpm capacity. These capacities

TABLE XLV

VARIABLE PUMPING COSTS PER ACRE INCH FOR ALTERNATIVE IRRIGATION SYSTEMS

Gallons Per Minute (GPM)	Resource Situation 1			Resource Situation 2
	Well 1	Well 2	Well 3	Well 1
1000				0.44
975				0.45
950				0.46
925				0.48
900				0.49
875				0.50
850	0.45			0.52
825	0.45			0.53
800	0.48			0.55
775	0.49			0.57
750	0.51			0.59
725	0.53			0.61
700	0.55	0.38		0.63
675	0.57	0.40		0.65
650	0.59	0.41		0.68
625	0.61	0.43		0.70
600	0.53[a]	0.45		0.73
575	0.55	0.47		0.76
550	0.58	0.49		0.80
525	0.60	0.51		0.84
500	0.63	0.54		0.88
475	0.66	0.57		0.93
450	0.69	0.60		0.98
425	0.73	0.47[a]		1.04
400	0.78	0.50		1.10
375	0.70[a]	0.53		1.17
350	0.75	0.57	0.67	1.26
325	0.81	0.61	0.72	1.35
300	0.88	0.66	0.78	1.47
275	0.96	0.73	0.85	1.60
250	1.05	0.65[a]	0.94	1.76
225	1.03[a]	0.72	1.04	1.95
200	1.15	0.81	1.00[a]	2.20
175	1.32	0.93	1.14	2.51
150	1.42[a]	0.92[a]	1.33	2.93
125	1.70	1.10	1.45[a]	3.51
100	1.98[a]	1.24[a]	1.81	4.40
75	2.64	1.65	2.41	5.86
50	3.96	2.47	3.62	7.79
25	7.92	4.94	7.24	11.14

[a] Reflects reductions in variable pumping costs per acre inch due to the addition of a new, smaller motor designed to fit the current pumping capacity of the system.

correspond to expected levels of pumping capacity at four-year intervals through time, given the expected rate of pumping and decline in the water level. Each new motor temporarily reduces, or slows the rate of increase in, variable pumping costs per acre inch. However, pumping costs increase from approximately $.49 to $2.12 per acre inch as pumping capacity declines from 780 to 100 gpm for well 1.

Columns 2 and 3 show variable pumping costs per acre inch for wells 2 and 3, Resource Situation 1. These costs are adjusted to reflect addition of new motors, designed to fit the current capacity of the well at four-year intervals. For well 2, variable pumping costs increase from $.38 per acre inch at 700 gpm to $1.83 per acre inch at 100 gpm. Well 3 is assumed to be a 350 gpm well with pump, motor and distribution system. The distribution system consists of 2,600 feet of underground eight-inch concrete asbestos pipe. No additional surface pipe is required. Variable pumping costs per acre inch increase from $.67 at 350 gpm to $1.81 at 100 gpm.

Column 4 of Table XLV contains variable pumping costs per acre inch for the original well assumed for Resource Situation 2. This well, which has an initial capacity of 1,000 gpm, includes pump, motor and distribution system. The distribution system includes 2,600 feet of 12-inch underground concrete asbestos pipe, 600 feet of gated aluminum pipe and 600 feet of ungated aluminum pipe.

Investment Costs for Alternative Systems

Investment costs for irrigation wells of each Resource Situation are presented in Table XLVI. During a 20-year simulation run, the representative farm operation for Resource Situation 1 expands irrigation

TABLE XLVI

INVESTMENT COSTS FOR ALTERNATIVE IRRIGATION COMPONENTS BY WELLS FOR A 20-YEAR SIMULATION RUN

Components	Resource Situation 1			Resource Situation 2
	Well 1	Well 2	Well 3	Well 1
	($)	($)	($)	($)
1st Well	3125.00	3125.00	3125.00	4065.00
1st Pump	3425.00	3425.00	2152.00	3635.00
1st Motor	1975.00	1575.00	765.00	2590.00
1st Dist. System	6666.00	84.00	4508.00	6666.00
2nd Well	3125.00	3125.00		
2nd Pump	2150.00	2150.00	2150.00	
2nd Motor	1335.00	930.00	430.00	
2nd Dist. System	1856.00[a]	84.00[b]		
3rd Motor	820.00	540.00	270.00	
3rd Pump	2150.00			
3rd Dist. System	1856.00[a]			
4th Motor	485.00	325.00		
5th Motor	325.00	215.00		
6th Motor	215.00			

[a] The underground concrete asbestos pipe is assumed to have an expected life of 25 years. This price reflects replacement costs for 600 feet each of eight-inch gated and nongated aluminum pipe.

[b] Well 2 is connected to the underground concrete distribution system of well 1. The valve required to make this connection is assumed to have a ten-year life and thus must be replaced.

facilities from one to three wells. During the 20-year period well 1 requires five motors and three pumps, and the well must be redrilled once. The underground concrete asbestos portion of the distribution system is assumed to last the entire 20-year period. Surface aluminum pipe is replaced during the fifth and fifteenth years.

The lower investment costs for well components over time reflect the fact that farm operators replace pumps and motors with smaller sizes appropriate for the current capacity of the irrigation system. Thus, each motor on well 1, Resource Situation 1, is designed for the lower capacity well and costs less. As previously explained, the smaller motor results in lower fuel requirements and lower variable pumping costs per acre inch of water pumped. Saturated thickness for Resource Situation 2 does not decline sufficiently during the 20-year period of the analysis to require a smaller irrigation motor. Thus, when the motor is worn out, it is assumed replaced with one of comparable size and cost.

FOOTNOTES

[1] Ron E. Shaffer and Vernon R. Eidman, "A Cost Study of Alternative Irrigation Systems in Northwestern Oklahoma," (unpublished manuscript, Department of Agricultural Economics, Oklahoma State University).

[2] Solomon Bekure, "An Economic Analysis of the Intertemporal Allocation of Ground Water in the Central Ogallala Formation" (unpub. Ph.D. dissertation, Oklahoma State University, 1971), pp. 206-210.

VITA

Harry Parks Mapp, Jr.

Candidate for the Degree of

Doctor of Philosophy

Thesis: AN ECONOMIC ANALYSIS OF WATER-USE REGULATION IN THE CENTRAL OGALLALA FORMATION

Major Field: Agricultural Economics

Biographical:

Personal Data: Born at Wardtown, Virginia, October 12, 1939, the son of Harry P. and Edith A. Mapp.

Education: Graduated from Northampton High School, Eastville, Virginia, in June, 1958; received the Bachelor of Science degree from Virginia Polytechnic Institute, Blacksburg, Virginia, in June, 1962, with a major in Agricultural Economics; received the Master of Science degree from Virginia Polytechnic Institute, Blacksburg, Virginia in June, 1964, with a major in Agricultural Economics; completed requirements for the Doctor of Philosophy degree at Oklahoma State University in May, 1972.

Professional Experience: Graduate Research Assistant, Department of Agricultural Economics, Virginia Polytechnic Institute, Blacksburg, Virginia, June, 1962 to September, 1963. Teacher, Northampton High School, Eastville, Virginia, September, 1963 to February, 1964. Officer, United States Air Force, Los Angeles, California and Greenville, South Carolina, February, 1964 to June, 1967. Graduate Research Assistant, Department of Agricultural Economics, Oklahoma State University, July, 1967 to November, 1971.

Organizations: American Agricultural Economics Association, Southern Agricultural Economics Association, Western Agricultural Economics Association, and Regional Science Association.