A LINEAR PROGRAMMING CROP SELECTION MODEL FOR IRRIGATION IN SOUTHWEST KANSAS WITH WATER AND SOIL MOISTURE CONSTRAINTS

by

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Chapter One

Introduction

One of the most important changes which will impact agriculture in western Kansas is the on-going shift from irrigation practices which have little regard for conservation, to a practice that emphasizes greater water use efficiency. In the past, irrigation water was readily available and the costs of pumping this water was very low which resulted in the goal of yield maximization among many western Kansas irrigators. Irrigation practices were adopted because of the increased income which could be achieved in comparison with dryland cropping practices. The techniques and practices, suitable in the past are no longer appropriate and the economic climate for irrigation production has changed and a new approach is needed. It is no longer acceptable practice to turn on the irrigation system and give no consideration to the actual needs of the crop, Musick (1976). Declining ground water supplies in the Ogallala aquifer, in addition to the increasing costs of pumping water, due primarily to increasing depths from which water must be pumped and reduced efficiencies, necessitates a change in application habits and beliefs. The emphasis is to apply water only when necessary for economic crop production, to receive the highest net return and avoid waste. Utilizing the relationships between available soil moisture in the root zone and grain yields, provides a rational basis for scheduling irrigations, Stewart (1973).

A new emphasis is coming into focus, that being the relationship between crop income, costs, yields and water use and deficits of usable moisture for the crop. The purpose of some recent research is to model crop growth and yield as they relate to net returns and water requirements. The new approach adds economic considerations to the soil-plant-water relationships.

Studies such as Mapp etal, 1975, review the critical reasons for a more integrated approach to irrigation water management, which is based on timing of the water availability and irrigations. The first and most direct reason for this emphasis is the net returns from crops based on availability of sufficient soil moisture at specific, critical stages of plant growth. For example, moisture availability at the silking stage as compared to the harvest stage in corn has a very different impact on final yield and income. Irrigating only at specified, critical periods of plant development may reduce total water usage without significantly reducing yields, thereby increasing net returns. If less critical stages can be defined, less water might be needed and thus saved for later, more critical stages. Two additional reasons have more of an organizational impact on how farmers irrigate. Due to reduced well yields, (GPM), there is a decrease in the ability to make the necessary, timely applications of water. The farmer must then adjust the irrigation schedule or reduce the acreage to be irrigated in order to avoid stress periods while maintaining yields and profitability. These decisions and actions influence the economic returns to irrigation.

To determine the economically optimal allocation of irrigation water to a given crop, the relationship between yield of the crop and its water use must be known. This emphasis on the yield-water relationship and associated magnitudes of response, depend upon several factors. The amount of soil moisture available at the time of irrigation and the amount of rainfall immediately after irrigation are very important components. Another equally important component is the plant's stage of development, because it affects the stress caused by soil moisture deficits on crop yield and is different for each stage of development. The effect of moisture deficits during various stages of plant development must be considered in yield reduction calculations, Shipley, (1975). Much of this work is of a technical manner and is not available in a form which can be used in a practical manner by an individual farmer. As a result, there is a need for a procedure that combines the plant-water-soil relationship into an economic decision-making framework to maximize net returns.

Problem Definition

The problem studied is the economically efficient use and allocation of a scarce resource, in this case, irrigation water. The agricultural economy of western Kansas rests in part upon irrigation of various crops. Irrigation of these crops depend upon withdrawls of water from underground aquifers. This source of water has become more costly in recent years for more than one reason. The energy crisis of the 1970's increased the cost of fuel to power irrigation pumps, thereby reducing net revenue from crop production. With the increased use of irrigation, which peaked in the late 1970's, the amount of water being removed from the aquifer was greater than recharge and therefore lowered the water table. As a result, the depth from which water must be pumped increased, further adding to the costs of irrigation. The additional amount of lift causes the pump efficiency to drop off and the amount of water applied to decline. As a result, an irrigator is faced with several problems. First the irrigator is faced with increased operating costs of the existing irrigation system, normally without corresponding increases in the value of the production. This reduces an already small net return in most cases even farther. Another set of problems is related to the reduction in well yield. As well yields drop off, the cropping alternatives diminish due to to the inability of the irrigation system to supply sufficient quantities of water for high water use crops such as corn. As these alternatives decrease, the potential for maintaining or increasing net returns also decreases. A new set of irrigation strategies are needed for dealing with these specific problems.

Objectives

Given the foregoing discussion, the objectives of this study are: (1) Conceptualize and develop a model useful in selecting irrigated crops, acreage of each and the amount of water to apply that maximizes net returns. The model is for foreward planning of crops to irrigate based on the expected water use of the crop and the expected availability of water. It is not an irrigation scheduling model, however the expected irrigation schedule is considered. (2) Develop the above model to include water use constraints for each growth stage for each crop; (3) Develop yield response to water estimates for 10 irrigation regimes for each crop; (4) Utilize the soil profile as a moisture reservoir which can be used to store moisture for use by crop as needed; (5) To design this model for flood irrigation application in western Kansas for corn, grain sorghum and wheat; (6) Test the model using an assumed well yield of 1200, 1000. 800, 600, 400, and 200 gallons per minute.

Chapter Two

Literature Review

In reviewing the literature concerning water-yield relationships, one key point arises that is of major importance. Possibly more important than the amount of water applied, is the timing of the water application. According to Hall and Butcher, 1968, research shows that the magnitude of yield reduction may depend as much if not more, upon the timing of the soil moisture deficiency, as it does upon the magnitude of the shortage, for each period and cumulatively over time. It is apparent that the yield response to a deficit at a particular growth stage, may not be a function of the deficit of that stage alone, but may have been influenced by previous deficits, Barrett etal, (1978). In the case of grain sorghum, stress at an earlier stage may harden or condition the plant against stress at a later stage. This effect of earlier deficits could lessen the yield reduction to a moisture deficiency in the current period. Numerous fuctions which model moisture-yield relations have been developed. Evapotranspiration is a value which is frequently used in these functions to establish a relationship to yield. This evapotranspiration calculation is a combination of evaporation and transpiration estimates. Evaporation is the process of removing moisture from soil or water surfaces and the surfaces of leaves of the plant, as a result of heat changing liquid water to vapor. Transpiration is the process by which water enters the plant roots and is either used to build plant tissue or cool the plant by passing through the leaves into the atmosphere, Kansas Irrigation Workshop, (1981). If the plant is unable to meet this evapotranspiration demand, stress occurs and a possible reduction in yield can occur. This amount of yield reduction is dependent, in part, upon the duration of the shortage. Evapotranspiration is affected by many environmental factors, among them are temperature, light, humidity and wind.

Many individuals have done work in trying to determine a functional form which will accurately reflect evapotranspiration and their studies will be evaluated individually as the review progresses. Numerous equations have risen out of this work. The equations derived, utilize meteorological data and are used to estimate evapotranspiration for periods of a day or longer. These equations have a wide range of complexity. The less complex equations require only average air temperature, day length and a crop coefficient. Equations which generally perform better require values for daily radiation, temperature, water vapor pressure and wind run to derive the estimates.

Thornwaite, 1948, developed one of the first equations which expressed evapotranspiration as a function of the mean monthly temperature and a heat index value. The Blaney-Criddle equation, Blaney and Criddle, 1952, popular in research dealing with irrigation, takes a different approach. This equation, U=KF, shows consumptive use, U, as a function of $\sum_{i=1}^{r} kf$ in which k is an empirical consumptive use coefficient for each month and f is equal to the product of the mean monthly temperatures and the monthly percentages of daytime hours of the year in total. Another approach, the modified Jensen-Haise method, Jensen etal, 1963 and 1980, goes farther in that it utilizes the saturation vapor pressure of water. This saturation figure is calculated by using the difference between the saturation water vapor pressure at the mean monthly maximum air temperature of the warmest month of the year and the mean monthly minimum of the same month.

Another often used formula is the Penman formula, Penman and Jensen, (1980). This formula utilizes a radiation term, a vapor pressure-temperature relationship, a wind term, and a vapor pressure deficit term in determining a reference crop evapotranspiration term. This term is then utilized in comparison with actual crop evapotranspiration values. An additional method is the Stress Day Index, Hiler etal, (1974). This equation is a function of a crop susceptability factor and an actual measure of plant water deficit. All of these equations and approaches have their drawbacks. The most important of these is their considerable complexity.

As a result of these shortcomings, work was undertaken at Oklahoma State University, Mapp etal, 1975, in which functions were developed which could be used to calculate yield reductions, as a function of pan evaporative values and soil moisture values. Three crops, corn, wheat and grain sorghum, were utilized in the research. The pan evaporative estimate was calculated as the difference of the actual value from a critical value, in this case .4 inches of moisture per day. Evaporation values greater than the critical value implied an inability of the plant to maintain transpiration and thus stress occurred, which in turn reduced yields. The soil moisture value was related to the amount of moisture at 80 percent of field capacity. Field capacity is a term used to describe the maximum amount of water left in the soil after losses to the forces of gravity have ceased and no surface evaporation has occurred, Donahue etal, (1976). This is the amount of water that is temporarily stored in the soil profile for plant utilization. For most soils, this condition is nearly optimal for plant growth. The research concluded that down to 80 percent of field capacity, no stress and associated yield reduction occurred. The concept of wilting point is used at the other end of the soil moisture spectrum. The permanent wilting point is the soil moisture level at which the plant is no longer able to obtain enough moisture to supply its transpiration needs and the plant permanently wilts and dies, Donahue etal, (1976). It is assumed that below this soil moisture level, no additional yield reduction will occur.

In the research, corn, grain sorghum and wheat were the three crops studied and were the ones used in the study for this work. The equations for grain sorghum were designed for three separate growth periods; pre-boot, boot-heading and grain filling. (See Figure 1 for the crop calender). These equations gave a maximum yield reduction for each stage of growth of 6.3 bushels per acre, 57.1 bushels per acre, and 26.7 bushels per acre respectively. This yield reduction figure is the amountof yield reduction from the maximum yield which would occur with the maximum stress level for each of the periods. For corn, five growth stages, first vegetative, second vegetative, silking, milk, and soft dough, were developed. Their respective yield reductions were 6 bushels per acre, 31.1 bushels per acre, 48.8 bushels per acre, 25.1 bushels per acre and 23.6 bushels per acre. Wheat had four stages, pre-boot, boot, flowering and milk with respective maximum yield reductions of 6.8 bushels per acre, 13.3 bushels per acre, 12.4 bushels per acre and 11.6 bushels per acre. From these equations and maximum yield reduction figures, the most critical stages begin to emerge. This determination of yield reduction figures and critical stages of growth are important when deciding which periods could possibly withstand less water without seriously impairing the final production figures.

Stewart etal, 1975, discusses another yield-moisture relationship, the yield reduction ratio. The yield reduction ratio is the percentage reduction in yield below the maximum possible yield, resulting from each percentage point of seasonal evapotranspiration deficit. Results indicate the largest ratio was for the late vegetative stage in grain sorghum and the pollination stage in corn, again showing these as the more critical stage of each plant.

The timing of irrigation appears to indeed be the crucial component to maximizing grain yields with limited availability of water. Each crop appears to react to stress at different times in slightly different manners.

Doorenboos etal, 1979 and 1977 and Musick etal, 1961, reported that the most critical period for grain sorghum, in terms of moisture stress, was the boot to heading stage. They also reported the boot to soft dough stages as the most responsive to water application. According to Musick etal, 1971, and a Texas A&M Bulletin, 1971, stress during the early vegetative stage of growth in grain sorghum, had less of an effect on yield than stress during the later more critical stages. Lewis etal, 1974 reports a yield reduction of 34 percent from a non-stressed yield, when a period of stress is imposed during the boot to bloom stage in grain sorghum. Lewis etal, 1974, also reported that research results indicated that the boot to bloom stage was the most critical one for water stress, with yields reduced to 93.72 bushels per acre from a non-stressed yield of 141.77 bushels per acre. Their research also showed that late vegetative to boot stage as the next most important stage with yields reduced to 117.4 bushels per acre in comparison to the non-stressed yields.

Wheat appears to have relatively less overall yield response to marginal irrigation applications than corn and grain sorghum. Despite this, there are still some critical stages of growth that have been identified. Doorenboos etal, 1977, and Schneider etal, 1969, all determined that moisture stress was critical in the stage of booting to early grain filling. Doorenboos etal, 1977 and Schneider, 1974, also concluded that the next most important stage was grain filling. Severe stress during this stage can cause significant yield reductions. Robins etal, 1962, and Framji etal, 1972, similiarly agree that the boot to flowering stages were the stages most sensitive to water deficits. They also reported that the growth period which produced the best response to irrigation was the jointing to soft dough stages. Framji etal, 1972, also reported that water deficiencies before booting did very little to reduce yields as long a sufficient moisture was available at later stages.

Considerable work has been undertaken in research with corn responses to water stress. Doorenboos etal, 1979, and Doorenboos etal, 1977, as well as Donahue etal, 1976, all discovered that the most critical growth stage is the tassel to pollination stages. In addition to this, Robins etal, 1953, found that the 12 leaf to blister stage in corn produced the greatest yield response to irrigation water. Gilley etal, 1980, found that witholding of irrigation water in early vegetative stages caused a 23 percent reduction in evapotranspiration, caused no yield reduction and saved 4.74 inches of irrigation water. Morgan, 1977, and Stewart etal, 1975, both found that irrigation after the blister stage had little effect upon increasing yield. Stewart etal, 1975, found that deficits at pollination had two results. If no prior deficits had occurred, a large yield reduction occurred. If prior deficits had occurred, this earlier stress appeared to condition the plant such that the yield reductions were not as great from a pollination stage deficit. This conditioning effect during the pollination stage was also observed by Gilley etal (1980). Stewart etal, 1975; Denmead etal, 1960; Denmead etal, 1960; and Barnes etal, 1969, have all completed considerable work on the amount of yield reduction associated with stress at various stages in corn. Moisture stress which occurs in the late vegetative stage, immediately prior to tasseling, can reduce yield by as much as 25 percent. Similiar stress in the grain filling stage can reduce yield by 21 percent. Stewart etal, 1975, found that wilting conditions of one to two days during the pollination period can cause a 22 percent reduction in corn yields. A longer stress period gave similiar results in all four studies, that of a 50 percent yield reduction.

A variety of approaches have been used to model, analyze and explain the problem of yield-moisture relationships and interactions. Some of these are simple and straight forward while some of the approaches are quite complex. Lacewell etal, 1971, utilized a linear programming approach to analyze water allocation and crop selections. In his model, Lacewell dealt with crops raised in semi-arid regions and he designed his constraint equations to allow for variations in annual water supplies. Rogers etal, 1970, also utilized a linear programming model to maximize net revenue considering crop costs and project costs. A water balance equation was established as the basis of the linear programming model. Burt etal, 1971, utilized the framework of stochastic dynamic programming to consider the problem of temporal allocation of limited irrigation water within the growing season of a single crop. Each of these previous approaches have been limited in their applicability of results to a general audience. Burt's study covered a single crop with little evaluation of crop combinations or alternative approaches. Additionally, the studies dealt with a given allocation of water and what yields would be produced rather than approaching it from a water conservation angle while still maintaining economically sound production levels.

A water balance approach method method was used by Wiser, 1965, which used climatological data. The equation related ending soil moisture content to initial soil moisture content, precipetation, evapotranspiration and an excess term. This equation was used to determine the yield response distribution necessary to evaluate the economic implications. A slightly different approach was taken by Anderson etal (1978). They utilized a digital computer model of irrigation systems to model the effects on farm income, based on water supply restrictions and cropping patterns. One of the applications of this model is the economic evaluations of irrigation practices, especially the ability to examine the effects of missed irrigations, in terms of the effects on yield and income. Dean, 1980, linked an irrigation sub-model to an agricultural runoff management model. This irrigation sub-model considers the water status of the soil to determine if irrigation is necessary. Morgan, 1977, combined a crop response model with an economic irrigation scheduling model. A high level of irrigation cost and a lower level of irrigation cost were explored. As irrigation costs increased, the amount of irrigation decreased. It was found that the periods of irrigation reduction corresponded to the periods, in the crop response model which gave the least yield response to water. Lorber etal, 1981, developed a model of corn yields which was based on several factors, including moisture stress. The model developed had a 3 to 8 percent error in predicting yields when compared with actual yields. Roeder, 1981, utilized a linear programming model to analyze the impact of decreasing well yields on irrigation. Roeder studied the impacts as they related to the allocation of irrigation water and the ultimate crop mixtures.

An additional approach to irrigation is set out by Jensen etal (1980). The concept of evapotranspiration deficit irrigation is put forth with a few guidelines. First, the maximum expected root zone is filled to field capacity at or near planting. The second major step is to maintain low soil deficits in the early season when system pumping capacity can satisfy the evapotranspiration demands. The third step is to irrigate frequently in the peak evapotranspirative period to maintain high soil water potentials in the upper soil levels. The fourth step is to apply sufficient irrigation amounts in the grain filling periods of seed crops so that these irrigations plus the earlier stored moisture in the lower soil profile can about supply the late season evapotranspiration requirements that are not satisfied by rainfall.

It is this last, deficit irrigation concept, that provides the nucleus for this study. It is the use, of the soil as a reservoir, not so much to meet late season crop needs, but to help maintain yields by supplying moisture during the short, high consumptive periods that are so critical to plant yield, that set this study apart from a large portion of prior works. Also the allowance of the model to utilize rainfall sets it apart from other works. By its design, the model is allowed to allocate water for crop needs from soil storage, rainfall or direct application in the needed amounts to whichever crop mix of corn, wheat or grain sorghum that proves to be the most economically feasible. This study also provides an approach, which is less a pure construct of theory and more a practical usable tool for irrigation of western Kansas.

Chapter Three

Conceptual Approach

Economic theory provides a guide for analyzing problems relating to production of products and the allocation of resources. The theroy is based on the Law of Diminishing returns and a comparison of marginal costs to marginal revenue. The most profitable resource use occurs when the cost of the marginal unit of input (MIC) is equal to the value of output produced by that input (MVP). Rational, fully informed individuals will continue to accrue profits by expanding production by increasing input as long as MIC$<$MPV and when MVP=MIC profits are maximized which is one goal of efficient resource allocation. Resource use in which MIC$>$MVP means that each additional unit costs more to produce than its value in the market place. Likewise, to use that quantity of resource when the MVP$>$MIC is a situation of less than maximum profits therefore it represents non-optimal resource allocation. In this instance, the return from the marginal unit of resource used is greater than the cost of that marginal unit and a profit results. Adding units of resources increases profits as long as MVP$>$MIC.

The previous discussed criteria for the most profitable use of a resource applies where the product produced is sold and the resource used is purchased. In the case of using a resource that is fixed to farm but variable among enterprises, the criteria becomes one of allocating the resource among enterprises in such a way as to equate the returns from the marginal unit in each enterprise. Thus the term MIC is replaced with a term representing the opportunity cost which is the MVP in an alternate use. In this case the criteria becomes: $MVP_{i(j)} = MVP_{i(h)}$ where i is the input and j and h are two alternative crops.

The most profitable allocation of irrigation water is based on the above principle and finds the alternative uses of water nearest the equation of the MVP among uses. In this study, each crop and irrigation regime has a different return and cost for the marginal unit because of different yield and pumping costs. Thus there are many combinations of crops and irrigation levels which all need to be evaluated independently and then compared to determine the one or combination providing the most profit. This enormous work load is lessened somewhat by use of linear programming procedures to calculate and compare all of the needed situations in a very short time with the aid of a computer.

The use of linear programming will, within the conditions and restrictions of the model, provide the best plan or organization of resources available using the principles previously discussed. This allows for the evaluation and analysis of many alternative combinations with minimal time. The linear programming procedure is efficient because it assumes an increase in output is proportional to an increase in input, or resource use. Thus the procedure does not adhere to the classical case which is based on the law of diminishing returns. The influence of the condition of proportionability in the input-output relations can be reduced by considering many different input-output combinations. For that reason, this study has many irrigation regimes for each crop, each specifying a different input-output combination. Each input-output combination represents specific marginal returns and costs.

Other assumptions of linear programming are: (1) the objective function is linear which means that the prices paid for inputs and received for output remains constant regardless of how many units are sold or purchased; (2) The decision variables cannot be negative which means that negative acreages of crops is not permitted; (3) Resource use and output can occur in fractional units; (4) The number of alternatives or choices is finite; and (5) That resource supplies, input-output coefficients, prices of products and inputs are known with certainty (AGRAUAL, 1972).

Chapter Four

Procedure and Model Development

Linear programming is a planning process which can be used as an aid in making decisions requiring a choice among a large number of alternative production alternatives with limited resources according to Roeder (1981). Linear programming can be used very effectively as a tool in the oveall planning process or used to develop general production recommendations. It is similiar to a sophisticated budgeting process, with the emphasis placed on the specification and organization of production alternatives called activities, with a given set of resources and constaints.

Specification of alternative input requirements is a very critical part of the procedure. Significant differences in a production process must be developed as a separate activity in the model. The production coefficients in the model are stated in units of the activity and resources being considered. For example, to raise an acre of corn, all of the production coefficients as well as the results would be in terms of per acre units.

Another critical factor which influences the results of linear programming solutions is price; (input) resource price and (product) output price. However actual prices used are less important than the relationship between the prices used. For example, if the model is set up with the price of corn low in relation to the prices of other commodities, such as grain sorghum or wheat, the model will be falsely skewed away from raising corn. This could result in the unprofitable organization of the fixed and variable resources. Thus, while one strives for reasonable prices, one needs to pay especially close attention to using prices which reflect an accurate relationship among commodities. Price mapping can be used to demonstrate the sensitivity of price relationships to the solutions. Linear programming is superior to sophisticated budgeting because it allows the use of constraints in a readily usable fashion. With linear programming these constraints can be placed on available land, labor or field working time. Each of these constraints can have an impact on the organizational structure of the results.

All of these components relate to the organizational results of a linear programming model in some important way. The overall goal of a linear programming model is to provide results which pertain to the optimal organization of resources (inputs) in alternative production activities, which will yield the maximum net returns given the resource constraints. Linear programming does not imply that the results are the best in all circumstances; but only within the given parameters which specify the production environment described in a specific model.

An explanation of linear programming is necessary to understand the use of linear programming, as well as to fully understand the results and implications. The generalized linear programming model specification is as follows:

The objective of linear programming is to

$$\text{Maximize} \quad Z = \sum_{j=1}^{n} c_j x_j$$

$$\text{Subject to} \quad \sum_{i=1}^{m} \sum_{j=1}^{n} A_{ij} x_j \leq b_i$$

$$\text{With the condition} \quad x_j \geq 0$$

$$i = 1 \ldots m \qquad j = 1 \ldots n$$

Where: c_j = return per unit of product

x_j = level of activity (production process) of a particular product

A_{ij} = amount of resource i used in activity (production process) of a particular product j

b_i = total amount of resource available

The concept of shadow prices are important to understanding linear programming. Shadow prices indicate how the value of the objective function would be altered if an additional unit of the limiting resource were available. These figures represent the amount that the returns would be increased for each particular unit added. Alternatively the negative shadow price represents the amount by which the objective value would be reduced for each unit decrease of the resource. Shadow prices are useful in interpeting results and can help improve management decisions. The procedure also calcualtes an opportunity return to the activities not in the final solution. Suppose the soybean activity has an opportunity return of $-10.00. If a manager was considering shifting from corn to soybeans, the results from a linear programming model would help him make the decision. If the manager decides to substitute one unit of soybean production for one unit of production that the model has already chosen as optimal, the objective value of the model will be reduced by $10.00 or the amount of the negative opportunity return for soybean production. If, on the other hand land had a $10.00 shadow price, then each additional unit of land available to the model could increase the returns by $10.00.

Model Components

The model used in this study meets the general requirements of a linear programming model. The actual model is considerably more complex to represent algebraically than the generalized model and is explained below:

Objective Function:

The objective function is as follow:

$$\text{Maximize } Z = \sum_{m=1}^{3} \sum_{n=1}^{10} [(R_{mn} * U_{mn}) - (C_{mn} * A_{mn}) - (CN * NU_{mn}) - (CPH * PHU_{mn}) - (CP * PU_{mn})] - \sum_{o=1}^{12}(LC_o * LU_o) - \sum_{p=1}^{23}(PC_p * PUN_p) - \sum_{p=1}^{23} \sum_{q=1}^{39} \sum_{r=1}^{2}(FS_{pqr} * FILL_{pqr}) - \sum_{s=1}^{12}(SR_s * SRC_s) - \sum_{t=1}^{22}(TSM_t * TSMC_t)$$

R=Price per bushel
U=Bushels of grain produced
C=Variable costs excluding pumping costs, fertilizer costs and hired labor costs
A=Crop Acres
CN=Cost of Nitrgen
NU=Units of nitrogen purchased to replace use
CPH=Cost of phosphorus
PHU=Units of phosphorus purchased to replace use
CP=Cost of potash
PU=Units of potash purchased to replace use
LC=Cost of hired labor per hour
LU=Hours of hired labor
PC=Pumping cost per hour of pumping
PUN=Number of hours that water is pumped
FS=Cost per hour of pumping for soil filling
FILLU=Number of hours that pumping for soil filling is conducted
SR=Water supplied by rainfall
SRC=Cost of rainfall; zero value in the objective value
TSM=Transfer of soil moisture from one period to the next
TSMC=Cost of transferring soil moisture; zero value in the objective value

m=1 to 3; Particular crop of corn, grain sorghum or wheat
n=1 to 10; Crop production possibility involving different irrigation regimes
o=1 to 12; Labor hired during each month

p=1 to 23; Periods into which pumping season has been partitioned(hours/period)
q=1 to 39; Soil filling periods related to the periods of irrigation
r=1 to 2; The upper and lower soil profile
s=1 to 12; Periods of rainfall supply, in this case on a per month basis
t=1 to 22; periods of soil moisture transfer

In general terms, the equation expresses the following relationship: Net Returns = Gross Returns - Variable Costs - Total Nitrogen Costs - Total Phosphorus Costs - Total Potash Costs - Total Hired Labor Costs - Total Pumping Costs - Total Soil Filling Costs - Total Rainfall Supply Costs - Total Soil Moisture Transfer Costs.

CONSTRAINT EQUATIONS

The objective function is maximized subject to the following constraint specifications.

Land Constraint: The first constraint equation is for land. The equation is $\sum_{m=1}^{3}\sum_{n=1}^{10} A_{mn} \leq 160$. This restricts the acreage in the model to 160 acres or less. This figure is the total acres for any combination of the three crops, m, and any combination of n irrigation regimes for each crop. The 30 activities represent variations in water application and crops. Rainfall is treated as water available and not as applied. Each of the 30 crop activities has unique variable cost, yield and water use relationships.

Labor Constraint: The labor constraint equation is $\sum_{m=1}^{3}\sum_{n=1}^{10}(L_{mno} - LH_o) \leq 54$. This equation limits the amount of operator labor to 54 hours in each period (month), excluding that which is hired, LH. Labor use is the amount required by each crop and irrigation regime for each month,o. Hired labor is used to meet the requirements not met by operator labor. The maximum amount of operator labor available is based on farm record information regarding an average sized irrigation farm in western Kansas. Estimates are based on one full time equivalent person per 640 acres irrigated. Thus 160 acres of irrigation is assigned 54 hours or one-fourth of the full time equivalent. Labor requirements per acre are taken from published labor standards(Kansas State University).

Pump Hour Constraint: The pumping hours equations limit the pumping that can occur in each period,p. The equation is $\sum_{m=1}^{3} \sum_{n=1}^{10} HRS_{mnp} \leq PHRS_p$. Pumping hours per period are calculated by multiplying 24 hours per day times the number of days per period. The pumping periods are specified in Figure 1 and explained in further detail in the section which explains the crop calender.

Soil Moisture Constraints: Soil moisture constraints specify the water holding capacity of the soil in its upper and lower profile. The differentiation between upper and lower soil profile is made due to the amount of reclaimable moisture in each profile. More water can be reclaimed, of the amount placed into, the upper 9 inches or upper profile than can be reclaimed from the lower profile or next 51 inches.

The constraints specify the maximum amount of water that can be stored in each profile which is available to meet crop water needs. The soil studied is a silt loam with a full soil water capacity of 16.3 inches of moisture.[1] However, not all of this moisture is available to the plant for use. This soil is fairly representative of the western Kansas irrigated areas. The upper soil profile equation, which constrains the amount of moisture that can be stored in the upper profile (ACINU), is $\sum_{m=1}^{3} \sum_{n=1}^{10} \sum_{q=1}^{39} ACINU_{mnq} \leq 224$. The equation for the lower soil profile is $\sum_{m=1}^{3} \sum_{n=1}^{10} \sum_{q=1}^{39} ACINL_{mnq} \leq 752$. The upper soil profile constraint

1. One acre inch is 27,158 gallons.

applies to the first 9 inches of soil profile and the lower profile refers to the next 51 inches of soil profile. In the upper profile there is .155 acre inches of moisture per inch of profile per acre at full soil capacity or 1.395 acre inches per acre in the first 9 inches. The corresponding figure for the lower soil profile is .092 acre inches of soil moisture per inch of profile per acre at full soil capacity or 4.962 acre inches per acre in the 51 inches of lower profile. In any particular pumping period, q, soil storage cannot exceed the maximum values based on soil water holding capacity and acreages. The two maximum values of soil storage, 224 acre inches for the upper profile and 752 acre inches for the lower profile, were calculated as the amount of available storage between field capacity and the permanent wilting point for each soil profile for the entire 160 acres.

Crop Calender

The crop irrigation calender, Figure 1, shows the relationship between irrigation periods and crop vegetative stages. The crop growing season is divided into vegetative stages because moisture deficits affect yield differently in each crop stage.

In general the crop stages are:

1) Pre-season and emergence: The stage which includes the time period from crop removal in the fall of the year until the time when the crop is planted, emerge and has begun growth.
2) Vegetative: This stage encompasses the time period from the end of the pre-irrigation until the flowering stage. The vegetative stage is when most of the plant growth occurs.

Figure 1: Crop irrigation calendar of pumping periods, number of days per period and crop vegetative stages.

<table>
<tr><th>Month and Day</th><th>Pump Period</th><th>No. of Days Per Period</th><th>Corn</th><th>Grain Sorghum</th><th>Wheat</th></tr>
<tr><td>April 1-30</td><td>1</td><td>30</td><td rowspan="2">Pre-Plant</td><td rowspan="7">Pre-Plant</td><td></td></tr>
<tr><td>May 1-6</td><td>2</td><td>6</td><td rowspan="2">Pre-Boot</td></tr>
<tr><td>May 6-15</td><td>3</td><td>9</td><td rowspan="3">First Vegetative</td></tr>
<tr><td>May 15-28</td><td>4</td><td>13</td><td>Boot</td></tr>
<tr><td>May 28 to June 3</td><td>5</td><td>9</td><td>Flowering</td></tr>
<tr><td>June 3-10</td><td>6</td><td>7</td><td rowspan="3">Second Vegetative</td><td>Fill</td></tr>
<tr><td>June 10-17</td><td>7</td><td>7</td><td rowspan="8">No Irrigation</td></tr>
<tr><td>June 17-30</td><td>8</td><td>12</td><td rowspan="3">Pre-Boot</td></tr>
<tr><td>June 30 to July 15</td><td>9</td><td>16</td><td>Silk</td></tr>
<tr><td>July 15-17</td><td>10</td><td>2</td><td rowspan="2">Milk</td></tr>
<tr><td>July 17 to Aug. 5</td><td>11</td><td>20</td><td rowspan="2">Boot and Heading</td></tr>
<tr><td>August 5-16</td><td>12</td><td>11</td><td rowspan="2">Dough</td></tr>
<tr><td>August 16-20</td><td>13</td><td>4</td><td rowspan="2">Filling</td></tr>
<tr><td>August 20 to Sept.2</td><td>14</td><td>12</td><td rowspan="3">No Irrigation</td></tr>
<tr><td></td><td></td><td></td><td rowspan="2">No Irrigation</td><td rowspan="2">Pre-Plant</td></tr>
<tr><td>September 12-27</td><td>15</td><td>15</td></tr>
</table>

3) Flowering:This stage is the shortest stage, lasting in some instances only a few days. This stage is the most critical in terms of the effect of moisture stress on yield.

4) Grain Formation: This stage includes the formation and filling of the grain. Moisture stress in this stage can reduce number as well as weights of individual kernals of grain and thus reduce yield.

5) Ripening: This is the final growth stage and involves the final maturity of the plant. In this stage excess moisture causes a problem due to the need for the crop to dry down as harvest approaches.

In corn, the silk stage is the flowering stage and the milk and soft dough stages correspond to the grain formation stage. In grain sorghum, the pre-boot stage is the vegetative stage, the boot and heading stages are the flowering and the head filling is the grain formation stage. For wheat, the pre-boot stage is the vegetative stage followed by a period of dormancy, the boot and heading stages are the flowering stage and grain filling stage is the grain formation stage.

Pumping periods are delineated by the growing stages of each crop. For example, period two is a six day period that begins with the pre-boot stage of wheat and ends with the finishing of the pre-season irrigation of corn stage. The yield response to water in corn is different in the stage following pre-season irrigation, therefore another pumping period is needed. Within a pumping period the yield response remains constant for all crops. A new pumping period is required if for at least one crop the growth stage changes so that the yield response changes.

In addition the model must reflect the amount of time available in each growth stage for pumping so that growth stage and pumping hours available match up. The first portion of the calender illustrated the pumping period by number and the days per pumping period. Each of the respective crop growth stages, are, for the most part, composed of several pumping periods because the crop growth stages of one crop overlap those of another. Additional irrigation can be done in the October to March periods. As the crop enters more critical stages and moisture needs and usage increase, there is an increase in the competition for the water available. With a limited water supply, which is available in these critical stages, allocation of water to the alternative crops is based on the highest net returns in each growth stage.

Activities of the Model

The activities of this model are grouped into ten categories. These include crop irrigation activities, crop sales, fertilizer supply, labor hiring, direct pumping, soil filling top, soil filling lower, transfer soil moisture upper, transfer soil moisture lower, and supply rainfall. Three major grain crops, corn, grain sorghum and wheat are irrigated in western Kansas and are included in this model.

If water is not a limiting factor, crops which utilize more water such as corn and grain sorghum are preferred to wheat as the primary choice of irrigators because the yield response to moisture is greater. If moisture is plentiful at a low cost, producers tend to shift to corn because it has higher net returns than wheat and grain sorghum. When moisture is limited and expensive, managers tend to switch to grain sorghum and wheat. It was for this reason that the three crops utilized in the model were chosen. Figure 2 is a diagram of the general format of the model used and references in the rest of this chapter will be to Figure 2.

Figure 2: General Format of the Linear Programming Model.

	Row #	Crop Regime	Crop Sales	Fertilizer Supply	Labor Hire	Direct Pumping	Soil Fill. Upper	Soil Fill. Lower	Transfer Soil Moist. Upp.	Transfer Soil Moist. Low.	Supply Rain	RHS
Objective	1	neg. coeff.	pos. coeff.	neg. coeff.	neg. coeff.	neg. coeff.	neg. coeff.	neg. coeff.	-0- coeff.	-0- coeff.	-0- coeff.	Z
Land	2	pos. coeff.										b_2
Fertilizer	3-5	pos. coeff.		neg. coeff.								b_3-b_5
Labor	6-17	pos. coeff.			neg. coeff.							b_6-b_{17}
Crop Production	18-20	neg. coeff.	pos. coeff.									b_{18}-b_{20}
Water Needs by Crop Stage	21-35	pos. coeff.				neg. coeff.			neg. coeff.	neg. coeff.	neg. coeff.	b_{21}-b_{35}
Pumping Hours Available	36-58					pos. coeff.	pos. coeff.	pos. coeff.				b_{36}-b_{58}
Water Applied to Upp. Prof.	59-73						neg. coeff.		pos. coeff.			b_{59}-b_{73}
Water Applied to Low. Prof.	74-98							neg. coeff.		pos. coeff.		b_{74}-b_{98}
Upper Soil Moist. Limit	99-113						pos. coeff.					b_{99}-b_{113}
Lower Soil Moist. Limit	114-128								pos. coeff.			b_{114}-b_{128}
Rainfall	129-140										pos. coeff.	b_{129}-b_{140}

Crop Activities

Ten different crop irrigation regimes were developed for each of the three crops. Water use needs and associated crop yields are listed for each crop combination in Table 1.

Variable costs include drying costs, which vary based on yield and are shown as a negative coefficient in the objective row of the crop regime activitiy in Figure 2. Positive coefficients show up for land, fertilizer, labor and water requirements for associated crop growth stages. A negative coefficient appears in the crop production row and represents a supply of the resource while a positive coefficient implies a usage of the resource. In the objective row, the signs of the coefficients have just the reverse meaning as in the other activity rows.

For each crop activitiy, a positive use coefficient appears in each of rows 3,4 and 5. These rows correspond to the various fertilizer components, nitrogen, phosphorous and potash, and represent the amount of nutrient removed from the soil to produce the yield. There are no limits on the units of fertilizer which can be supplied.

The land row, #2, shows a positive use coefficient, and represents the amount of ground needed for each unit of crop produced. This resource has a limit which is imposed on the model, and no additional ground can be provided for the model.

The labor rows, 6-17, correspond to the calender months, and represent the amount of labor required per month, for each unit of crop produced. Additional labor can be hired if economical.

Rows 18-20 provide for the crop production for each of the crops. With these rows, there are no limits.

Rows 21-35, show positive use coefficients which provide for the

Table One: Water requirements of Corn, Grain Sorghum and Wheat by stage of growth, yield per acre and irrigation regime. [Acre inches per acre]

	Irrigation Regime									
Crop Stage	1	2	3	4	5	6	7	8	9	10
Corn										
Pre-Irr.	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
1st Veg.	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96
2nd Veg.	10.5	10.5	10.1	10.1	9.1	10.1	10.1	10.1	10.1	9.1
Silk	6.12	6.12	6.2	6.2	6.2	6.2	6.2	6.0	6.0	6.2
Milk	8.03	7.74	7.8	7.8	7.9	7.7	7.7	7.7	7.3	7.4
Dough	4.9	4.94	4.6	4.6	4.8	4.4	4.0	4.5	4.7	3.9
Yield per Acre	146.4	138.72	136.8	129.59	119.68	114.36	105.59	99.17	91.11	87.62
Grain Sorghum										
Pre-Irr.	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Boot	11.5	11.0	10.4	11.0	11.0	11.0	10.4	10.4	11.0	10.4
Heading	10.6	10.3	11.1	10.3	10.4	10.4	10.5	10.2	10.2	10.2
Filling	4.8	4.9	4.9	5.0	4.9	4.6	4.9	4.8	4.7	4.6
Yield per Acre	140.54	134.16	130.70	128.09	108.52	102.17	98.71	90.99	82.03	78.57
Wheat										
Pre-Irr	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Pre-Boot	4.2	4.2	3.9	3.9	3.9	3.9	4.2	3.9	3.9	3.9
Boot	3.7	3.6	3.6	3.6	3.6	3.6	3.7	3.4	3.4	3.4
Flower	3.2	3.0	3.1	3.1	3.1	3.2	3.1	3.2	3.2	2.6
Milk	2.7	2.7	2.7	2.7	2.6	2.6	2.5	2.7	2.6	2.3
Yield per Acre	54.0	50.57	48.25	46.37	43.71	40.25	40.10	35.90	33.53	26.30

amounts of water needed for each crop stage within each crop regime. With these rows, there are again, no limits.

Crop Sales Activities

The crop sales activities provide for the disposal of crop production and the generation of income for the model. The positive coefficient in the crop production row, reduces the crops produced as a means of providing production for sale.

Fertilizer Supply Activities

The fertilizer supply activities provide for the replacement of nutrients used in crop production. In this model, the purpose of this seperate activity was to act as a place holder and allow for analysis of fertilizer price changes in later studies. In the crop production activities, the actual dollar cost per unit is used. In order to supply this fertilizer need, the model must supply the needed dollar amounts at a constant cost of one dollar for one dollar. Fertilizer requirements are different for each crop irrigation regime and the costs are based on the USDA cost figures from 1982 for each nutrient.

Labor Hire Actities

The model can hire labor to meet needs above the amounts of operator labor available. The negative objective value, in Figure 2, for labor hire, represents the cost per unit of hired labor. Each unit hired, supplies one unit of labor to the respective month.

Direct Pumping Activities

Twenty-three pumping periods are specified in the model; (Rows 36-58). These pumping periods reflect periods that allow for the irrigation of any of the three crops. This activity provides direct water application. A variation, soil filling, provides water to the soil profile for later use, and will be discussed later.

The objective function coefficient reflects total pumping costs based on the hourly cost of pumping and the number of hours pumped. Six different flow rates were used in seperate analysis with the model. Pumping hours and costs were estimated for the applicable flow rates (GPM) and are listed in Table 2. (Williams, etal., 1983).

Table 2: Pumping cost for Six Flow Rates by Amount of Water Applied.

Amount of Water Applied	1200 GPM	1000 GPM	800 GPM	600 GPM	400 GPM	200 GPM
			dollars per hour			
6"	5.08	4.27	3.48	2.74	2.04	1.36
12"	4.56	3.84	3.20	2.56	1.94	1.31
18"	4.39	3.71	3.11	2.40	1.90	1.29
24"	4.30	3.64	3.06	2.47	1.88	1.28
Average	4.58	3.87	3.30	2.57	1.94	1.31

The following factors were used in the development of the pumping costs:

Lift: 150'
Pump Efficiency: 60%
Drive Efficiency: 95%
Fuel Cost: \$2.50/100Ft^3 N.G.
Oil Cost: \$5.00/Gallon
Maintenence of Power Unit: \$2.35/BHP
System Maintenence: \$1.00/Acre
PSI: 10
Acres: 160

To study the effect of a 1200, 1000, 800, 600, 400, or 200 GPM well yield on crop selection, required changing the coefficients in the objective row relating to the pumping activities and the amount of water pumped per hour, each time the flow rate was changed. The pumping activities are in units of acre-inches per hour and the calculations showing the conversion of gallons per minute to net acre inches are reported in Table 3.

Table 3: Calculations of Acre Inches of Maximum Water Applications At Different Flow Rates.

Flow Rate		Gallons per Acre Inch	Gross Application Amount(100% effic.)		Efficiency percent	Net Application Amount
1200	÷	450	= 2.67 Ac.In./hr.	x	75%	= 2.00 Ac.In./hr.
1000	÷	450	= 2.22 Ac.In./hr.	x	75%	= 1.67 Ac.In./hr.
800	÷	450	= 1.78 Ac.In./hr.	x	75%	= 1.34 Ac.In./hr.
600	÷	450	= 1.33 Ac.In./hr.	x	75%	= 1.00 Ac.In./hr.
400	÷	450	= .89 Ac.In./hr.	x	75%	= .67 Ac.In./hr.
200	÷	450	= .44 Ac.In./hr.	x	75%	= .33 Ac.In./hr.

The hours of total pumping time per period are limited to the total calendar hours per period. Each pumping activity is also restricted to the specific vegetative growth stage.

A flood irrigation system was assumed in this study. An application efficiency of 75 percent was used due to water loss in application.

Soil Filling Activities

The model allows for water storage in the soil for use at a later time through use of the soil moisture filling activities. There is an upper and a lower soil profile which differ in the amount of reclaimable moisture that each can store. This affects the model in that an acre inch of moisture pumped to fill the upper soil profile will have a greater percentage available for reclaimation by the plant and thus a lower cost per unit of relaimable moisture than will an acre inch placed in the lower profile.

The soil filling activities utilize pumping hours available, rows 36-58, to provide soil moisture stored, into rows 59-73 or 74-98. The objective value is the same as for direct pumping. Each soil profile has a maximum amount of storage space and with each unit pumped, the respective soil moisture limit is adjusted by the positive coefficients in rows 99-113 or 114-128.

Soil Moisture Transfer Activities

The soil moisture transfer activities allow available water not used by the plant to become available at a later period. There is no associated cost with the transfer. The transfer coefficients show a positive use figure from the soil profiles, (rows 59-98) and a negative supply coefficient in the respective crop growth stage, row 21-35.

Rainfall Activities

Moisture available as rainfall is supplied to the various stages of crop growth at no cost. The moisture level available from rainfall in each period is fixed and is based on historical rainfall data from Garden City, Kansas. These figures are listed in Table 4. The negative coefficient, rows 21-35, supplies moisture to the various crop stages, while the positive use coefficients, rows 129-140, reduce the amount available by one unit.

Table 4: Monthly Historical Rainfall Data from Garden City, Kansas.

Month	Amount	Month	Amount	Month	Amount
January	.35	May	3.26	September	1.47
February	.45	June	2.87	October	.87
March	1.15	July	2.16	November	.75
April	1.42	August	2.16	December	.32

Chapter Five

Linear Programming Coefficient Specification

A variety of information and data were utilized in the development of the coefficients for the linear programming model. A model developed by Roeder, 1981, provided a starting point for the model used in this study. Roeder's model studied the effects of limited irrigation on crop selection by reducing flow rates and then evaluating shifts in crop selections. His model did not consider storing water in the soil as a means of meeting water needs during critical crop periods.

Expected costs and returns for corn, grain sorghum, and wheat were based on the 1983 Kansas State University Farm Management Guides. The specific budgets appear in Appendix A. The budgets are based on data derived from actual farm operation records. Variable costs for corn and grain sorghum are adjusted for the model as yields vary because different fertilizer requirements are based on yield per acre. Variable costs also vary with the specification for irrigation water use.

The variable costs for pumping the water are specified in the water pumping activities section of the model. The greater the amount of water supplied by irrigation and the lower the flow rate (GPM), the greater the hours that are required to pump water to supply crop needs. This results in higher variable costs.

Labor requirements used in the model are from the Kansas State University Labor Requirements of Western Kansas Crops bulletin, (1975). Labor requirements are specified for crop and field work as well as the labor needed for irrigation in this bulletin. Also from this bulletin, the hours of operator labor available were derived. The coefficients in the bulletin were for 640 acres and thus were reduced by one-fourth to represent the 160 acres used in the model.

Crop Yield and Available Soil Moisture

Grain yields are specified as a function of a particular soil moisture regime. The relationship between soil moisture and grain yield is a key portion of the model.

Results reported by Mapp etal, 1975, are the basis for the water-yield relationships specified in the study model. The relationship reported by Mapp etal, 1975, estimates yield reduction relative to moisture stress levels.

The equation is outlined as follows:

$$YR_{ijk} = A_{jk} * [13.8 - SMT_{ij}] / 5.1 + B_{jk} * [P_{ij} - P_a]$$

Where: YR_{ijk} = The amount of yield reduction on day i, crop stage j and crop k.

A_{jk} = Yield reduction coefficient related to adverse soil moisture content.

13.8 = A constant term measured in inches of soil moisture. This constant indicates the threshold level where plants begin to suffer stress and yield reductions. Once soil moisture falls below this level, stress and yield reduction occur.

SMT_{ij} = Amount of moisture which is in the entire soil profile on day i and crop stage j.

5.1 = A constant which represents the amount of soil moisture difference between 13.8 and the permanent wilting point which occurs at 8.7 inches of soil moisture.

B_{jk} = Coefficient which expresses the relationship of yield reduction and atmospheric stress.

P_{ij} = Coefficient of pan evaporation for the particular day i and crop stage j.

P_a = Constant pan evaporation level below which no yield reduction due to atmospheric conditions will occur.

The values for A_{jk} and B_{jk}, which vary with each crop and growth stage are listed in Table 5.

Table 5: Yields Reduction Equation Coefficient Values by Crop and Growth stage.

Corn			Grain Sorghum			Wheat		
Stage	A_{jk}	B_{jk}	Stage	A_{jk}	B_{jk}	Stage	A_{jk}	B_{jk}
1st. Vege.	.2	.1	P-Boot	.3	1.3	P-Boot	.5	.0
2nd. Vege.	1.15	.6	Boot-Head	2.04	1.65	Boot	1.02	1.1
Silk	3.05	1.6	Filling	1.27	1.50	Flower	1.55	1.2
Milk	1.14	.4				Filling	1.66	1.5
Dough	1.57	.1						

Pan evaporation figures are derived from historical data from the Garden City, Kansas Experiment Station Branch. Monthly figures in Table 6 show the potential evaporation per day. [Table 6 found on Page 39].

The study examines four different soil moisture levels and the effects these moisture levels have on yield and ultimately crop irrigation choices and amounts. The first level maintains soil profile moisture at 85 percent of field capacity which is approximately 13.8 inches of soil moisture. Maintaining soil moisture at this level is assumed to avoid plant stress and consequently result in no yield reduction. A second moisture level of 75 percent of field capacity and a third of 65 percent of field capacity were used as well. A fourth level at about 53.37 percent of field capacity, assumed that permanent wilting would be avoided.

By using the equation from Mapp etal, 1975, and the above four soil moisture levels, the coefficients for yield reductions in Table 7 were calculated. In the equation, values for $A_{jk}$and B_{jk} were drawn from those given in Table 5 and P_a was a constant value of .4 acre inches per day per acre. The only two terms to vary were P_{ij} which was taken from Garden City record data and SMT_{ij}. SMT_{ij} for any given point was determined by a simple debit and credit accounting system. For example to maintain corn at 75 percent of capacity, SMT_{ij} was maintained at a level such that it never fell below the 75 percent level. As these computations occurred a tally was kept of the amount of yield reduction as well as the amount of moisture required to maintain the soil moisture at the desired level. These figures were then incorporated into the model. The yield reduction estimates are in Table 7 and were used to determine each yield amount for each crop and irrigation scheme. The amounts of moisture needed were also used in the coefficients for water needed for the crops with their respective yield figures. Analysis of the information provided in Table 1, indicates that there is an increasing water use efficiency as the amount of water applied

Table 6: Potential Evaporation Values by Month (P_{ij}).

Month	Potential Evaporation		Days		Amount/Day
April	8.79"	÷	30	=	.293"
May	10.96"	÷	31	=	.3536"
June	13.90"	÷	30	=	.463"
July	14.96"	÷	31	=	.483"
August	12.78"	÷	31	=	.412"
September	9.80"	÷	30	=	.327"
October	7.13"	÷	31	=	.23"

Table 7: Yield Reductions for Different Levels of Available Soil Moisture By Crop and Stage. (bu./ac.)

Crop and Stage	Soil Moisture Levels			
	85%	75%	65%	53.37%
Grain Sorghum				
Pre-Boot	2.56	5.90	8.94	12.40
Boot-Heading	1.90	21.47	41.64	65.18
Filling	--	6.07	12.42	20.00
Wheat				
Pre-Boot	--	1.35	4.20	6.75
Boot	--	3.43	7.67	12.61
Flower	.30	2.96	6.30	14.25
Filling	.70	4.27	7.98	11.62
Corn				
1st Vegetative	--	.155	3.65	5.91
2nd Vegetative	1.05	10.61	20.52	31.90
Silking	2.08	17.82	32.64	50.88
Milk	.50	8.15	16.21	25.56
Dough	--	7.22	14.79	23.57

increases. This problem will be discussed in detail later.

Marketing Activities

The crop selling activity provides a way of incorporating gross receipts into the model. The prices are based on long term average price relationships in the western Kansas area.

Pumping Activities

The variable costs for the pumping activities in the objective function for each flow rate considered are found in Table 2. An application efficiency of 75 percent is used to account for inefficiencies in the flood irrigation water application.

Soil filling activities are an extension of the pumping activities. This activity allows for irrigated water to be stored in the soil for later use. Using the soil as a moisture reservoir allows irrigation to occur in periods of smaller demand when more time is available for irrigation.This allows the manager to more easily meet required moisture needs during the critical growth stages. The corn silk stage is a critical period for moisture needs and is a relatively short period. Due to high evapotranspiration demands occuring at this time, it may be impossible to provide adequate moisture by direct pumping to meet the needs of the crop unless a high GPM is possible. If however, the soil profile could hold a portion of the moisture needed, then less rèliance would need to be placed on pumping irrigation water during the growth period.

Chapter Six

Model Results

Results from the six levels of flow rates, with all other variables held constant, sutdied are reported in Table 8. The six situations are based on flow rates of 1200, 1000, 800, 600, 400, and 200 gallons per minute (GPM). The underlying purpose for studying these 6 alternative flow rates in the study, is to ascertain the progression in adjustments and decisions which are a function of the level of the flow rate. The changes in GPM studied could represent the changes in an irrigation system over time or the conditions representative of various irrigation systems in the same area.

1200 GPM Results For a flow rate of 1200 GPM, the results indicate that all 160 acres of cropland are used and planted to corn. All operator labor available is used in four months, so additional labor is hired. The total acre inches of irrigation water supplied either for direct irrigation or for soil filling is 4,238.4 acre inches or 26.49 acre inches per acre. Of this total, 2,108.8 acre inches (13.18 acre inches per acre) is pumped for soil filling with 672 acre inches (4.2 acre inches per acre) going into the upper profile and 1,436.8 acre inches (8.98 acre inches per acre) going into the lower profile. As can readily be seen both of these per acre amount are above capacity. This is possible due to the filling, draw down and subsequent repeating of the process which occurs during the season. Corn production is 23,424 bushels (146.4 bu. per acre) for gross returns of $70,272.00. The objective value or net returns, for costs considered, is $36,175.66 (226.10 per acre). Acre inches of rainfall used are 2,083.2 acre inches (13.02 acre inches per acre) from March through August. This rainfall use remains constant throughout the study. The corn production alternative chosen is the highest yield level available. The 1200 GPM well capacity is adequate to meet moisture requirements without a reduction in yield as well as allow some excess capacities to exist. The shadow price of land is $189.53 per acre and the shadow price for labor is $5.00 which is the cost of hiring an additional unit of labor. The shadow prices are outlined in Table 9. The shadow price of an additional acre inch of moisture in the most significant periods is $2.29 which is the cost of pumping an acre inch of water.

With the shadow price on cropland of $189.53. each additional acre could add that amount to the objective value. In this situation, land is the limiting resource, because more water is available for a cost of $2.29 per acre inch and labor is available, if profitable, in unlimited quantities.

1000 GPM Results

For a flow rate of 1000 GPM, the results indicate that 160 acres of cropland are used and planted to corn. All operator labor available is used in four months and additional labor is hired. The total acre inches of irrigation water supplied either for direct irrigation or for soil filling is 4,238.28 acre inches or 26.49 acre inches per acre. Of this total, 922.42 acre inches (5.77 acre inches per acre) are pumped for soil filling with 447.56 acre inches (2.80 acre inches per acre) going into the upper profile and 474.86 acre inches (2.97 acre inches per acre) going into the lower profile. Corn production from this result is 23,242 bushels (146.4 bu. per acre) for gross returns of $70,272.00. The objective value or net returns for costs considered in this situation, are $36,059.68 ($255.37 per acre). As with the 1200 GPM situation, the

Table 8: Model Results

	1200 GPM	1000 GPM	800 GPM	600 GPM	400 GPM	200 GPM
Objec. Value[1]	$36,175.66	$36,059.68	$35,262.42	$33,989.28	$30,899.81	$24,997.70
Objec. Va/Ac.	226.10	225.37	220.39	212.43	193.12	180.55
Cropland Used	160.00	160.00	160.00	160.00	160.00	132.97
Corn Acres	160.00	160.00	154.81	109.47	72.49	45.73
Grain Sor. Ac.	--	--	5.19	49.55	51.96	25.59
Wheat Acres	--	--	--	.98	35.55	61.65
Labor Hours Used (Operator)						
March	49.60	49.60	49.60	49.30	38.58	22.11
April	54.00	54.00	54.00	51.93	36.68	22.28
May	11.20	11.20	12.39	22.65	24.93	18.28
June	54.00	54.00	54.00	54.00	54.00	54.00
July	54.00	54.00	54.00	54.00	54.00	50.14
August	52.80	52.80	51.90	44.46	47.17	45.08
September	25.60	25.60	25.65	26.52	41.41	48.04
October	24.00	24.00	23.22	16.52	14.43	13.02
November	54.00	54.00	54.00	54.00	54.00	54.00
December	38.40	38.40	38.40	38.16	29.87	17.12
Corn Produced	23,424.00	23,424.00	22,664.00	16,026.62	10,612.68	6,695.08
Corn Prod/Ac	146.4	146.4	146.4	146.4	146.4	146.4
Grain Sorg.Prod	--	--	729.56	6,694.32	7,302.68	3,596.84
Grain Sorg.Prod/ Acre	--	--	140.5	140.5	140.5	140.5
Wheat Produced	--	--	--	52.62	1,919.53	3,329.10
Wheat Produced Per Acre	--	--	--	53.7	53.7	53.7
Nitorgen Cost	$ 4,100.00	$ 4,100.00	$ 4,034.20	$ 3,450.18	$ 2,892.73	$ 2,140.85
Phos. Cost	$ 1,248.00	$ 1,248.00	$ 1,268.25	$ 1,438.73	$ 1,358.22	$ 976.72
Potash Cost	$ 520.00	$ 520.00	$ 520.00	$ 520.00	$ 520.00	$ 432.17
Labor Units Hired						
April	13.20	13.20	11.64	--	--	--
June	14.80	14.80	15.01	17.11	28.96	25.16
July	.40	.40	.40	.48	3.24	--
November	94.80	94.80	94.70	92.90	60.70	11.82

[1]Net returns given the costs considered.

corn production alternative chosen is the one with the highest costs and production due to the fact that there is adequate water to avoid a reduction in yield. Again, there is excess irrigation capacity available.

The results of this situation give a shadow price of $188.45 for

Table 9: Shadow Price Comparisons.

	1200 GPM	1000 GPM	800 GPM	600 GPM	400 GPM	200 GPM
Land per acre	$ 189.53	$ 188.45	$ 151.07	$ 123.62	$ 89.05	$ 0.0
Labor per Hour	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
Cost of Pumping an Additional Acre Inch of Moisture	$ 2.29	$ 2.32	$ 2.48	$ 2.57	$ 2.90	$ 3.97
Value of Added Unit of Soil Moisture by Crop Stage						
CPREIR	$ 2.29	$ 2.32	$ 2.48	$ 2.57	$ 2.90	$ -.-
C1ST	$ 2.29	$ 2.32	$ 2.48	$ 2.57	$ 2.90	$ -.-
C2ND	$ 2.29	$ 2.32	$ 3.53	$ 3.85	$ 5.56	$ 9.60
CSILK	$ 2.29	$ 2.32	$ 3.53	$ 4.85	$ 5.56	$ 9.60
CMILK	$ 2.29	$ 2.32	$ 3.53	$ 4.85	$ 5.56	$ 9.60
CDOUGH	$ 2.29	$ 2.32	$ 3.53	$ 4.85	$ 5.56	$ 9.60
GSPREIR	$ 2.29	$ 2.32	$ 2.48	$ 2.57	$ 2.90	$ -.-
GSPBOOT	$ .40	$ .45	$ 2.48	$ 2.57	$ 4.57	$ 7.98
GSBOOTH	$ 2.29	$ 2.32	$ 3.53	$ 4.85	$ 5.56	$ 9.60
GSFILL	$ -.-	$ -.-	$ -.-	$ 2.57	$ 2.90	$ 9.60
WPREIR	$ -.-	$ -.-	$ -.-	$ -.-	$ 2.90	$ 12.81
WPBOOT	$ 2.29	$ 2.32	$ 2.48	$ 2.57	$ 2.90	$ -.-
WBOOT	$ -.-	$ -.-	$ -.-	$ -.-	$ -.-	$ -.-
WFLOWER	$ -.-	$ -.-	$ 3.53	$ 3.85	$ 5.56	$ 9.60
WMILK	$ -.-	$ -.-	$ 3.53	$ 3.85	$ 5.56	$ 9.60

cropland, $5.00 for labor and $2.32 for an additional unit of moisture. The labor shadow price is the same as for the 1200 GPM level. The shadow price of an additional acre inch of moisture is $2.32 which is again, equal to the cost of pumping the additional acre inch of water (Total Costs for one hour is $3.87 which supplies 1.67 acre inches of water). As before, it is not profitable to apply additional water. If additional land is available, and all other resources and variables are the same, the objective value can be improved. Labor and moisture are not the limiting resources but land is, resulting in a high shadow price.

<u>800 GPM Results</u>

For a flow rate of 800 GPM, the results indicate that 160 acres of cropland are used. In this situation though, 154.81 acres are planted to corn and 5.19 acres planted to grain sorghum.

The operator and hired labor are the same as in previous situations. The total acre inches of irrigation water supplied either for direct irrigation or for soil filling are 4,220.84 acre inches or 26.38 acre inches per acre. Of this total, 2,133.22 acre inches (13.3 acre inches per acre) are pumped for soil filling with 953.2 acre inches (5.96 acre inches per acre) going into the upper soil profile and 1,180.02 acre inches (7.38 acre inches per acre) going into the lower profile. Corn production from this situation is 22,664 bushels (146.4 bu. per ac.) and grain sorghum production is 729.56 bushels (140.57 bu. per ac.). Gross returns are $69,830.49 with an objective value or net returns of $35,262.42 for the costs considered or $220.39 per acre. For the 800 GPM situation, using the soil as a water reservoir becomes important. The well capacity is unable to meet the moisture needs during critical crop stages without storing some in earlier periods. As before, the crop production level chosen, for both corn and grain sorghum, are the ones with the highest costs and production with no yield reductions. The substitution to grain sorghum is beginning due to its reduced water needs when compared to corn, as well as a slightly different usage pattern.

In this situation, the shadow price of land is $151.07 with a shadow price of $5.00 for labor. For water, two shadow prices emerge, $2.48 and $3.53. The shadow price for additional water points out in which growth periods water is a limiting resource. For corn, the stages of second vegetative, silk, milk and dough have a higher shadow price as does the boot to heading stage in grain sorghum. These periods represent fairly high consumptive demands as well as overlap in terms of competition for moisture. The lower shadow price is equal to the cost of pumping an additional acre inch of moisture. The higher shadow price specifies in which period the value of water exceeds the cost of pumping that water.

As before, land is a limiting resource and more acres would increase the objective value. In this alternative however, moisture is becoming more of a limiting resource. In comparison to the 1200 GPM level, the 800 GPM level has 97.5 percent of the return of the 1200 GPM level, with the same amount of water used.

600 GPM Results

For the flow rate of 600 GPM, the results indicate that 160 acres of cropland are used. In this situation, 109.47 acres are planted to corn, 49.55 acres are planted to grain sorghum and .98 acres are planted to wheat. All operator labor available is used in three months with the balance needed in those months being hired. The total acre inches of irrigation water supplied either for direct irrigation or for soil filling is 3.742.6 acre inches or 23.39 acre inches per acre. Of this total, 2,343.87 acre inches (14.65 acre inches per acre) are pumped for soil filling with 608 acre inches (3.8 acre inches per acre) going into the upper soil profile and 1,735.87 acre inches (10.85 acre inches per acre) going into the lower soil profile. Corn production is 16,026.62 (146.4 bu. per acre), grain sorghum production is 6,964.32 bushels (140.57 bu. per acre) and wheat production is 52.62 bushels (53.7 bu. per acre).

Gross returns are $65,841.48 with an objective value or net return figure of $33,989.28 (212.43 per acre) for the costs considered.

Crop production levels chosen are again the high for each of the crops, both in terms of costs and production and water use. The model selects the crop alternative that avoids any reduction in crop yield. At this well yield, the problem of moisture begins to be more noticable and significantly affects the crop mix.

In this situation, the shadow price of land is $123.63 and the shadow price for labor, as before, is $5.00. For the additional acre inch of moisture shadow prices, three now emerge: $2.57, $3.58 and $4.85. As before, the $2.57 shadow price reflects a period in which the cost of pumping is equal to the value of the added acre inch. At the $3.58 shadow price, the value of the additional acre inch of water has a value of 149 percent of the cost of pumping the added unit. The $4.85 shadow price level shows a period during which the vaule is 189 percent of the cost of pumping the unit (4.85 shadow price vs. the $2.57 cost to pump). The $3.58 shadow prices correspond to the second vegetative stage of corn and the flower and milk stages of wheat. The $4.85 shadow prices correspond to the silk, milk, and dough stages of corn, and the boot to heading stage of grain sorghum. Again these are the high use periods as well as those which have the greatest competition among crops.

Land is still a limiting resource but the shadow price has declined to 65 percent of the respective shadow price at the 1200 GPM level. This further stresses the importance water supply is assuming as well yield declines. In addition, the 600 GPM level has 94 percent of the returns of the 1200 GPM level and uses 96 percent of the moisture used at the 1200 GPM level.

400 GPM Results

For a flow rate of 400 GPM, the results indicate 160 acres of cropland are again used. In this situation 72.49 acres are planted to corn, 51.96 acres are planted to grain sorghum and 35.55 acres are planted to wheat. All operator labor available is used in June, July and November and is handled as before. The total acre inches of irrigation water supplied, either for direct irrigation or for soil filling is 2,857.9 acre inches or 17.87 acre inches per acre. Of this total, 1,957.58 acre inches (12.23 acre inches per acre) are pumped for soil filling with 770.74 acre inches (4.82 acre inches per acre) going into the upper soil profile and 1,186.84 acre inches (7.42 acre inches per acre) going into the lower profile. Corn production from this situation is 10,612.68 bushels (146.4 bu. per acre), grain sorghum production is 7,302.68 bushels (140.5 bu. per acre) and wheat production is 1,919.63 bushels (53.9 bu. per acre). Gross returns are $57,957.70 with an objective value or net return figure of $30,899.31 ($193.12 per acre) for the costs considered. Crop production is again the highest in terms of costs and yields with no reduction in yield for any crop resulting from a shortage of water. At this level, a dramatic shift from corn to wheat occurs.

In this situation, the shadow price of land is $89.05 and for labor is once again $5.00. For an additional acre inch of moisture, three shadow prices once again emerge: $2.90, $4.57 and $5.57. The $2.90 shadow price corresponds to the cost of pumping an additional acre inch of moisture. The $4.57 shadow price shows a value of 158 percent of the cost of pumping and the $5.57 level shows a value of 192 percent of the cost of pumping the additional unit. The $4.57 shadow price occurs in relation to the pre-boot stage of grain sorghum. The $5.57 shadow price occurs in relation to the second vegetative, silk, milk, and dough stages of corn, the boot to heading stage in grain sorghum and the flower and milk stages in wheat. Those periods again correspond to periods of high usage and considerable competition among crops. Land is limiting again, however its shadow price is only 47 percent of the shadow price at the 1200 GPM level and land is becoming less and less of a factor in the results. Total revenue is at 82 percent of the 1200 GPM level; the objective value is at 85 percent of the 1200 GPM level; and the water used is at 84 percent of the 1200 GPM level.

200 GPM Results

For a flow rate of 200 GPM several significant differences unfold. In this situation, 45.73 acres of corn are planted, 25.59 acres of grain sorghum are planted and 61.65 acres of wheat are planted for a total of 132.97 acres of cropland out of 160 acres possible being used. All operator labor available is used in June and November and is handled as before. The total acre inches of irrigation water supplied either for direct irrigation or for soil filling is 1,370.16 acre inches (10.3 acre inches per acre). Of this amount, 935.12 acre inches (7.03 acre inches per acre) are pumped for soil filling with 229.68 acre inches (1.73 acre inches per acre) going into the upper soil profile and 705.44 acre inches (5.3 acre inches per acre) going into the lower soil profile. Corn production from this situation is 6,695.08 bushels (146.4 bu. per acre), grain sorghum production is 3,596.84 bushels (140.5 bu. per acre), and wheat production is 3,329.10 bushels (54 bu. per acre). Gross returns are $42,532.26 with an objective value or net return figure of

$24,007.70 ($180.55 per acre). for costs considered. Crop production alternative choices again are at the top cost and production alternative possibilities without any reduction in crop yield caused by lack of water

In this situation, the only shadow prices of any importance are for the additional acre inches of water. In this situation, three shadow prices again emerge: $7.98, $9.60 and $12.81. Unlike before, the cost of supplying an additional acre inch of water is $3.97 which places all three shadow prices above the cost of pumping. Thus in any period, an additional acre inch of moisture could return double its cost of pumping. The $7.98 shadow price level corresponds to the pre-boot stage of grain sorghum. The $9.60 shadow price corresponds to the second vegetative, silk, milk and dough stages of corn, the boot to heading and filling stages of grain sorghum and the flower and milk stages of wheat. The $12.81 shadow price corresponds to the wheat pre-irrigate stage.

In this situation, the total returns are 61 percent of the 1200 GPM level; the objective value is 67 percent of the 1200 GPM level; and the moisture used is 60 percent of the 1200 GPM level.

Chapter Seven

Analysis and Conclusions of Model Results

In analyzing the results from this study, several observations can be made, all of which impact the final conclusions of the study.

From 1200 GPM to 200 GPM, the objective value decreases from \$36,175.66 to \$24,007.70 or a 34 percent decrease. The total returns decline from \$70,272.00 to \$42,532.26 or a 40 percent decline. The total water usage drops from 6,321.6 acre inches (39.51 acre inches per acre) to 3,810.96 acre inches (28.66 acre inches per acre), for a decline of 40 percent. This roughly proportional change is not totally unexpected due to the nature of linear programming. However, with the way the crop alternatives are set up, this proportional change is not forced upon the results.

The objective value decline is expected due to the shift away from corn, a high return crop, to wheat, a lower return crop as well capacity declines.

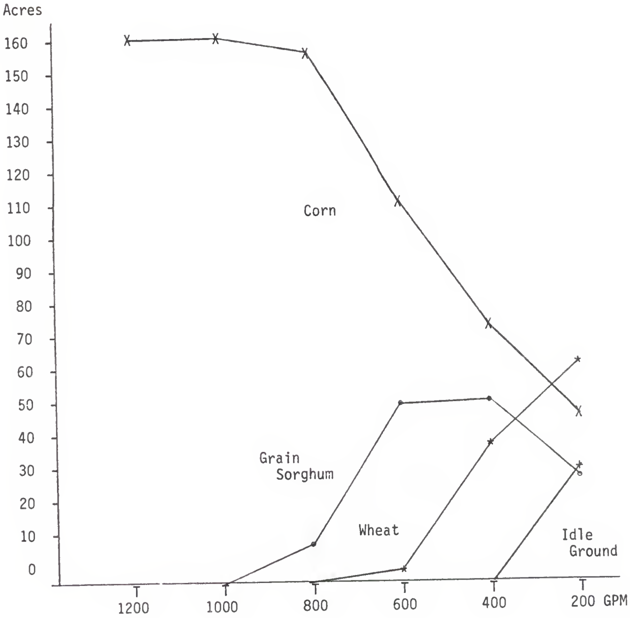
Returns for an additional acre inch of water were evaluated in Table 9. At 1200 GPM the returns for an additional acre inch of water are \$2.29 per acre inch. At the 200 GPM level the returns range up to \$12.81 per acre inch. At the 1200 GPM level the \$2.29 return value per acre inch is equal to the cost to pump each acre inch; (\$4.58 per unit ÷ 2 acre inches per unit = \$2.29 per acre inch). At this level, no crop stage would show benefit from added moisture. At the 200 GPM level, three different returns emerge. \$12.81, \$9.60 and \$7.98 per acre inch. In Table 9 the various return levels were associated with the respective crop growth stages. The cost at this level for each added acre inch is $3.97; ($1.31 per unit * .33 acre inches per unit = $3.97 per acre inch).

A shift occurs from high moisture usage crops such as corn, to wheat which uses less water per acre. With 1200 GPM and 1000 GPM, corn is the only crop as compared with the 200 GPM level with 28.6 percent corn, 16 percent grain sorghum, and 38.5 percent wheat with 16.9 percent of the ground idle.

The model hires labor to supplement the existing operator labor during the critical spring and fall periods. A shadow price of $5.00 throughout the study reflects the cost to hire an additional unit of labor. Any change in the cost of hired labor or in the availability of operator labor could effect the model results. If less operator labor is available the model would be forced to hire additional labor or shift crop alternatives. If the cost of hired labor increases the net returns could be reduced due to the additional costs or crop selections would shift to avoid additional labor hiring. Labor could become a limiting resource as was land in part of the model results.

Considerable emphasis is placed on using the soil as a water reservoir. For all well yield situations, the model stores water in the soil to supply water needs during the critical yield formation stages. The amount ranges from 922.42 acre inches (5.77 acre inches per acre) to 2,343.87 acre inches (17.63 acre inches per acre). The provision to store moisture has considerable impact on the selection of high moisture consumptive crops as compared to other studies. The structure of this model, with its ability to store moisture in the soil profile for later

Figure 3: Model results for crop mix by flow rate.



usage, allows the cropping patterns to change less than they would if all of the crop needs, not met by rainfall, had to be met by direct irrigation. A better knowledge of crop needs and responses and the water storage capacity of the soil allows for a more efficient allocation of a scarce resource, water.

Land proved to be a limiting resource in most of the situations studied. With the 1200 GPM and 1000 GPM situations, the water supply is adequate to meet crop needs, so land is the most limiting resource. As well yields decline further, water becomes relatively scarce and more important to the selection of the crop. When water is relatively unlimited, the model selects enterprises based on highest returns to land. As water becomes scarce, crop selection is based on returns to water and land.

The shadow price of an additional acre inch of moisture during any crop stage increases as well yield decreases. This result is not unexpected, however the comparison between the cost to pump that additional unit and the shadow price shows the value of water as it becomes less available.

The final result involves considerably more corn and grain sorghum than is expected, due partially to the ability of the model to meet moisture needs in a better manner than by relying on direct application alone. In addition, the amount of idle ground implies the feasibility of a fallow wheat program on a portion of the ground. This would be due to the ability of a fallow wheat program to raise a crop without additional water beyond rainfall. This utilization of the idle acres could help the overall return figures as well as the net return figures.

Several points need to be addressed to fully deal with the results. In terms of general applicability to producers, the model does not function as easily as is necessary. The benefit of the model is to provide a basis for further experimentation and analysis. The model allows for more what-if planning before the crop year begins based on expected crop needs and potential water availabilities. The added advantage is the availability of the soil profile as a moisture reservoir. This allows more flexibility to the manager.

Additionally, through the structure of the model, with the soil moisture storage, the potential exists for the continued usage of high consumptive usage crops such as corn. This could have an impact on the shifts which are currently under way in western Kansas irrigated agriculture.

In analyzing the results, one apparent weakness of the results appears. In this study, land is idled as well capacity becomes very low. This result runs contrary to the other studies and results. Further analysis shows a potential problem in the derivation of the water use coefficients, which occurred exogenous to the model. Apparently the water use-yield relationships used in this model provide a situation in which water use efficiency increases as well yields increase. As far as the model went, the point where marginal returns began increasing at a declining rate was never reached. As such, it was economically un-feasible to produce at any crop regime below maximum water use or yield levels. Thus land was idled instead of reducing yield levels and fully utilizing cropground. It does not appear that the process of coefficient derivation was erroneous, however, further study needs to be pursued to determine the best method of coefficient development. While this is a weakness, it does not weaken the sucess of the model, nor its applicability in further study.

The final net returns or loss will depend upon the other costs which vary with crop or farm operation such as debt service and machinery costs. However, the model and its results deal with that portion of the operation directly affected by the water supply and irrigation.

The overall goal of the study, the development of an approach and model which will allow for analysis and results of a reduced irrigation regime based on crop needs and its impacts on crop mix, is accomplished by this study. Clearly, with an approach which better addresses water usage by crops, a better organization of the resources available will result in a potentially higher return level for irrigators. As the adoption of new technology continues, items such as super hybrids, higher efficiency irrigation systems and different cultural practices will all have an impact on the results of the model.

Appendix One

Reference Materials

Tables

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Table A.1 Labor requirements for crop by month for a flood irrigation system on an average sized farm. [Hours per acre per month]

Tillage and Harvesting

	Wheat	Corn	Grain Sorghum
January	0.0	0.0	0.0
February	0.0	0.0	0.0
March	0.0	.31	.31
April	0.0	.42	.12
May	0.0	.07	.30
June	.61	.35	.26
July	.42	.35	.17
August	.42	0.0	0.0
September	.47	0.0	0.0
October	0.0	.11	0.0
November	0.0	.93	.91
December	0.0	.24	.24

Irrigation

	Wheat	Corn	Grain Sorghum
March	0.0	0.0	0.0
April	0.0	0.0	0.0
May	.12	0.0	0.0
June	.16	.08	.21
July	0.0	.34	.17
August	0.0	.33	.16
September	.12	.16	.17
October	.10	.04	0.0

Labor Requirements of Western Kansas Crops
Page 7; Bulletin 593 October 1975
Agricultural Experiment Station, KSU, Manhattan, Kansas.

Table A.2 Per acre variable costs for corn for different yield per acre levels.

Corn Budget Calculations

Seed	$20.00
Herbicide (25) and Insecticide (10)	35.00
Fuel and Oil (Crop)	17.50
Repairs (Crop Machinery)	12.00
Drying Costs @ $.10 per bu.	(1) see below
Miscellaneous	3.00
Interest @ 17% per year @ ½ year	(2) see below
Total Variable Costs	(3) see below

Yield	Drying Costs(1)	Interest Costs (2)	Total (3)
146.40	$14.60	$8.77	$111.91
138.72	13.87	8.70	111.07
136.80	13.68	8.69	110.87
129.59	12.96	8.62	110.08
119.68	11.97	8.54	109.01
114.36	11.94	8.49	108.43
105.59	10.56	8.42	107.48
99.19	9.92	8.37	106.79
91.11	9.11	8.30	105.91
87.62	8.76	8.27	105.53

KSU Farm Management Guide
Flood Irrigated Corn MF-578
Don D. Pretzer
August 1982, Kansas State University
Cooperative Extension Service, Manhattan Kansas

Table A.3 Per acre variable costs for grain sorghum by yield per acre.

Grain Sorghum Budget Calculations	
Seed	$ 3.60
Herbicide(15) and Insecticide	25.00
Fuel and Oil (crop)	16.50
Repairs (crop machinery)	12.00
Miscellaneous	3.00
Drying @ $.10 per bu.	(1) see below
Interest @ 17% per yr. @ ½ yr.	(2) see below
Total Variable Costs	(3) see below

Yield	Drying Costs (1)	Interest Costs (2)	Total (3)
140.54	$14.05	$ 6.31	$80.46
134.16	13.42	6.25	79.77
130.70	13.07	6.22	79.39
128.09	12.81	6.20	79.11
108.52	10.85	6.03	76.98
102.17	10.22	5.98	76.30
98.71	9.87	5.95	75.92
90.99	9.10	5.88	75.05
82.03	8.20	5.81	74.11
78.50	7.85	5.78	73.73

KSU Farm Management Guide
Flood Irrigated Grain Sorghum MF-580
Don D. Pretzer
August 1982, Kansas State University
Cooperative Extension Service, Manhattan Kansas

Table A.4 Per acre variable costs for wheat.

Seed	$ 6.00
Fuel and Oil (crop)	11.50
Repairs (crop machinery)	12.00
Miscellaneous	3.00
Interest @ 17% per yr. @ ½ yr.	2.76
Total Variable Costs	$35.26

KSU Farm Management Guide
Flood Irrigated Wheat MF-590
Don D. Pretzer
August 1982, Kansas State University
Cooperative Extension Service, Manhattan Kansas

Table A.5: Linear Equation Print-out Copy.

LINEAR EQUATIONS

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Z              - 111.91000 * CORN1     - 111.07001 * CORN2     - 110.87000 * CORN3     - 110.08000 * CORN4     - 109.00999 * CORN5
               - 108.42999 * CORN6     - 107.48000 * CORN7     - 106.78999 * CORN8     - 105.91000 * CORN9     - 105.53000 * CORN10
               -  80.46001 * SORG1     -  79.77000 * SORG2     -  79.39000 * SORG3     -  79.11000 * SORG4     -  76.98000 * SORG5
               -  76.30000 * SORG6     -  75.92000 * SORG7     -  75.08000 * SORG8     -  74.11000 * SORG9     -  73.73000 * SORG10
               -  35.25999 * WHEAT1    -  35.25999 * WHEAT2    -  35.25999 * WHEAT3    -  35.25999 * WHEAT4    -  35.25999 * WHEAT5
               -  35.25999 * WHEAT6    -  35.25999 * WHEAT7    -  35.25999 * WHEAT8    -  35.25999 * WHEAT9    -  35.25999 * WHEAT10
               +   3.00000 * SLCORN    +   2.52000 * SLSORG    +   4.02000 * SLWHEAT   -   1.00000 * SNFERT    -   1.00000 * SP2O5
               -   1.00000 * SPOTASH   -   5.00000 * HRLABJ    -   5.00000 * HRLABF    -   5.00000 * HRLABM    -   5.00000 * HRLABA
               -   5.00000 * HRLABMY   -   5.00000 * HRLABJU   -   5.00000 * HRLABJL   -   5.00000 * HRLABAU   -   5.00000 * HRLABS
               -   5.00000 * HRLABO    -   5.00000 * HRLABN    -   5.00000 * HRLABD    -   4.58000 * PCCPR1    -   4.58000 * PCCPR2
               -   4.58000 * PCCPR3    -   4.58000 * PCC1V1    -   4.58000 * PCC1V2    -   4.58000 * PCC1V3    -   4.58000 * PCC2V1
               -   4.58000 * PCC2V2    -   4.58000 * PCC2V3    -   4.58000 * PCC2V4    -   4.58000 * PCCS      -   4.58000 * PCCM1
               -   4.58000 * PCCM2     -   4.58000 * PCCD1     -   4.58000 * PCCD2     -   4.58000 * PCSPR1    -   4.58000 * PCSPR2
               -   4.58000 * PCSPR3    -   4.58000 * PCSPR4    -   4.58000 * PCSPR5    -   4.58000 * PCSPR6    -   4.58000 * PCSPR7
               -   4.58000 * PCSPR8    -   4.58000 * PCSPB1    -   4.58000 * PCSPB2    -   4.58000 * PCSPB3    -   4.58000 * PCSBH1
               -   4.58000 * PCSBH2    -   4.58000 * PCSF1     -   4.58000 * PCSF2     -   4.58000 * PCWPR1    -   4.58000 * PCWPR2
               -   4.58000 * PCWPB1    -   4.58000 * PCWPB2    -   4.58000 * PCWB      -   4.58000 * PCWFL1    -   4.58000 * PCWFL2
               -   4.58000 * PCWM      -   4.58000 * FSTCPR1   -   4.58000 * FSLCPR1   -   4.58000 * FSTCPR2   -   4.58000 * FSLCPR2
               -   4.58000 * FSTCPR3   -   4.58000 * FSLCPR3   -   4.58000 * FSTC1V1   -   4.58000 * FSLC1V1   -   4.58000 * FSTC1V2
               -   4.58000 * FSLC1V2   -   4.58000 * FSTC1V3   -   4.58000 * FSLC1V3   -   4.58000 * FSTC2V1   -   4.58000 * FSLC2V1
               -   4.58000 * FSTC2V2   -   4.58000 * FSLC2V2   -   4.58000 * FSTC2V3   -   4.58000 * FSLC2V3   -   4.58000 * FSTC2V4
               -   4.58000 * FSLC2V4   -   4.58000 * FSTCS     -   4.58000 * FSLCS     -   4.58000 * FSTCM1    -   4.58000 * FSLCM1
               -   4.58000 * FSTCM2    -   4.58000 * FSLCM2    -   4.58000 * FSTCD1    -   4.58000 * FSLCD1    -   4.58000 * FSTCD2
               -   4.58000 * FSLCD2    -   4.58000 * FSTGPR1   -   4.58000 * FSLGPR1   -   4.58000 * FSTGPR2   -   4.58000 * FSLGPR2
               -   4.58000 * FSTGPR3   -   4.58000 * FSLGPR3   -   4.58000 * FSTGPR4   -   4.58000 * FSLGPR4   -   4.58000 * FSTGPR5
               -   4.58000 * FSLGPR5   -   4.58000 * FSTGPR6   -   4.58000 * FSLGPR6   -   4.58000 * FSTGPR7   -   4.58000 * FSLGPR7
               -   4.58000 * FSTGPR8   -   4.58000 * FSLGPR8   -   4.58000 * FSTGPB1   -   4.58000 * FSLGPB1   -   4.58000 * FSTGPB2
               -   4.58000 * FSLGPB2   -   4.58000 * FSTGPB3   -   4.58000 * FSLGPB3   -   4.58000 * FSTGBH1   -   4.58000 * FSLGBH1
               -   4.58000 * FSTGBH2   -   4.58000 * FSLGBH2   -   4.58000 * FSTGF1    -   4.58000 * FSLGF1    -   4.58000 * FSTGF2
               -   4.58000 * FSLGF2    -   4.58000 * FSTWPR1   -   4.58000 * FSLWPR1   -   4.58000 * FSTWPR2   -   4.58000 * FSLWPR2
               -   4.58000 * FSTWPR3   -   4.58000 * FSLWPR3   -   4.58000 * FSTWPB1   -   4.58000 * FSLWPB1   -   4.58000 * FSTWPB2
               -   4.58000 * FSLWPB2   -   4.58000 * FSTWB     -   4.58000 * FSLWB     -   4.58000 * FSTWF1    -   4.58000 * FSLWF1
               -   4.58000 * FSTWF2    -   4.58000 * FSLWF2    -   4.58000 * FSTWM     -   4.58000 * FSLWM
                OBJECTIV
- 2 CROPLAND       1.00000 * CORN1     +   1.00000 * CORN2     +   1.00000 * CORN3     +   1.00000 * CORN4     +   1.00000 * CORN5
               +   1.00000 * CORN6     +   1.00000 * CORN7     +   1.00000 * CORN8     +   1.00000 * CORN9     +   1.00000 * CORN10
               +   1.00000 * SORG1     +   1.00000 * SORG2     +   1.00000 * SORG3     +   1.00000 * SORG4     +   1.00000 * SORG5
               +   1.00000 * SORG6     +   1.00000 * SORG7     +   1.00000 * SORG8     +   1.00000 * SORG9     +   1.00000 * SORG10
               +   1.00000 * WHEAT1    +   1.00000 * WHEAT2    +   1.00000 * WHEAT3    +   1.00000 * WHEAT4    +   1.00000 * WHEAT5
               +   1.00000 * WHEAT6    +   1.00000 * WHEAT7    +   1.00000 * WHEAT8    +   1.00000 * WHEAT9    +   1.00000 * WHEAT10
               <=       60.0
- 3 N-FERT        25.63000 * CORN1     +  24.00000 * CORN2     +  23.60001 * CORN3     +  22.06000 * CORN4     +  19.95000 * CORN5
               +  18.82001 * CORN6     +  16.95000 * CORN7     +  15.58000 * CORN8     +  13.87000 * CORN9     +  13.13000 * CORN10
               +  12.80000 * SORG1     +  12.80000 * SORG2     +  12.80000 * SORG3     +  12.80000 * SORG4     +  12.80000 * SORG5
               +  12.80000 * SORG6     +  12.80000 * SORG7     +  12.80000 * SORG8     +  12.80000 * SORG9     +  12.80000 * SORG10
               +  10.40000 * WHEAT1    +  10.40000 * WHEAT2    +  10.40000 * WHEAT3    +  10.40000 * WHEAT4    +  10.40000 * WHEAT5
               +  10.40000 * WHEAT6    +  10.40000 * WHEAT7    +  10.40000 * WHEAT8    +  10.40000 * WHEAT9    +  10.40000 * WHEAT10
               -   1.00000 * SNFERT
               <=        0.0
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- 4  P205          7.80000 * CORN1     +  7.80000 * CORN2     +  7.80000 * CORN3     +  7.80000 * CORN4     +  6.50000 * CORN5
               +   6.50000 * CORN6     +  6.50000 * CORN7     +  6.50000 * CORN8     +  6.50000 * CORN9     +  6.50000 * CORN10
               +  11.70000 * SORG1     + 11.70000 * SORG2     + 11.70000 * SORG3     + 11.70000 * SORG4     + 11.70000 * SORG5
               +  11.70000 * SORG6     + 11.70000 * SORG7     + 11.70000 * SORG8     + 11.70000 * SORG9     + 11.70000 * SORG10
               +   5.20000 * WHEAT1    +  5.20000 * WHEAT2    +  5.20000 * WHEAT3    +  5.20000 * WHEAT4    +  5.20000 * WHEAT5
               +   5.20000 * WHEAT6    +  5.20000 * WHEAT7    +  5.20000 * WHEAT8    +  5.20000 * WHEAT9    +  5.20000 * WHEAT10
               -   1.00000 * SP205
               <=            0.0
  5  POTASH        3.25000 * CORN1     +  3.25000 * CORN2     +  3.25000 * CORN3     +  3.25000 * CORN4     +  3.25000 * CORN5
               +   3.25000 * CORN6     +  3.25000 * CORN7     +  3.25000 * CORN8     +  3.25000 * CORN9     +  3.25000 * CORN10
               +   3.25000 * SORG1     +  3.25000 * SORG2     +  3.25000 * SORG3     +  3.25000 * SORG4     +  3.25000 * SORG5
               +   3.25000 * SORG6     +  3.25000 * SORG7     +  3.25000 * SORG8     +  3.25000 * SORG9     +  3.25000 * SORG10
               +   3.25000 * WHEAT1    +  3.25000 * WHEAT2    +  3.25000 * WHEAT3    +  3.25000 * WHEAT4    +  3.25000 * WHEAT5
               +   3.25000 * WHEAT6    +  3.25000 * WHEAT7    +  3.25000 * WHEAT8    +  3.25000 * WHEAT9    +  3.25000 * WHEAT10
               -   1.00000 * SPOTASH
               <=            0.0
- 6  LABJA        -1.00000 * HRLABJ
               <=            54.0
  7  LABFE        -1.00000 * HRLABF
               <=            54.0
- 8  LABMA         0.31000 * CORN1     +  0.31000 * CORN2     +  0.31000 * CORN3     +  0.31000 * CORN4     +  0.31000 * CORN5
               +   0.31000 * CORN6     +  0.31000 * CORN7     +  0.31000 * CORN8     +  0.31000 * CORN9     +  0.31000 * CORN10
               +   0.31000 * SORG1     +  0.31000 * SORG2     +  0.31000 * SORG3     +  0.31000 * SORG4     +  0.31000 * SORG5
               +   0.31000 * SORG6     +  0.31000 * SORG7     +  0.31000 * SORG8     +  0.31000 * SORG9     +  0.31000 * SORG10
                   1.00000 * HRLABM
               <=            54.0
- 9  LABAP         0.42000 * CORN1     +  0.42000 * CORN2     +  0.42000 * CORN3     +  0.42000 * CORN4     +  0.42000 * CORN5
               +   0.42000 * CORN6     +  0.42000 * CORN7     +  0.42000 * CORN8     +  0.42000 * CORN9     +  0.42000 * CORN10
               +   0.12000 * SORG1     +  0.12000 * SORG2     +  0.12000 * SORG3     +  0.12000 * SORG4     +  0.12000 * SORG5
               +   0.12000 * SORG6     +  0.12000 * SORG7     +  0.12000 * SORG8     +  0.12000 * SORG9     +  0.12000 * SORG10
               -   1.00000 * HRLABA
               <=            54.0
- 10 LABMY         0.07000 * CORN1     +  0.07000 * CORN2     +  0.07000 * CORN3     +  0.07000 * CORN4     +  0.07000 * CORN5
               +   0.07000 * CORN6     +  0.07000 * CORN7     +  0.07000 * CORN8     +  0.07000 * CORN9     +  0.07000 * CORN10
               +   0.30000 * SORG1     +  0.30000 * SORG2     +  0.30000 * SORG3     +  0.30000 * SORG4     +  0.30000 * SORG5
               +   0.30000 * SORG6     +  0.30000 * SORG7     +  0.30000 * SORG8     +  0.30000 * SORG9     +  0.30000 * SORG10
               +   0.12000 * WHEAT1    +  0.12000 * WHEAT2    +  0.12000 * WHEAT3    +  0.12000 * WHEAT4    +  0.12000 * WHEAT5
               +   0.12000 * WHEAT6    +  0.12000 * WHEAT7    +  0.12000 * WHEAT8    +  0.12000 * WHEAT9    +  0.12000 * WHEAT10
               -   1.00000 * HRLABMY
               <=            54.0
- 11 LABJU         0.43000 * CORN1     +  0.43000 * CORN2     +  0.43000 * CORN3     +  0.43000 * CORN4     +  0.43000 * CORN5
               +   0.43000 * CORN6     +  0.43000 * CORN7     +  0.43000 * CORN8     +  0.43000 * CORN9     +  0.43000 * CORN10
               +   0.47000 * SORG1     +  0.47000 * SORG2     +  0.47000 * SORG3     +  0.47000 * SORG4     +  0.47000 * SORG5
               +   0.47000 * SORG6     +  0.47000 * SORG7     +  0.47000 * SORG8     +  0.47000 * SORG9     +  0.47000 * SORG10
               +   0.77000 * WHEAT1    +  0.77000 * WHEAT2    +  0.77000 * WHEAT3    +  0.77000 * WHEAT4    +  0.77000 * WHEAT5
               +   0.77000 * WHEAT6    +  0.77000 * WHEAT7    +  0.77000 * WHEAT8    +  0.77000 * WHEAT9    +  0.77000 * WHEAT10
               -   1.00000 * HRLABJU
               <=            54.0
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- 12  LABJL      0.34000 * CORN1     +   0.34000 * CORN2     +   0.34000 * CORN3     +   0.34000 * CORN4     +   0.34000 * CORN5
           +     0.34000 * CORN6     +   0.34000 * CORN7     +   0.34000 * CORN8     +   0.34000 * CORN9     +   0.34000 * CORN10
           +     0.34000 * SORG1     +   0.34000 * SORG2     +   0.34000 * SORG3     +   0.34000 * SORG4     +   0.34000 * SORG5
           +     0.34000 * SORG6     +   0.34000 * SORG7     +   0.34000 * SORG8     +   0.34000 * SORG9     +   0.34000 * SORG10
           +     0.42000 * WHEAT1    +   0.42000 * WHEAT2    +   0.42000 * WHEAT3    +   0.42000 * WHEAT4    +   0.42000 * WHEAT5
           +     0.42000 * WHEAT6    +   0.42000 * WHEAT7    +   0.42000 * WHEAT8    +   0.42000 * WHEAT9    +   0.42000 * WHEAT10
           -     1.00000 * HRLABJL
           <=              54.0
  13  LABAU      0.33000 * CORN1     +   0.33000 * CORN2     +   0.33000 * CORN3     +   0.33000 * CORN4     +   0.33000 * CORN5
           +     0.33000 * CORN6     +   0.33000 * CORN7     +   0.33000 * CORN8     +   0.33000 * CORN9     +   0.33000 * CORN10
           +     0.16000 * SORG1     +   0.16000 * SORG2     +   0.16000 * SORG3     +   0.16000 * SORG4     +   0.16000 * SORG5
           +     0.16000 * SORG6     +   0.16000 * SORG7     +   0.16000 * SORG8     +   0.16000 * SORG9     +   0.16000 * SORG10
           +     0.42000 * WHEAT1    +   0.42000 * WHEAT2    +   0.42000 * WHEAT3    +   0.42000 * WHEAT4    +   0.42000 * WHEAT5
           +     0.42000 * WHEAT6    +   0.42000 * WHEAT7    +   0.42000 * WHEAT8    +   0.42000 * WHEAT9    +   0.42000 * WHEAT10
           -     1.00000 * HRLABAU
           <=              54.0
- 14  LABSE      0.16000 * CORN1     +   0.16000 * CORN2     +   0.16000 * CORN3     +   0.16000 * CORN4     +   0.16000 * CORN5
           +     0.16000 * CORN6     +   0.16000 * CORN7     +   0.16000 * CORN8     +   0.16000 * CORN9     +   0.16000 * CORN10
           +     0.17000 * SORG1     +   0.17000 * SORG2     +   0.17000 * SORG3     +   0.17000 * SORG4     +   0.17000 * SORG5
           +     0.17000 * SORG6     +   0.17000 * SORG7     +   0.17000 * SORG8     +   0.17000 * SORG9     +   0.17000 * SORG10
           +     0.59000 * WHEAT1    +   0.59000 * WHEAT2    +   0.59000 * WHEAT3    +   0.59000 * WHEAT4    +   0.59000 * WHEAT5
           +     0.59000 * WHEAT6    +   0.59000 * WHEAT7    +   0.59000 * WHEAT8    +   0.59000 * WHEAT9    +   0.59000 * WHEAT10
           -     1.00000 * HRLABS
           <=              54.0
  15  LABOC      0.15000 * CORN1     +   0.15000 * CORN2     +   0.15000 * CORN3     +   0.15000 * CORN4     +   0.15000 * CORN5
           +     0.15000 * CORN6     +   0.15000 * CORN7     +   0.15000 * CORN8     +   0.15000 * CORN9     +   0.15000 * CORN10
           +     0.10000 * WHEAT1    +   0.10000 * WHEAT2    +   0.10000 * WHEAT3    +   0.10000 * WHEAT4    +   0.10000 * WHEAT5
           +     0.10000 * WHEAT6    +   0.10000 * WHEAT7    +   0.10000 * WHEAT8    +   0.10000 * WHEAT9    +   0.10000 * WHEAT10
           -     1.00000 * HRLABO
           <=              54.0
- 16  LABNO      0.93000 * CORN1     +   0.93000 * CORN2     +   0.93000 * CORN3     +   0.93000 * CORN4     +   0.93000 * CORN5
           +     0.93000 * CORN6     +   0.93000 * CORN7     +   0.93000 * CORN8     +   0.93000 * CORN9     +   0.93000 * CORN10
           +     0.91000 * SORG1     +   0.91000 * SORG2     +   0.91000 * SORG3     +   0.91000 * SORG4     +   0.91000 * SORG5
           +     0.91000 * SORG6     +   0.91000 * SORG7     +   0.91000 * SORG8     +   0.91000 * SORG9     +   0.91000 * SORG10
           -     1.00000 * HRLABN
           <=              54.0
- 17  LABDE      0.24000 * CORN1     +   0.24000 * CORN2     +   0.24000 * CORN3     +   0.24000 * CORN4     +   0.24000 * CORN5
           +     0.24000 * CORN6     +   0.24000 * CORN7     +   0.24000 * CORN8     +   0.24000 * CORN9     +   0.24000 * CORN10
           +     0.24000 * SORG1     +   0.24000 * SORG2     +   0.24000 * SORG3     +   0.24000 * SORG4     +   0.24000 * SORG5
           +     0.24000 * SORG6     +   0.24000 * SORG7     +   0.24000 * SORG8     +   0.24000 * SORG9     +   0.24000 * SORG10
           -     1.00000 * HRLABD
           <=              54.0
- 18  CORN    -146.39999 * CORN1     - 138.72000 * CORN2     - 136.80000 * CORN3     - 129.59000 * CORN4     - 119.67999 * CORN5
           - 114.36000 * CORN6     - 105.59000 * CORN7     -  99.17000 * CORN8     -  91.11000 * CORN9     -  87.62000 * CORN10
           +     1.00000 * SLCORN
           <=              0.0
- 19  MILO    - 140.53999 * SORG1    - 134.16000 * SORG2     - 130.70000 * SORG3     - 128.09000 * SORG4     - 108.52000 * SORG5
           - 102.17000 * SORG6     -  98.71001 * SORG7     -  90.99001 * SORG8     -  82.03000 * SORG9     -  78.57001 * SORG10
           +     1.00000 * SLSORG
           <=              0.0
```

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20  WHEAT    -  54.00000 * WHEAT1    - 50.57001 * WHEAT2    - 48.25000 * WHEAT3    - 46.37000 * WHEAT4    - 43.71001 * WHEAT5
             -  40.25000 * WHEAT6    - 40.10001 * WHEAT7    - 35.89999 * WHEAT8    - 33.53000 * WHEAT9    - 26.30000 * WHEAT10
             +   1.00000 * SLWHEAT
             <=            0.0
21  CPREIR       8.00000 * CORN1     +  8.00000 * CORN2     +  8.00000 * CORN3     +  8.00000 * CORN4     +  8.00000 * CORN5
             +   8.00000 * CORN6     +  8.00000 * CORN7     +  8.00000 * CORN8     +  8.00000 * CORN9     +  8.00000 * CORN10
             -   2.00000 * PCCPR1    -  2.00000 * PCCPR2    -  2.00000 * PCCPR3    -  1.00000 * SRCPR1    -  1.00000 * SRCPR2
             -   1.00000 * SRCPR3
             <=            0.0
22  C1ST         1.96000 * CORN1     +  1.96000 * CORN2     +  1.96000 * CORN3     +  1.96000 * CORN4     +  1.96000 * CORN5
             +   1.96000 * CORN6     +  1.96000 * CORN7     +  1.96000 * CORN8     +  1.96000 * CORN9     +  1.96000 * CORN10
             -   2.00000 * PCC1V1    -  2.00000 * PCC1V2    -  2.00000 * PCC1V3    -  1.00000 * SRC1V1    -  1.00000 * SRC1V2
             -   1.00000 * TSMCPRT   -  1.00000 * TSMCPRL
             <=            0.0
23  C2ND        10.50000 * CORN1     + 10.50000 * CORN2     + 10.06000 * CORN3     + 10.06000 * CORN4     +  9.10000 * CORN5
             +  10.06000 * CORN6     + 10.06000 * CORN7     + 10.06000 * CORN8     + 10.06000 * CORN9     +  9.10000 * CORN10
             -   2.00000 * PCC2V1    -  2.00000 * PCC2V2    -  2.00000 * PCC2V3    -  2.00000 * PCC2V4    -  1.00000 * SRC2V
             -   1.00000 * TSMC1VT   -  1.00000 * TSMC1VL
             <=            0.0
24  CSILK        6.12000 * CORN1     +  6.12000 * CORN2     +  6.21000 * CORN3     +  6.21000 * CORN4     +  6.21000 * CORN5
             +   6.21000 * CORN6     +  6.21000 * CORN7     +  5.96000 * CORN8     +  5.96000 * CORN9     +  6.21000 * CORN10
             -   2.00000 * PCCS      -  1.00000 * SRCS      -  1.00000 * TSMC2VT   -  1.00000 * TSMC2VL
             <=            0.0
25  CMILK        8.03000 * CORN1     +  7.74000 * CORN2     +  7.79000 * CORN3     +  7.79000 * CORN4     +  7.94000 * CORN5
             +   7.72000 * CORN6     +  7.72000 * CORN7     +  7.66000 * CORN8     +  7.33000 * CORN9     +  7.39000 * CORN10
             -   2.00000 * PCCM1     -  2.00000 * PCCM2        1.00000 * SRCM1     -  1.00000 * SRCM2     -  1.00000 * TSMCST
             -   1.00000 * TSMCSL
             <=            0.0
26  CDOUGH       4.90000 * CORN1     +  4.94000 * CORN2     +  4.62000 * CORN3     +  4.62000 * CORN4     +  4.83000 * CORN5
             +   4.42000 * CORN6     +  4.03000 * CORN7     +  4.50000 * CORN8     +  4.73000 * CORN9     +  3.92000 * CORN10
             -   2.00000 * PCCD1     -  2.00000 * PCCD2     -  1.00000 * SRCD      -  1.00000 * TSMCMT    -  1.00000 * TSMCML
             <=            0.0
27  GSPREIR      8.00000 * SORG1     +  8.00000 * SORG2     +  8.00000 * SORG3     +  8.00000 * SORG4     +  8.00000 * SORG5
             +   8.00000 * SORG6     +  8.00000 * SORG7     +  8.00000 * SORG8     +  8.00000 * SORG9     +  8.00000 * SORG10
             -   2.00000 * PCSPR1       2.00000 * PCSPR2    -  2.00000 * PCSPR3    -  2.00000 * PCSPR4    -  2.00000 * PCSPR5
             -   2.00000 * PCSPR6    -  2.00000 * PCSPR7    -  2.00000 * PCSPR8    -  1.00000 * SRGPR1    -  1.00000 * SRGPR2
             -   1.00000 * SRGPR3
             <=            0.0
28  GSPBOOT     11.45000 * SORG1     + 11.00000 * SORG2     + 10.37000 * SORG3     + 11.00000 * SORG4     + 11.00000 * SORG5
             +  11.00000 * SORG6     + 10.37000 * SORG7     + 10.37000 * SORG8     + 11.00000 * SORG9     + 10.37000 * SORG10
             -   2.00000 * PCSPB1       2.00000 * PCSPB2    -  2.00000 * PCSPB3    -  1.00000 * SRSPB1    -  1.00000 * SRSPB2
             -   1.00000 * TSMSPRT   -  1.00000 * TSMSPRL
             <=            0.0
29  GSBOOTH     10.61000 * SORG1     + 10.25000 * SORG2     + 11.09000 * SORG3     + 10.25000 * SORG4     + 10.39000 * SORG5
             +  10.39000 * SORG6     + 10.49000 * SORG7     + 10.15000 * SORG8     + 10.16000 * SORG9     + 10.15000 * SORG10
             -   2.00000 * PCSBH1    -  2.00000 * PCSBH2    -  1.00000 * SRSBH1    -  1.00000 * SRSBH2    -  1.00000 * TSMSPBT
             -   1.00000 * TSMSPBL
             <=            0.0
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 30  GSFILL      4.77000 * SORG1    +  4.90000 * SORG2    +  4.89000 * SORG3    +  4.97000 * SORG4    +  4.89000 * SORG5
               + 4.57000 * SORG6    +  4.59000 * SORG7    +  4.76000 * SORG8    +  4.70000 * SORG9    +  4.55000 * SORG10
               - 2.00000 * PCSF1    -  2.00000 * PCSF2    -  1.00000 * SRSF1    -  1.00000 * SRSF2    -  1.00000 * TSMBHT
               - 1.00000 * TSMBHL
            <=       0.0
- 31  WPREIR     8.00000 * WHEAT1   +  8.00000 * WHEAT2   +  8.00000 * WHEAT3   +  8.00000 * WHEAT4   +  8.00000 * WHEAT5
               + 8.00000 * WHEAT6   +  8.00000 * WHEAT7   +  8.00000 * WHEAT8   +  8.00000 * WHEAT9   +  8.00000 * WHEAT10
               - 2.00000 * PCWPR1   -  2.00000 * PCWPR2   -  1.00000 * SRWPR1   -  1.00000 * SRWPR2
            <=       0.0
- 32  WPBOOT     4.15000 * WHEAT1   +  4.15000 * WHEAT2   +  3.92000 * WHEAT3   +  3.92000 * WHEAT4   +  3.92000 * WHEAT5
               + 3.92000 * WHEAT6   +  4.15000 * WHEAT7   +  3.92000 * WHEAT8   +  3.92000 * WHEAT9   +  3.92000 * WHEAT10
               - 2.00000 * PCWPB1   -  2.00000 * PCWPB2   -  1.00000 * SRWPB
            <=       0.0
- 33  WBOOT      3.68000 * WHEAT1   +  3.60000 * WHEAT2   +  3.55000 * WHEAT3   +  3.60000 * WHEAT4   +  3.60000 * WHEAT5
               + 3.55000 * WHEAT6   +  3.68000 * WHEAT7   +  3.37000 * WHEAT8   +  3.37000 * WHEAT9   +  3.37000 * WHEAT10
               - 2.00000 * PCWB     -  1.00000 * SRWB     -  1.00000 * TSMWPBT  -  1.00000 * TSMWPBL
            <=       0.0
- 34  WFLOWER    3.19000 * WHEAT1   +  3.03000 * WHEAT2   +  3.13000 * WHEAT3   +  3.05000 * WHEAT4   +  3.06000 * WHEAT5
               + 3.16000 * WHEAT6   +  3.14000 * WHEAT7   +  3.16000 * WHEAT8   +  3.17000 * WHEAT9   +  2.59000 * WHEAT10
               - 2.00000 * PCWFL1   -  2.00000 * PCWFL2   -  1.00000 * SRWFL    -  1.00000 * TSMWBT   -  1.00000 * TSMWBL
            <=       0.0
- 35  WMILK      2.71000 * WHEAT1   +  2.71000 * WHEAT2   +  2.69000 * WHEAT3   +  2.74000 * WHEAT4   +  2.58000 * WHEAT5
               + 2.59000 * WHEAT6   +  2.53000 * WHEAT7   +  2.68000 * WHEAT8   +  2.55000 * WHEAT9   +  2.34000 * WHEAT10
               - 2.00000 * PCWM     -  1.00000 * SRWML    -  1.00000 * TSMWFT   -  1.00000 * TSMWFL
            <=       0.0
- 36  PHRMAR     1.00000 * PCCPR1   +  1.00000 * FSTCPR1  +  1.00000 * FSLCPR1
            <=     720.0
- 37  PHRAPR     1.00000 * PCCPR2   +  1.00000 * PCSPR1   +  1.00000 * FSTCPR2  +  1.00000 * FSLCPR2  +  1.00000 * FSTGPR1
               + 1.00000 * FSLGPR1
            <=     744.0
- 38  PHRMY1     1.00000 * PCCPR3   +  1.00000 * PCSPR2   +  1.00000 * PCWPB1   +  1.00000 * FSTCPR3  +  1.00000 * FSLCPR3
               + 1.00000 * FSTGPR2  +  1.00000 * FSLGPR2
            <=     144.0
- 39  PHRMY2     1.00000 * PCC1V1   +  1.00000 * PCSPR3   +  1.00000 * PCWPB2   +  1.00000 * FSTC1V1  +  1.00000 * FSLC1V1
               + 1.00000 * FSTGPR3  +  1.00000 * FSLGPR3  +  1.00000 * FSTWPB1  +  1.00000 * FSLWPB1
            <=     216.0
  40  PHRMY3     1.00000 * PCC1V2   +  1.00000 * PCSPR4   +  1.00000 * PCWB     +  1.00000 * FSTC1V2  +  1.00000 * FSLC1V2
               + 1.00000 * FSTGPR4  +  1.00000 * FSLGPR4  +  1.00000 * FSTWPB2  +  1.00000 * FSLWPB2
            <=     312.0
  41  PHRMY4     1.00000 * PCC1V3   +  1.00000 * PCSPR5   +  1.00000 * PCWFL1   +  1.00000 * FSTC1V3  +  1.00000 * FSLC1V3
               + 1.00000 * FSTGPR5  +  1.00000 * FSLGPR5  +  1.00000 * FSTWB    +  1.00000 * FSLWB
            <=     168.0
- 42  PHRJU1     1.00000 * PCC2V1   +  1.00000 * PCSPR6   +  1.00000 * PCWFL2   +  1.00000 * FSTC2V1  +  1.00000 * FSLC2V1
               + 1.00000 * FSTGPR6  +  1.00000 * FSLGPR6  +  1.00000 * FSTWF1   +  1.00000 * FSLWF1
            <=      24.0
- 43  PHRJU2     1.00000 * PCC2V2   +  1.00000 * PCSPR7   +  1.00000 * PCWM     +  1.00000 * FSTC2V2  +  1.00000 * FSLC2V2
               + 1.00000 * FSTGPR7  +  1.00000 * FSLGPR7  +  1.00000 * FSTWF2   +  1.00000 * FSLWF2
            <=     168.0
- 44  PHRJU3     1.00000 * PCC2V3   +  1.00000 * PCSPR8   +  1.00000 * FSTC2V3  +  1.00000 * FSLC2V3  +  1.00000 * FSTGPR8
               + 1.00000 * FSLGPR8  +  1.00000 * FSTWM    +  1.00000 * FSLWM
            <=     168.0
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- 45  PHRJH4      1.00000 * PCC2V4    +  1.00000 * PCSPB1    +  1.00000 * FSTC2V4   +  1.00000 * FSLC2V4   +  1.00000 * FSTGPB1
              +   1.00000 * FSLGPB1
              <=            288.0
- 46  PHRJL1      1.00000 * PCCS      +  1.00000 * PCSPB2    +  1.00000 * FSTCS     +  1.00000 * FSLCS     +  1.00000 * FSTGPB2
              +   1.00000 * FSLGPB2
              <=            384.0
- 47  PHRJL2      1.00000 * PCCM1     +  1.00000 * PCSPB3    +  1.00000 * FSTCM1    +  1.00000 * FSLCM1    +  1.00000 * FSTGPB3
              +   1.00000 * FSLGPB3
              <=            48.0
- 48  PHRJL3      1.00000 * PCCM2     +  1.00000 * PCSBH1    +  1.00000 * FSTCM2    +  1.00000 * FSLCM2    +  1.00000 * FSTGBH1
              +   1.00000 * FSLGBH1
              <=            480.0
- 49  PHRAU1      1.00000 * PCCD1     +  1.00000 * PCSBH2    +  1.00000 * FSTCD1    +  1.00000 * FSLCD1    +  1.00000 * FSTGBH2
              +   1.00000 * FSLGBH2
              <=            264.0
- 50  PHRAU2      1.00000 * PCCD2     +  1.00000 * PCSF1     +  1.00000 * FSTCD2    +  1.00000 * FSLCD2    +  1.00000 * FSTGF1
              +   1.00000 * FSLGF1
              <=            96.0
- 51  PHRAU3      1.00000 * PCSF2     +  1.00000 * FSTGF2    +  1.00000 * FSLGF2
              <=            288.0
- 52  PHRSE2      1.00000 * PCWPR1    +  1.00000 * FSTWPR1   +  1.00000 * FSLWPR1
              <=            360.0
- 53  PHROCT      1.00000 * PCWPR2    +  1.00000 * FSTWPR2   +  1.00000 * FSLWPR2
              <=            744.0
- 54  PHRNOV      1.00000 * FSTWPR3   +  1.00000 * FSLWPR3
              <=            720.0
- 55  CPIT       -2.00000 * FSTCPR1   -  2.00000 * FSTCPR2   -  2.00000 * FSTCPR3   +  1.00000 * TSMCPRT
              <=            0.0
- 56  CPIL       -2.00000 * FSLCPR1   -  2.00000 * FSLCPR2   -  2.00000 * FSLCPR3   +  1.00000 * TSMCPRL
              <=            0.0
- 57  C1VT       -2.00000 * FSTC1V1   -  2.00000 * FSTC1V2   -  2.00000 * FSTC1V3   +  1.00000 * TSMC1VT
              <=            0.0
- 58  C1VL       -2.00000 * FSLC1V1   -  2.00000 * FSLC1V2   -  2.00000 * FSLC1V3   +  1.00000 * TSMC1VL
              <=            0.0
- 59  C2VT       -2.00000 * FSTC2V1   -  2.00000 * FSTC2V2   -  2.00000 * FSTC2V3   -  2.00000 * FSTC2V4   +  1.00000 * TSMC2VT
              <=            0.0
- 60  C2VL       -2.00000 * FSLC2V1   -  2.00000 * FSLC2V2   -  2.00000 * FSLC2V3   -  2.00000 * FSLC2V4   +  1.00000 * TSMC2VL
              <=            0.0
- 61  CSILT      -2.00000 * FSTCS     +  1.00000 * TSMCST
              <=            0.0
- 62  CSILL      -2.00000 * FSLCS     +  1.00000 * TSMCSL
              <=            0.0
- 63  CMILT      -2.00000 * FSTCM1    -  2.00000 * FSTCM2    +  1.00000 * TSMCMT
              <=            0.0
- 64  CMILL      -2.00000 * FSLCM1    -  2.00000 * FSLCM2    +  1.00000 * TSMCML
              <=            0.0
- 65  CDOUT      -2.00000 * FSTCD1    -  2.00000 * FSTCD2
              <=            0.0
  66  CDOUL      -2.00000 * FSLCD1    -  2.00000 * FSLCD2
              <=            0.0
- 67  GSPIT      -2.00000 * FSTGPR1   -  2.00000 * FSTGPR2   -  2.00000 * FSTGPR3   -  2.00000 * FSTGPR4   -  2.00000 * FSTGPR5
              -   2.00000 * FSTGPR6   -  2.00000 * FSTGPR7   -  2.00000 * FSTGPR8   +  1.00000 * TSMSPRT
              <=            0.0
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 68  GSPIL       -2.00000 * FSLGPR1  -  2.00000 * FSLGPR2  -  2.00000 * FSLGPR3  -  2.00000 * FSLGPR4  -  2.00000 * FSLGPR5
                 -2.00000 * FSLGPR6  -  2.00000 * FSLGPR7  -  2.00000 * FSLGPR8  +  1.00000 * TSMSPRL
             <=             0.0
- 69  GSPBT      -2.00000 * FSTGPB1  -  2.00000 * FSTGPB2  -  2.00000 * FSTGPB3  +  1.00000 * TSMSPBT
             <=             0.0
- 70  GSPBL      -2.00000 * FSLGPB1  -  2.00000 * FSLGPB2  -  2.00000 * FSLGPB3  +  1.00000 * TSMSPBL
             <=             0.0
- 71  GSBHT      -2.00000 * FSTGBH1  -  2.00000 * FSTGBH2  +  1.00000 * TSMBHT
             <=             0.0
- 72  GSBHL      -2.00000 * FSLGBH1  -  2.00000 * FSLGBH2  +  1.00000 * TSMBHL
             <=             0.0
- 73  GSFLT      -2.00000 * FSTGF1   -  2.00000 * FSTGF2
             <=             0.0
- 74  GSFLL      -2.00000 * FSLGF1   -  2.00000 * FSLGF2
             <=             0.0
- 75  WPIT       -2.00000 * FSTWPR1  -  2.00000 * FSTWPR2  -  2.00000 * FSTWPR3
             <=             0.0
- 76  WPIL       -2.00000 * FSLWPR1  -  2.00000 * FSLWPR2  -  2.00000 * FSLWPR3
             <=             0.0
- 77  WPBT       -2.00000 * FSTWPB1  -  2.00000 * FSTWPB2  +  1.00000 * TSMWPBT
             <=             0.0
- 78  WPBL       -2.00000 * FSLWPB1  -  2.00000 * FSLWPB2  +  1.00000 * TSMWPBL
             <=             0.0
- 79  WBT        -2.00000 * FSTWB
             <=             0.0
  80  WBL        -2.00000 * FSLWB
             <=             0.0
- 81  WFLT       -2.00000 * FSTWF1   -  2.00000 * FSTWF2   +  1.00000 * TSMWBT   +  1.00000 * TSMWFT
             <=             0.0
  82  WFLL       -2.00000 * FSLWF1   -  2.00000 * FSLWF2   +  1.00000 * TSMWBL   +  1.00000 * TSMWFL
             <=             0.0
- 83  WFIT       -2.00000 * FSTWM
             <=             0.0
  84  WFIL       -2.00000 * FSLWM
             <=             0.0
- 85  CPITL       1.00000 * FSTCPR1  +  1.00000 * FSTCPR2  +  1.00000 * FSTCPR3
             <=             112.0
- 86  CPILL       1.00000 * FSLCPR1  +  1.00000 * FSLCPR2  +  1.00000 * FSLCPR3
             <=             376.0
- 87  C1VTL       1.00000 * FSTC1V1  +  1.00000 * FSTC1V2  +  1.00000 * FSTC1V3
             <=             112.0
- 88  C1VLL       1.00000 * FSLC1V1  +  1.00000 * FSLC1V2  +  1.00000 * FSLC1V3
             <=             376.0
- 89  C2VTL       1.00000 * FSTC2V1  +  1.00000 * FSTG2V2  +  1.00000 * FSTC2V3  +  1.00000 * FSTC2V4
             <=             112.0
- 90  C2VLL       1.00000 * FSLC2V1  +  1.00000 * FSLG2V2  +  1.00000 * FSLC2V3  +  1.00000 * FSLC2V4
             <=             376.0
- 91  CSILTL      1.00000 * FSTCS
             <=             112.0
- 92  CSILLL      1.00000 * FSLCS
             <=             376.0
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- 93  CMILTL      1.00000 * FSTCM1   +   1.00000 * FSTCM2
           <=              112.0
- 94  CMILLL      1.00000 * PSLCM1   +   1.00000 * PSLCM2
           <=              376.0
- 95  CDOUTL      1.00000 * FSTCD1   +   1.00000 * FSTCD2
           <=              112.0
- 96  CDOULL      1.00000 * FSLCD1   +   1.00000 * PSLCD2
           <=              376.0
  97  GSPITL      1.00000 * FSTGPR1  +   1.00000 * PSTGPR2  +   1.00000 * FSTGPR3  +   1.00000 * FSTGPR4  +   1.00000 * FSTGPR5
           +      1.00000 * FSTGPR6  +   1.00000 * FSTGPR7  +   1.00000 * FSTGPR8
           <=              112.0
- 98  GSPILL      1.00000 * FSLGPR1  +   1.00000 * FSLGPR2  +   1.00000 * FSLGPR3  +   1.00000 * FSLGPR4  +   1.00000 * FSLGPR5
           +      1.00000 * FSLGPR6  +   1.00000 * FSLGPR7  +   1.00000 * FSLGPR8
           <=              376.0
  99  GSPBTL      1.00000 * FSTGPB1  +   1.00000 * FSTGPB2  +   1.00000 * FSTGPB3
           <=              112.0
-100  GSPBLL      1.00000 * FSLGPB1  +   1.00000 * PSLGPB2  +   1.00000 * FSLGPB3
           <=              376.0
-101  GSBHTL      1.00000 * FSTGBH1  +   1.00000 * FSTGBH2
           <=              112.0
-102  GSBHLL      1.00000 * FSLGBH1  +   1.00000 * FSLGBH2
           <=              376.0
-103  GSFLTL      1.00000 * FSTGF1   +   1.00000 * FSTGF2
           <=              112.0
-104  GSFLLL      1.00000 * FSLGF1   +   1.00000 * FSLGP2
           <=              376.0
-105  WPITL       1.00000 * FSTWPR1  +   1.00000 * FSTWPR2  +   1.00000 * FSTWPR3
           <=              112.0
-106  WPILL       1.00000 * FSLWPR1  +   1.00000 * PSLWPR2  +   1.00000 * FSLWPR3
           <=              376.0
-107  WPBTL       1.00000 * FSTWPB1  +   1.00000 * FSTWPB2
           <=              112.0
-108  WPBLL       1.00000 * FSLWPB1  +   1.00000 * FSLWPB2
           <=              376.0
-109  WBTL        1.00000 * FSTWB
           <=              112.0
-110  WBLL        1.00000 * FSLWB
           <=              376.0
.111  WFLTL       1.00000 * FSTWF1   +   1.00000 * PSTWF2
           <=              112.0
-112  WFLLL       1.00000 * FSLWF1   +   1.00000 * FSLWF
           <=              376.0
-113  WPITL       1.00000 * FSTWM
           <=              112.0
-114  WFILL       1.00000 * FSLWM
                  <=       376.0
-115  RAINM       1.00000 * SRCPR1
           <=              184.0
-116  RAINA       1.00000 * SRCPR2   +   1.00000 * SRGPR1
           <=              227.2
-117  RAINMY      1.00000 * SRCPR3   +   1.00000 * SRC1V1   +   1.00000 * SRGPR2   +   1.00000 * SRWPB    +   1.00000 * SRWB
           <=              521.6
```

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-118  RAINJU      1.00000 * SRC1V2   +   1.00000 * SRC2V    +   1.00000 * SRGPR3   +   1.00000 * SRSPB1   +   1.00000 * SRWFL
              +   1.00000 * SRWML
              <=            459.2
-119  RAINJL      1.00000 * SRCS     +   1.00000 * SRCM1    +   1.00000 * SRSPB2   +   1.00000 * SRSBH1
              <=            345.6
-120  RAINAU      1.00000 * SRCM2    +   1.00000 * SRCD     +   1.00000 * SRSBH2   +   1.00000 * SRSF1
              <=            345.6
-121  RAINS       1.00000 * SRSF2    +   1.00000 * SRWPR1
              <=            235.2
-122  RAINO       1.00000 * SRWPR2
              <=            139.2
```

A LINEAR PROGRAMMING CROP SELECTION MODEL FOR IRRIGATION IN SOUTHWEST KANSAS WITH WATER AND SOIL MOISTURE CONSTRAINTS

BY

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ABSTRACT

Irrigation is a very important part of agriculture in Western Kansas. The water supply is diminishing because water use exceeds recharge. Also the cost of pumping is increasing because of higher energy costs. Thus, with reduced water availability and higher costs the importance increases for an economic efficient use of water. Surveys and statistics show that farmers are adjusting irrigation practices toward more efficient use of water.

The objective of this study was to improve on a linear programming crop selection model to include consideration of soil moisture storage. The objective of the model was to maximize gross margin to land, operator labor and water.

The model included ten irrigation regimes for each crop, wheat, corn and grain sorghum. Each regime specified a different combination of water applied during the growth stages and yields estimate consistent with the water applied. The different regimes represent different levels of plant stress at different stages caused by water deficiencies. Yield reductions from estimated maximum attainable yields were based on equations by Mapp.

One irrigation regime for each crop represented full irrigation with no crop stress during any stage and with maximum attainable yield.

Crops selected and water stored in the soil were estimated for a 1200, 1000, 800, 600, 400. and 200 GPM well and 160 acres flood irrigated. Results were that soil moisture storage occurs for all GPM levels but increases as GPM decreases; crop selection is affected with less than 800 GPM well capacity; gross margin decreases at an increasing rate as GPM decreases and value of water increases as GPM decreases. Crops were selected to provide a more profitable distribution of water use which

became more important as GPM decreased.

The model considers storing water in the upper and lower profile. The upper profile is the top nine inches and the lower profile is the next 51 inches of soil. The soil is assumed to be a silt loam soil with 2.1 inches available water capacity per foot of soil. The water stored in the soil is used if direct application is insufficient. Water stored in the upper profile is used first.