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SIMULATING THE WATER REQUIREMENTS AND ECONOMIC FEASIBILITY OF CORN IN THE MIDWEST

by

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January 1981

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ABSTRACT

An evaluation of the economics of supplemental irrigation when using a surface water supply must be site specific in order to account for variations in soil moisture holding capacity, watershed area supplying the runoff, climatic conditions, and proposed irrigation management procedures.

With the use of farm specific simulation models to determine grain yields, availability of irrigation water, and economic expenditures involved in irrigation, an economic evaluation of supplemental irrigation can be performed. In the model presented in this report, the Duncan SIMAIZ model is used to predict grain yields using long-term daily weather information. SIMAIZ also determines irrigation water demand for the crop. The Haan Water Yield Model is used to predict flow into a reservoir using the same weather information. By knowing daily water flow into a reservoir and water demand for irrigation, a reservoir size is determined which will supply water at all times for the study period. Simulations are then run by incrementally reducing, by volume, the size of this reservoir, thus limiting the availability of irrigation water, and resulting in reduced irrigated yields.

An economic evaluation is performed for each reservoir size. Costs and benefits included are: initial cost of constructing the reservoir, yearly reservoir maintenance cost, yearly irrigation costs of operation, and additional income resulting from the increase in grain yields. After the project life has been assumed, the model determines the capital available for investing in an irrigation system for a given year and reservoir size. By ranking these values, a probability distribution is obtained indicating the probability of making money in any given year. By using the Central Limit Theorem, these results are converted to the probability of making money over the life of the system.

A sensitivity analysis examines the sensitivity of capital available for investment in an irrigation system to select input variation. The results indicate that great care should be exercised when assigning values to some inputs, while for others, a reasonable estimate is adequate.

This model can be used as a tool for evaluating which irrigation practices, if any, are economically feasible. An example of its use is shown.

Descriptors: Irrigation*; Crop Response; Crop Production; Field Crops; Economic Feasibility; Economic Justification; Scheduling

Identifiers: Simulation Model; Crop Growth; Water Requirements for Irrigation; Reservoir Size

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CHAPTER I

INTRODUCTION

Irrigation research and irrigation technique have primarily been developed for arid regions where most crops will not grow if natural precipitation is not supplemented. Due to years of research and experience, farmers in the arid western states are well informed on irrigation scheduling and management practices. They know which growth periods are more susceptible to moisture stress than others, and can conserve water by emphasizing this information. Irrigation scheduling and management models have been developed for arid regions and are not utilized by consulting firms and county agents to assist the farmer on all levels of irrigation decision making.

In semi-humid regions, irrigation research generally begins as a result of public pressure following a period of draught. In most cases, the research projects fail to be carried out over a long enough period to experience the wide range of climatic conditions which occur in sub-humid regions. This type of irrigation in sub-humid climates is called "supplemental irrigation", since rainfall does occur during the growing season, and generally, the total amount is adequate to meet the crop water needs for a growing season. Irrigation is only needed when drought periods occur and the normal rainfall needs to be supplemented for optimum plant growth. Due to the sporadic interest in irrigation from both the researcher and farmer, advances in supplemental irrigation management techniques and practices have been minimal.

The major question confronting the farmer is, will the investment in supplemental irrigation be an economically sound decision? In discussions with farmers in Kentucky who have invested in irrigation systems, it seems that little professional or technical assistance is available. In one case, a farmer was applying .25 inch of water each time he irrigated a 200 acre farm with a center pivot system. His belief was that when the corn needed to be irrigated it should be done all at once, so within one day he applies .25 inch of water. This is a poor practice, for only the upper layer of soil would receive any of the water and the majority of the root zone would be dry. Also, on very hot days, which is often the case when irrigation is needed, the free water evaporation rate can be as high as .25 inch. Obviously, this farmer would benefit from guidance with irrigation management and scheduling. In another case in Kentucky, a farmer was uncertain about his irrigation investment involving a reservoir constructed to store surface runoff for irrigation. In an extremely dry year, the reservoir went dry after three irrigations. Now this farmer is uncertain if his reservoir is too small or if this year was exceptionally dry and under normal circumstances he would have an adequate water supply.

Irrigation extension specialists are needed and could alleviate some of these problems, but since no sound method exists for evaluating supplemental irrigation economics, much of the advice from a specialist would be just guess work.

A site specific evaluation of the economic feasibility for irrigation is the best approach for determining if supplemental irrigation will benefit an individual farming operation. With the use of simulation models, daily calculations of crop growth and water demand, water supply availability, and economic expenditures can be performed rapidly, thereby allowing for a more detailed analysis of an individual site. The purpose of this research is to develop a model to evaluate the economics of supplemental irrigation. Several years of climatic information are used to determine if irrigation is economical and to determine the size of reservoir needed for surface water storage to be used for irrigating corn.

In the site specific evaluation of the economics of supplemental irrigation, the dependability of water from either a stream or aquifer must be considered. If the flow rate from the aquifer is inadequate to meet the irrigation demand, a reservoir may be constructed for storage of water. In many cases, due to inadequate flows from groundwater aquifers, the water supply for irrigation must be surface streamflow. If the streamflow is undependable, a reservoir is required. The required size of a reservoir depends on the variability of the water supply as well as the irrigation demand. If the water flow is sufficient to meet the irrigation demand, an analysis of the irrigation expenses and benefits is needed before determining if irrigation is economically feasible. The optimum reservoir size, as well as the economics of supplemental irrigation, will depend on variations in soil moisture holding capacity, hydrologic characteristics of the watershed supplying the waterflow, climatic conditions, agronomic practices, irrigation management practices,and increased crop yield due to irrigation.

Crop response to supplemental irrigation is highly site specific and variable from year to year. The site dictates soil water holding capacity. Some soils have a large enough water holding capacity, or soil water reservoir, to supply crops with the water required for evapotranspiration between most rainfall events. Conversely, some soils have such low water holding capacities that short periods without rainfall cause plant water stress. If the soil reservoir is too small and the rainfall is so undependable that frequent periods of stress occur, supplemental irrigation should be considered. The irrigation demand will be stochastic because of the stochastic nature of rainfall and evapotranspiration.

Since crop growth occurs without irrigation in humid mid-western regions, the economic question to be answered is whether or not the return from increased yields from supplemental irrigation offsets the expense of installing and maintaining an irrigation system. This question must be answered on a site specific basis since plant available water and water yield are highly variable within a geographic region.

The problem of evaluating the economics of supplemental irrigation of corn in a humid region is addressed herein. Simulation models are used to determine grain yields, availability of irrigation water, and the capital outlay involved in irrigation. Climatic data, agronomic practices, and irrigation management practices are inputs to these models. Daily water demand for irrigation, water flow into a reservoir, and a mass balance are used to determine the reservoir size which will supply water at all times for the study period. This reservoir size is incrementally reduced, thus limiting the availability of irrigation water, which results in reduced irrigated yields. For each reservoir size, the grain yields and irrigation expenses are calculated. An economic evaluation is made using the increased income and additional expenses from irrigation. A family of curves is generated at different risk levels which indicate the amount of capital needed for investment in the irrigation systems as a function of reservoir size.

These curves can be used as a guide to selecting the point at which irrigation is economically feasible.

CHAPTER II

LITERATURE REVIEW

To accomplish the modeling effort indicated in the introduction, a search of the literature concerning the following areas is necessary: surface runoff models; corn growth models; results from irrigation studies; evapotranspiration prediction methods; management and scheduling practices for irrigation, especially for corn; and economic studies concerning irrigation.

MANAGEMENT AND PLANNING OF IRRIGATION PROJECTS

Evapotranspiration Modeling

For proper on-farm irrigation management, evapotranspiration rate must be known. A complete review of evapotranspiration research and methods of calculation through 1968 was compiled by Rosenberg et al. (1968). In this review, methods of ET prediction based on the physics of evapotranspiration include: mass transport methods, aerodynamic methods, eddy correlation, the energy budget, and Bowen's ratio. A general form of the mass transport method predicts evaporative flux as a function of vapor pressure and wind speed. The aerodynamic method has undergone many refinements primarily involving the incorporation of stability corrections for different surface conditions. The eddy correlation is a method to estimate the vertical flux of heat or vapor. Energy balance techniques for estimating ET have proven reasonably accurate in the more humid regions of the country. The Bowen ratio variants of the energy budget have given good results, even where advection is considerable. Some of the empirical methods in which ET is related to one or more meteorological parameters were also reviewed by Rosenberg et al., along with different studies using these methods. The empirical methods that Rosenberg et al. discussed were: the Thornthwaite equation, the Penman equation, the Blaney-Criddle equation, and van Bavel's equation.

Morton (1976) presents a method of predicting evapotranspiration over a large area when temperature, humidity, sunshine duration, and albedo are known. This method works well when time intervals are no shorter than 5 to 10 days.

Many methods have been developed to predict potential evapotranspiration (PET). A more difficult problem is calculating actual evapotranspiration (ET). In addition to being dependent on the same variables as PET, ET is dependent upon the soil moisture conditions and stage of development of the crop. A few methods for predicting ET will be presented.

Ligon et al. (1965), in addition to reviewing existing potential evapotranspiration (PET) relationships, presented a method which uses PET values to calculate actual evapotranspiration (ET) under three conditions.

If rainfall occurs

$$ET = PET/2 \tag{1}$$

If the readily available soil moisture is not depeleted

$$ET = PET \tag{2}$$

If the readily available soil moisture is depleted

$$ET = PET \times ((Mu\ actual)/(Mu\ maximum)) \tag{3}$$

where Mu is the less readily available soil moisture. The results indicated that this method compared well with data from Lexington, Kentucky for three years. This method for predicting ET is dependent upon the soil moisture status.

In a lecture presented by Pruitt (1974), four methods of predicting PET were described which could be used for determining ET for several crops. These methods are: Blaney-Criddle, Radiation, Penman, and Pan Evaporation. Once these methods were described, a method was presented for calculating a K value used to relate PET to crop ET. This K value is dependent upon the specific crop, climatic region, and varies throughout the growing season. A curve needs to be generated which will relate the K value with days into the growing season. Steps necessary to develop the K curve are:

(1) Determine planting date for a given climatic region.

(2) Determine length of growing season and the following growth stages: initial, crop development, mid-season and late-season. Values for different crops and locations are tabulated in a complete report on this procedure by Doorenbos and Pruitt (1974).

(3) Obtain K values for the following development stages: initial, mid-season, and late-season. Details on these procedures can also be found in Doorenbos and Pruitt (1974).

Ritchie (1972) developed a model for predicting ET from a row crop. The model calculates evaporation from the soil surface and plant canopy separately. Soil evaporation is considered in two stages: when the soil is evaporating as a free water surface and when the hydraulic properties of the soil govern moisture movement. Transpiration calculations are made using a relationship developed by Ritchie and Burnett (1971), relating transpiration to potential evapotranspiration (PET) as influenced by leaf area index of the crop. The total evapotranspiration is a combination of both soil evaporation and transpiration. This value must not be greater than a potential evapotranspiration value, based on Penman's equation. Ritchie's model is used in Duncan's corn model (1974) for determining soil moisture status. Ritchie's model was tested in Temple, Texas using grain sorghum. Precipitation timing caused some error in over-estimating soil evaporation when the soil was originally in the second stage of soil drying and the rain did not occur until evening while the model assumed it occurred at the beginning of the day. The total evaporation calculated for the test period was 125 mm, which compared favorably with the measured water loss of 120 mm.

Tanner and Jury (1976) developed an evapotranspiration model similar to that of Ritchie. Tanner used the Priestley and Taylor formula for potential evapotranspiration calculations. Both models considered the soil as a semi-infinite, one-dimensional medium, without gravity, undergoing monotonic surface drying from a uniform initial condition. This can only serve as an approximation to the behavior of soil in the field receiving rainfall or irrigation and water extraction by roots. Thus, neither model is preferable from a theoretical point of view. This model was tested on potatoes using two years of lysimeter measurements. The standard error of estimated varied from .4 to .94 mm/day. The estimate of accumulated ET for four weeks varied from measured values a maximum of 1.0 cm for a total 9.7 cm ET.

Coble and Bowen (1973) developed a computerized mathematical approach to soil drying based on liquid and vapor movement in the soil. It is the first successful deterministic model responsive to weather input which correctly describes both the formulation of a dry layer on the soil surface and the redistribution of water in the soil. To validate the model, experimental data was taken using an indoor test facility (Edaphotron) which physically simulates the outside environment. The soil moisture profile after two and eight days of running the test showed close agreement between observed and simulated results.

Lambert et al. (1976) developed a simulation model that described water flow through the soil, into and through the plant. This model describes the physical process of transpiration in much greater detail than other evapotranspiration models. Because of this detail, the microclimatic variables are of prime importance in the model. Stem resistance was also found to be critical in calculating leaf water potential. At this time this model appears to be too complex for practical use in irrigation planning.

Rosenthal et al. (1977) evaluated an evapotranspiration model for corn. A detailed description of this model can be found in Kanemasu et al. (1976). The results of testing this model showed that predictions were within six percent of neutron attentuation measurements. Daily inputs for the Rosenthal model are: leaf area index, solar radiation, precipitation, and maximum and minimum temperatures. Daily outputs are transpiration, evaporation, advective contribution, and soil water content. This model has a good potential for use in irrigation scheduling on a regional basis.

Planning Models

The economics of irrigation is dependent upon farm management and planning as in any business or industry venture. Much research has been directed towards understanding and developing good management systems. A few areas of previous work will be discussed.

Boisvert (1976) developed a farm planning model which determines the time suitable for field work and the yield losses associated with untimely crop production. Bottlenecks, which occur both at planting and harvesting, result in costly delays and place a limitation on manageable farm size. The model examines ways of expanding the field capacity such as hiring labor, using larger machinery, having custom work done, and combining field operations. As an example of the model output, in Minnesota, Boisvert (1976) predicted that the average corn planted during the first half of May results in yields of 13.6 bu/ac greater than corn planted during the last half of May.

Feddes and Van Wijik (1977) developed a model that relates the effects of soil drainage on crop yield. Soil drainage is related to the number of workable days in the spring for planting and ground preparation and in the fall for harvesting. Delayed planting, harvesting, and improper timing of management affect yield.

Allison (1968) stressed that the most important aspect for successful irrigation is compatability between water, land, and people. According to Allison, a highly motivated farmer with knowledge of how the equipment operates and when and how to irrigate, is going to have a much higher success rate. Neglecting any one area of irrigation can result in decreased returns.

The use of earth resource satellites and aerial photography as a potential aid for management decisions was reviewed by Anderson (1979). He attempted to instill an awareness of remote sensing's tremendous potential in irrigation planning and management. Earth resource satellites produce images which could help estimate current water requirements and locate areas with a high potential for irrigation development. Aerial photography could be used for determining pre-planting field conditions, emergence success, mid-season stand, growth and development, water stress, insect and weed control, improper drainage, pre-harvest stand and potential problems, total area harvested, and regrowth problems. Basically, aerial photography allows the farmer to get an overview of the field and document special situations of potential damage.

Management of irrigation on a regional basis may help solve some of the water supply problems. Fok (1979) presented a regional trade-off analysis for irrigated corn production. By concentrating irrigation projects in the humid Midwest, crop yields could be increased without dangerously depleting the water supply. A dangerously heavy demand is being placed on the Ogallal aquifer and the Colorado River for irrigation purposes (Canby, 1980).

Irrigation Management and Scheduling Models

Lord et al. (1977) describes SWAP/ET a soil-water-atmosphere-plant/evapotranspiration model. Harza has been using SWAP/ET to assist farmers in the San Joaquin Valley of California in planning irrigation systems and scheduling irrigations.

Thompson and Fischback (1977) described AGNET's irrigation scheduling model used in Nebraska. The model performs all the calculations, updates weather data files, and predicts when the next irrigation should be. The scheduler provides maximum and minimum temperatures, rainfall amount, and readings from four stations of soil moisture blocks. The soil moisture blocks insure that water use predictions are correct and that other irrigation management problems do not arise. A more detailed prediction model is available that does not require soil moisture block readings, but requires additional inputs such as solar radiation, relative humidity, and wind data. The model should be used under the guidance of a qualified irrigation scheduler. The University of Nebraska will be offering short courses to train irrigation schedulers. This service is offered through extension offices and some county agents in Nebraska.

Hashemi and Decker (1969) presented a method of using climatic information and weather forecasting as aids in economizing water for corn irrigation. A computer model was developed to evaluate this procedure. Numerical probability forecasts have only been issued since 1966. A method was needed to calculate a probability forecast. Using Bayes' inverse probability theorem and the computer, it was possible to compute probability forecasts from past weather records. By incorporating probability forecasts in decision making, a significant savings of irrigation water was made. Irrigation was delayed at times because of the probability of a rainfall event occurring. If irrigation was delayed and the forecast precipitation did not occur when the available soil moisture fell sufficiently below the 50 percent level, irrigation began. In areas where supplemental irrigation is needed, this method could possibly work well in saving water. A determination needs to be made of whether or not the procedure produces economic benefits.

Buchhiem and Ploss (1977) reported on the use of computerized irrigation scheduling using neutron probes. Periodic neutron probe readings are used to verify the soil moisture status which is calculated using an evapotranspiration model. In a typical scheduling operation, only one access tube is needed for each field when properly located and maintained. Using this scheduling model, the optimum irrigation date and the amount of water to apply can be provided to the irrigator.

Udeh and Busch (1974) developed a Bayesian decision theory optimization model applied to optimal irrigation management strategies. The model is suited for limited data, is flexible, and non-intensive in time and money. The purpose is to select the optimum land area to be irrigated, as controlled by stochastic hydrologic and probabilistic irrigation efficiency input parameters, and the irrigator's risk response function under the specified probabilistic conditions.

Stegman et al. (1976) developed regression equations relating leaf xylem pressure versus ambient air temperature and available soil moisture to determine a stress level for initiating irrigation. By using this method for irrigation scheduling, as compared to irrigating when 50 percent of the soil moisture is depleted, a 20 percent savings in irrigation water resulted with similar yields. By using these relationships, plant stress criteria could improve irrigation scheduling, resulting in water savings and reduced costs.

Evaluating Different Irrigation Strategies

A large number of studies have been conducted to evaluate different irrigation strategies. The optimum strategy will differ between climatic regions of the country. This should be considered when evaluating any one strategy. A few studies will be reviewed here.

Singh et al. (1976) showed that the soil moisture potential at which growth stops for corn is a function of both the age of the plant and earlier moisture stress. The earlier moisture stress conditions the corn plant, allowing it to withstand more severe drought periods before growth stops. This information can be useful for corn irrigation scheduling when water use must be limited. These growth experiments with corn were conducted under controlled environmental conditions.

Howell and Hiler (1975) studied water use efficiency in relation to seasonal water usage and grain yield. The best water use efficiency resulted with a high frequency of irrigation; three per week. Yield increases under frequent irrigation were not substantial, but the water conservation was significant.

A study by Kroutil (1979), using a variety of irrigation amounts, showed that regular application with less water than required for maximum evapotranspiration produced best water use efficiencies for corn. The study also showed that full irrigation is not needed during all growth periods to produce maximum yields. In fact, the study showed that the quantity of water which some irrigators apply is actually detrimental to the crop and can suppress yields by five percent. A lack of aeration reduces yields and too much drainage through the soil profile carries away necessary nutrients.

Heermann and Duke (1978) established two limited water application plots using center pivot systems planted with corn. Water stress was quantified by measuring water applied, soil moisture, canopy temperature, and plant water potentials. The yield reductions were linearly related to the applied water and average canopy temperature. Reduction in yield was significantly correlated with the increase in canopy temperature, as compared to a well watered plot. It was found that the temperature difference must exceed 1.5 degrees centigrade before a yield reduction is probable. Although this information would be useful for irrigation scheduling, it is impractical for field usage, as a check plot is needed. A device has been developed and is now marketed by Teletemp Corporation which determines a similar stress index by comparing canopy temperature with air temperature.

As the cost of manufacturing this device goes down and confidence in its usage increases, it could prove to be a valuable tool in irrigation scheduling (McClintic, 1980).

Maurer et al. (1979) studied the effects of timing and amount of irrigation water on corn. The growing season was divided into three growth stages and seven irrigation treatments were applied using combination of uniform and gradient irrigation applications. No evidence was found that prestressing conditioned the plants to later drought stress. Also, irrigation options for optimum use of water is limited.

Irrigation Management and Scheduling - Humid Region

Most of the irrigation research in the United States has been directed towards problems in the arid western states. Water shortage is becoming an increasingly important problem in these areas, hence, water use efficiency is of prime concern. In the more humid regions in the East, adequate rainfall occurs for most plant growth. The problem is that short periods of high temperatures and no rainfall occur, resulting in water stress and yields do not reach their maximum potential. Irrigation in these regions is referred to as supplemental irrigation as it only supplements rainfall. A few sources and problems dealing with supplemental irrigation will be mentioned.

One of the first books dealing with supplemental irrigation was by Rubey (1954). In it he discusses when supplemental irrigation is advisable, how to plan, install and operate a satisfactory system, and what to expect from it.

Kidder et al. (1958) describes, in general, different water supply sources and soil and crop water needs for supplemental irrigation. Also discussed are methods used to design such a system and what important considerations are needed when deciding to irrigate.

Jamison and Beale (1958) developed a handbook for irrigating corn in humid areas. They recommend irrigation throughout the growing season if the water supply is plentiful and time is not limited. If either one of these conditions do not hold, they recommend irrigation from tasseling through grain maturity. They also give practical guidance for determining when to irrigate. During drought periods, corn will use 50 percent of the total plant available water (PAW) in 12 to 15 days on a silt loam soil and 4 to 5 days on a sandy soil. Two ways of visually determining when 50 percent of the PAW remains is to examine the corn plants for wilting at about 10:00 a.m. and check the soil at plow depth for balling. About 50 percent of the PAW has been removed from a sandy loam soil when it will not ball under hand pressure; from a loam or silt loam when it will ball but is crumbly; and from a clay or clay loam when it is slightly pliable but cracks appear. Another way to determine when to irrigate is by using weather data and estimating daily evapotranspiration rates. By keeping a daily soil moisture balance, the 50 percent level can be determined. The recommendations for irrigating is to apply enough water to refill storage capacity of the soil to approximately the two foot depth.

A computer model that evaluates the performance of a supplemental irrigation system, using a reservoir as the water supply, was developed by Zovne and Steichen (1980). The reservoir water balance accounts for direct precipitation, evaporation, seepage, overflows, irrigation withdrawals, and runoff from the watershed. The runoff is calculated by using the SCS curve number method. Irrigation rates are those recommended by the SCS Kansas irrigation guide. An advantage of this model is its ability to specify any number of crop rotations on as many plots as the operator would use. One of the disadvantages is that the model does not size the reservoir.

An interesting concept for supplemental irrigation scheduling proposed by Allen and Lambert (1971) is to use an irrigation cost-to-crop ratio. The following ratios are proposed:

if $P > C/L$ irrigate
if $P = C/L$ either one
if $P < C/L$ do not irrigate

where

P = probability of irrigation occurring
C = cost of irrigation
L = loss due to not irrigating

The cost of irrigation would be relatively easy to compute depending on type of system, cost of pumping, and use of water. The problem lies in determining the loss due to not irrigating. This would depend on the probability of rainfall within a given time frame, stage of crop development, and moisture stress effect on the final yield.

Economics of Irrigation

Whenever an investment in an irrigation system is being considered, economics is an important aspect of the decision making process. The specific economic considerations vary tremendously depending on the region, crops, water supply, labor force, etc. In essence, every situation should be independently evaluated. A considerable amount of research has been conducted concerning irrigation economics. The type of research and reports is as varied as the problem itself. A few of the current works will be mentioned.

Reutlinger and Seagraves (1962) presented a method for predicting the economic return from limited irrigation in semi-humid regions. Experimental results relating yields to irrigation, rainfall, and temperature data for several years, was used for yield predicting. The most satisfactory method for economic consideration was an internal rate of return comparison. They felt the main reason for considering irrigation in semi-humid regions is to reduce yield variability. The value of this insurance varies with each situation, so estimating the value in a general way is impractical.

Asopa et al. (1973) evaluated the returns of irrigated corn in a sub-humid region. A multiple regression equation was used for yield predictions. The equation is based on temperatures and precipitation amounts for different periods of the season. Serious short comings of the method include: inadequate representation of the crop water use, the water holding capacity of the soil, and the lack of a plausible measure of the effects of climatolotical variables on yield prior to the beginning of the irrigation cycle. If the biological situation at each point in time were known, a more realistic effect of moisture stress on final yield would be known. The model showed a tendency to over-estimate additional income. This could result from the way irrigation costs were figured. A yearly value of $20.00 per acre per year was assumed to cover the costs for irrigation.

Ruttan (1965) made projections of water use into the 1980's. He pointed out that irrigation development in the sub-humid East represents an economic substitute for the extension of submarginal irrigation in more arid regions. Water is becoming scarce in many arid regions and industrial and private uses for water are having higher demands than agricultural uses. One way to compensate for reduced agricultural production is to irrigate in sub-humid regions which have more abundant and renewable water supplies. A problem is the questionable return on investment for irrigation in sub-humid regions. Methods need to be developed to help evaluate the feasibility of irrigation.

Clark (1966) discusses irrigation economics for several countries, and presents applied economics and critically important facts over a wide climatic range. He points out that many unjustified claims have been made for irrigation projects and that individual evaluations of economics must be made for specific costs of irrigation.

Economic considerations regarding irrigation are not limited to only farming situations. Much irrigation research is carried out at universities. A method for determining if irrigation research is justified has been proposed by Parvin and Nelson (1973). Crop yields have been recorded at most research centers for years. These values can be used to determine if irrigation research is justifiable. First, the crop yields must be adjusted for improved technology, soil fertility, improved hybrids, etc., before an appropriate comparison can be made. It was assumed that at least one year had ideal weather conditions which produced the best yield and is comparable to an irrigated situation. By using this yield as the expected yield from irrigation, it can be compared with the average yield for the entire period of record and an average yield increase can be determined. If the benefits from this average yield increase exceeds the estimated average irrigation cost, then irrigation research would be justified.

The economic consequences resulting from irrigation affects more than just the immediate parties involved. A study by Roesler et al. (1968) showed that the irrigation economics in Nebraska, since World War II, has affected all industrial sectors, not only the farmer and equipment suppliers.

A study by Long and Raup (1965) on the economics of supplemental irrigation in central Minnesota showed irrigation to be beneficial. Supplemental irrigation of corn allowed for more dependable and higher yields than could be obtained from dryland farming where a drought risk may occur. The study was conducted in the early 1960's when interest rates were six percent and energy costs for pumping were considerably lower.

Parvin (1973) pointed out that the utilization of an irrigation system is very important in the economic results. The cost per acre decreases as the utilization of a system increases, thus there is an inverse relationship between the total cost per acre and the use and size of the system. He also emphasized there is no guarantee that irrigation returns will cover irrigation costs, but that it is necessary for the estimated average irrigation cost to be exceeded by the average value of irrigated returns. The results of his study showed that irrigation of corn tends to be more economical for larger systems with a high level of utilization.

Westberry (1975) conducted an economic analysis for a center pivot irrigation system that will irrigate 56 hectars of corn in Florida. It showed that break-even yields were realistic with relatively low corn prices. He also pointed out that the average corn yields in Florida from 1971 to 1974 were about half the national average for the same time period. A lack of water at proper times was suspected as the reason, indicating that irrigation may be needed.

Swansen and Jones (1976) used yield relationships for estimating annual investment returns for irrigated corn. Two years of data were used to estimate constants for a regression equation for yield. The variables used were pounds of nitrogen per acre, plant population, and plant available moisture, during a 17 day critical period (bloom or tasseling stage). Operation costs, such as labor, fuel, and repair for harvesting and fertilization, were considered as one constant value per application ($3.62/ac). Irrigation response was calculated at a given maximum yield. For the nonirrigated yield, 58 years were studied in 5 and 10 year sequences to determine if irrigation is beneficial. The difference between irrigated and nonirrigated values is taken to determine the expected yield increase and additional income.

Hogg and Vieth (1977) presents a method for evaluating irrigation projects. Linear crop production functions are used to determine water use and crop production based on evapotranspiration and rainfall. A comparison of different irrigation projects for irrigation over a planning period allows the planner to evaluate the best system. Price and climatic uncertainties are dealt with, assuming the probability distributions are known. A benefit-cost ratio, internal rate of return, and net present worth are measures used to evaluate the economics.

Mantanga et al. (1971) proposed an irrigation optimization model for cropping patterns in relation to economics. Components considered were land area per crop, cost of production, irrigation water, irrigation labor, and price of each crop. This is a valuable tool in planning irrigation projects over an irrigation season. Different crops have unique water needs and costs.

A computer model developed by Chen et al. (1976) analyzes different irrigation systems for energy requirements and economic cost. This is a very useful model if a farmer is certain that he/she wants to irrigate, but is unsure of the most economical system to use. The model does not consider the benefits resulting from irrigation, but simply analyzes just the energy use and economic expenditures for different systems.

Fogel et al. (1976) presented a methodology for instituting an irrigation policy that considers the possibility of rainfall while maximizing net returns to the farmer. Some of the considerations for the model are as follows: optimum soil water content must be defined, loss of nutrients due to excess soil water must be determined, and an additional expense for applying the water must be calculated. This expense must be considered along with those that reflect a yield reduction due to water shortage. Other expenses are operation and maintenance, which include power, labor, and repairs. These costs are assumed proportional to the amount of water applied for each irrigation. The decision to irrigate is influenced by the possibility of rainfall and the growth stage of the corn plant.

Clouser and Miller (1980) examined economic returns for irrigating corn and soybeans in the humid Midwest on a fine textured soil with a restricted root zone. They developed an optimization model to predict which irrigation method and water supply will produce the highest returns as compared to dryland farming. Because this model assumes a reservoir size and neglects the periodic inflows due to watershed runoff, proper determination of a reservoir size and economics is unlikely. The yield increases from irrigation, operating costs, reservoir size, and cost are fixed, predetermined values. This model is a useful tool, but requires more input information than is normally known.

Burt and Stauber (1971) developed an economic model for the analysis of irrigation in sub-humid climates. An optimal supplemental irrigation policy would indicate the amount of water to apply at each time period, for all possible combinations of crop conditions and levels of water supply in order to maximize expected net returns. A simplifying assumption is made that additions to the storage reservoir during the irrigation season are negligible. An approximation is allowed in which the expected additions to storage for that time period is treated as if already in storage. The justification is that in the sub-humid eastern United States the irrigation season is both short and relatively dry as compared to the rest of the season. This may be true, but the potential additional runoff between irrigations could contribute significantly to replenishing reservoir volume. Corn is the crop simulated, and tasseling date must be known for each year for proper yield predictions and irrigation scheduling. The negative effects on yield from too much water are also considered. Variable costs were fuel, oil, repairs, and labor. Cost of harvesting is figured as being proportional to yield.

Of the methods previously mentioned which do use a reservoir for water storage, none of them consider any inflow due to rainfall during the growing season. Due to the high cost of water storage, it is apparent that a method is needed which will evaluate the economics of irrigation and properly size an irrigation water supply reservoir so as to maximize the cost/benefit ratio. This is especially important in sub-humid regions where much uncertainty exists concerning the economics of irrigation.

CORN MODELS

Much research has been conducted describing plant and yield response to environment. Duncan (1974) published a report on the physiology of maize in which he describes in detail the different plant parts, germination, reproductive development, temperature effects, and yield relations. In this report he also gives a brief description of SIMAIZ, a corn growth simulation model which Duncan developed. SIMAIZ is a mathematical representation of the plant's physiological components described in the 1974 report. SIMAIZ has the ability to adapt to different varieties and soil types, allowing it to be site specific in determining water needs and yield response. Barfield et al. (1977) presents a brief documentation of SIMAIZ, and a comparison of both irrigated and nonirrigated conditions where 12 plot years of corn yields are used to compare simulated versus actual corn yields. Good results were obtained for the nonirrigated yields, whereas poor correlation resulted with the irrigated yields. This could be attributed to the lack of information of when and how much water was applied. A detailed documentation of SIMAIZ, describing the separate subroutines and input information, is reported by Palmer et al. (1981). A few of the more important relationships SIMAIZ is based on are as follows:

(1) Phenological development is based on degree days.

(2) Dry matter accumulation is based on photosynthate produced and stage of phenological development.

(3) Photosynthate production is based on solar radiation and leaf area index.

(4) Leaf area growth is based on degree days and follows a sigmoidal curve.

(5) Potential yield is based on a ratio of potential grain weight to stalk weight at pollination. This value is readjusted, based on the photosynthate production after a latent period has elapsed.

(6) Soil moisture balance is calculated daily based on Ritchie's row crop evapotranspiration model.

(7) Effects of water stress on dry matter accumulation and evapotranspiration rate is based on a curve which relates the moisture content in each of ten soil layers with a stress factor which reduces dry matter accumulation and potential evapotranspiration.

In a study by Fritten (1975), the problems encountered when trying to adapt a corn model to an area other than the locale in which it was developed, were evaluated using SIMAIZ and a Nebraska corn model. Even though SIMAIZ has soil and plant variety parameters to facilitate adaptation to different conditions, considerable time, effort, and guidance was necessary for adapting the input parameters in this situation. Also, at this time, documentation of how SIMAIZ worked was not available. Once the model was forced to accurately predict silking date, yield and dry matter production were also accurately predicted. In the same report, another physiologically based simulation model, the Nebraska Corn Model, was tested (Splinter, 1974). The Nebraska Corn Model lacks the sophistication of the Duncan model. It requires three basic inputs: average daily light intensity, average temperature, and soil resistivity block readings. The Nebraska Model also had to be physically forced to accurately predict silking date. Once this was done, (Fritton, 1975) results were reasonable.

Another corn growth model developed in Nebraska was by Childs et al. (1977). This model uses the same degree day concept for estimating growth stages, as did Splinter in his model. It uses more input data and attempts to simulate the environmental and physiological processes involved in corn growth. Soil water flow and root water extraction are simulated, resulting in a model adequate to simulate both irrigated and nonirrigated conditions. This model was improved upon by Tscheschke et al. (1979) in the areas of: root water extraction, dry matter production, maintenance respiration, growth respiration, photosynthesis, and transpiration.

Ayres (1976) developed a simulation model which has mathematically described components that predict physiological maturity, climate and soil relationships, the moisture content, and yield of grain any time after physiological maturity.

Miles et al. (1976) describes a Fortran based GASP IV crop simulation model. It is versatile in that the user developes Fortran equations to describe the different growth stages for any crop where simulation is desired. Once familiar with the usage of this model, it would be very useful for multiple cropping simulations.

Blakie and Schneeberger (1971) developed a crop yield projection model where the growing season is divided into ten periods. At the end of each period, rooting depth is adjusted so the moisture balance can be more accurately determined. The effect of stress on final yield is also determined during each period. Moisture stress is determined as follows: the number of days moisture content falls below 50 percent is determined for each period, depending on the period and number of stress days the potential yield is reduced by a percentage, thus allowing a projected yield based on current weather conditions. This would be a good model for scheduling supplemental irrigation.

Miles et al. (1976) outlined areas of concern for developers of physiologically based crop simulation models. It is important to identify and qualify objectives of the model, development of the model, verification of the model, and a sensitivity analysis. Emphasis was placed on publication so other potential users can become aware that a model exists and of its user potentials.

Arnold (1977) illustrated problems that arise when trying to establish temperature-rate relationships from field data and using these relationships to determine significant stages of corn development.

In an experiment conducted by Singh et al. (1976), measurements of leaf area, dry matter weight, stem diameter, and plant height were taken of corn plants grown in controlled growth chambers. The measurements indicated that growth occurred between 10 degrees centigrade and 35 degrees centigrade. Outside of this range the plants started decreasing in size after reserves were depleted.

Another type of corn growth model is based on linear regression equations that relate evapotranspiration to yields. Many models of this type exist for a wide range of geographic and climatic conditions. Most work well for the variety and location that they were developed for, but break down when adaptation to other regions is attempted. A few of the existing regression models will be mentioned along with the results from verification studies.

Musick and Dusek (1978) related three years of grain yields and evapotranspiration measurements by linear regression. The main purpose of the three year study was to determine optimum water use efficiency and relate sensitivity of yields to plant water stress. The study was conducted in the southern high plains region. Treatments that experienced moderate stress during vegatative growth were more efficient than those that experience stress during grain filling. It was found that limited irrigation in these regions involves unacceptably high risks and should not be practiced. If reduced water usage is needed in high evaporative demand climates, it should be restricted to the early part of the growing season.

Stegman and Aflatount (1978) developed regression equations relating relative yield (Y/Y_{max}) versus relative evapotranspiration (ET/ET_{max}) for three growth periods. The three growth periods are planting to 12 leaf stage, 12 leaf stage to black layer, black layer to plant maturity. The findings from this study suggest some yield loss may occur due to water stress before an ET depression occurs. It was also determined that the least yield reduction results when stress occurs during the early vegetative period and that the highest yield per unit of applied water occurred when irrigation is reduced during this period. Yields will probably be depressed from the Y_{max} potential whenever irrigation regimes do not permit the maintenance of potential ET rates.

An extensive research project by Stewart et al. (1977) involved two years of irrigated corn plots in four states: California, Arizona, Utah, and Colorado. The objective of the project was to test existing models and develop new production functions for estimating corn growth and yield as influenced by different levels of salinity and water supply at different stages of growth. The models evaluated were two developed by Steward (denoted as S1 and S2), two models by Hanks (denoted as H1 and H2), and the Hall-Butcher model.

The S1 model predicts yield by subtracting the yield reduction due to total ET deficit from the maximum potential yield, while in the S2 model, yield predictions are calculated in much the same way except more complex coefficients are used which associate ET deficits for separate growth periods with yield reduction. The simpler S1 model will predict as accurately as the more complex S2 model, unless the corn variety has distinctly different growth stage sensitivities and the management of water is such that ET deficits are overly concentrated in the sensitive periods. Under these conditions the S2 model should produce markedly better yield predictions.

The Hanks H1 and H2 models take an approach similar to the Stewart models; however, in the Hanks models, yield is based on transpiration and potential transpiration only. The H1 model relates the ratio of actual seasonal transpiration and potential seasonal transpiration to yield. The H2 model was developed in recognition that grain yield may not be so simply related to ET because of differences in water stress effects during different growth stages. The H2 model divides the season into five periods, and considers the effects of transpiration during each period. The ratio of actual to potential transpiration is determined for each of the five growth periods. Each ratio is taken to a weighting factor which varies with the growth stage. These values are multiplied by each other and the final value is equal to the ratio of grain yield to potential grain yield. In this study, the simpler model resulted in more accurate predictions.

The Hall-Butcher model assumed that crop yield can be calculated from soil moisture during three growth periods: vegetation, pollination, and maturation. The ratios of actual plant available water to potential plant available water for each growth period is raised to a power in which the coefficient varies with the growth period. These values are obtained for each growth period and are multiplied by each other along with a constant to determine a ratio of actual to maximum yield. The overall comparison of the models indicates that the Stewart models correlate with the data well at all locations. Since the simpler S1 model worked about as well as the S2 model, the S1 model is preferable due to its simplicity. The Hank H2 model overpredicted at all locations, but the H1 model gave generally good results. Since the Hank models were not calibrated with the data at each location, this good prediction is an indication of the transferability of the H1 model. Improvement may be possible for the H2 model by developing better codfficients. The results from the Hall-Butcher model were varied. In some locations, reasonable correlations were obtained while at others the correlations were poor. The coefficients were also quite variable among locations and even between years at the same location. It appears that the data collected in this study could not be transferred to another location with reasonable results. An advantage the Hall-Butcher model would have over the others is in a situation where water content alone was measured. The study also showed that strong linear relationships exists between both dry matter and grain yields and evapotranspiration for all growth stages.

Another set of corn models have been developed that are based on aspects of farming system production on yield and not the climatic effects.

One such model by Parsons and Holtman (1977) simulates the complex interactions of corn production on a farm. Components incorporated are off-farm corn marketing; production supply points; on-farm drying, handling and storage facilities; fields; and roadways. The soil and weather are also simulated, as they play an important role in the production system.

Another model by Baker and Harrocks (1967) is one of the first attempts to combine in simulation form the relationships between tillage and harvesting systems with the development of the corn plant. It simulates the energy and gas exchange at the plant-air interface, as influenced by spring and fall tillage and harvesting operations. Even though further development is needed, by attempting to understand crop production in relation to environmental interactions, valuable information is obtained to help in the decision making processes.

Holtman et al. (1973) transformed observations of real-world system behavior into obtainable information for modeling processes. With this information, a model was developed that evalutes all the operations involved in corn production and allows an effective tool for system planning.

It must be understood that corn models can only be used as tools and are generally developed with a specific purpose in mind. Corn models were discussed here to give an idea of what is available, how these models can be used, and to emphasize some of their shortcomings.

A corn growth model is essential to simulate the economics of irrigating corn. The model must be able to incorporate different irrigation plans, predict the soil moisture content, determine the stress effects on the corn at all stages of growth, and be adaptable to different locations and varieties. A regression type growth model would not meet these requirements, but a physiologically based model would. Of the physiologically based models reviewed, SIMAIZ proved to be most satisfactory as it fulfilled the above requirements. Another important consideration is that the model developer was available for personal consultation. This proved to be a great asset in understanding the model, an important consideration when alterations are needed in order to combine more than one model.

RUNOFF MODELS

Many relationships exist relating rainfall to surface runoff. Knowing surface runoff volume is important when conducting flood studies, solving erosion control problems, and water supply for various reasons. For this study it is necessary to model surface runoff relations in order to determine the size of a reservoir for irrigation water supply. In order to determine a mass balance for an irrigation reservoir, a daily calculation of runoff volume flowing into the reservoir site, irrigation water requirements determined for a corn growth model, and other direct inflows and outflows such as precipitation, evaporation, seepage, and prior water rights are needed.

Most rainfall runoff relationships are designed to predict runoff from a single event and quite often for specific locations. These restrictions make this type of model desirable for flood and erosion studies, but undesirable when a continuous flow is needed for reservoir sizing. A few of the single event rainfall runoff relationships will be mentioned.

The Soil Conservation Service (SCS) of the U.S. Department of Agriculture (1972) developed a method for predicting surface runoff based on rainfall amount and a parameter which incorporates the effects of infiltration and surface storage. This method was developed from many years of storm flow records of agricultural watersheds in many parts of the U.S. The method is commonly referred to as the curve number method because what is known as a curve number is used to calculate the parameter used to determine runoff. The curve number indicates the runoff potential for a given area. To determine a value for the curve number, one must first know what hydrologic soil group the soil in question belongs to. The SCS has classified over 4000 soils into four hydrologic soil groups. Once the hydrologic soil group is determined, the curve number can be found, depending upon land use and antecedent moisture conditions. Curve number values are tabulated relating the land use and hydrologic soil group for antecedent moisture condition II. To convert the curve number to antecedent moisture conditions I or III, a factor is used depending on the value of the curve number for condition II and which antecedent moisture condition exists.

Curve number values are less than or equal to 100. One advantage of using the curve number method is that a large data base was used in developing the method, hence, with good engineering judgement, reliable results can be obtained.

Engman and Ragawski (1974) developed a runoff model based on a partial area contribution concept. The watershed is divided into homogeneous areas and is characterized by the necessary data inputs. The runoff from a rainfall event can then be predicted for the entire watershed.

An area where runoff relationships are not well defined is in mountainous regions. Hawkins (1973) proposed an improvement over using the curve number method to predict a single rainfall storm runoff relationship.

A factor, K, is proposed which is a function of curve number and precipitation which adjusts the results to mountainous regions.

For small, semi-arid watersheds, Fogel (1969) used a regression approach. Based on the total rainfall event and initial infiltration rate, a regression equation was developed to describe the rainfall-runoff relationship.

For agricultural watersheds, Melvin et al. (1971) used Horton's infiltration equation to predict surface runoff. The parameters being determined are based on antecedent moisture content. A regression equation is used to relate total watershed runoff to surface runoff.

A model using empirical equations was developed by Betson et al. (1969) for runoff prediction in Tennessee. Once the model is calibrated for a watershed, runoff can be predicted knowing rainfall volume, week of the year, and antecedent moisture content.

Criss and Bittler (1969) developed a runoff model for a 257 square mile watershed in Pennsylvania. The model uses a first order linear differential equation with time varying coefficients dependent upon two empirical parameters. A single storm event is used in which rainfall frequency is proportional to runoff frequency.

The most desirable type of runoff model for reservoir sizing considers the flow which occurs both during and in between rainfall events. These models are known as continuous simulation models and will be the next group of models discussed.

One model which simulates watershed runoff on a continuous basis is Haan's (1972) water yield model. This model uses daily rainfall, potential evapotranspiration, initial soil conditions, and four parameters which characterize the watershed. These four parameters represent maximum infiltration rate in inches per hour, maximum daily seepage in inches, moisture holding capacity of the less readily available storage in inches, and fraction of seepage that becomes runoff. Because of the variability in most watersheds, these parameters must be optimized using previously recorded streamflow characteristics. Haan's complete model has a parameter optimization section, hence, the user should optimize the four parameters with recorded streamflow if possible. When recorded streamflow does not exist, a procedure developed by Jarbo and Haan (1974) describes how the four parameters can be calculated. Rainfall is broken into six minute intervals by a predetermined convention to allow for varied rainfall intensities. The rainfall is then divided into infiltration and surface runoff. Deep seepage is calculated daily, depending upon the maximum seepage rate and the percentage of less readily available soil moisture. From this deep seepage value the volume of return flow is calculated. The total volume of runoff for a given day is the direct runoff from precipitation plus the return flow volume. Details of Haan's model are found in a later section.

Many runoff models are developed for specific locations. De Boer and Johnson (1971), for example, developed a model to predict runoff where depressions are created from glaciers.

Sinha et al. (1971) developed a model that accounts for infiltration, transpiration, evaporation, and percolation losses. The direct runoff is routed overland and the ground water flow is channeled to the reservoir system. Sinha's model is similar to Haan's model in that it predicts runoff on a continuous basis. Depending upon the difficulty of usage, it may have potential for use as a reservoir inflow estimator.

Wilson et al. (1977) developed a five day water yield model. The analysis mode optimizes 11 parameters using recorded runoff. The simulation mode uses the 11 parameters to calculate runoff knowing daily rainfall values. When using converged parameters, runoff predictions ranged from 97.5 percent to 103.1 percent of observed.

Huggins and Monke (1968) attempted to define a watershed as a grid of small independent elements to avoid the use of lumped parameters. The idea is good, but more applied research is needed before a watershed can be easily and accurately defined.

One of the more commonly used runoff models is the United States Department of Agriculture Hydrologic Model (USDAHL). It is based on the physical processes of infiltration, evapotranspiration, and overland flow. Crow et al. (1977) adapted the USDAHL model to a 37 hectar grassland watershed near Stillwater, Oklahoma. Good correlation was obtained between simulated and measured monthly runoff. Crow et al. (1980) used longer calibration and test periods for the same 37 hectar watershed. The model was then applied to two more grassland watersheds using parameters obtained from the 37 hectar watershed. The objective was to simulate runoff from grassed watersheds with and without prior calibration. With prior calibration, satisfactory results were obtained for one-half of the study period. For watersheds not calibrated, a tendency for overprediction occurred.

Arlin et al. (1977) applied the USDAHL model to a watershed in the southern great plains. They found that the model does not account for varying surface reservoir storage which could account for some of the prediction error. In wet years the model overpredicted runoff and in dry years it underpredicted runoff.

Fisher et al. (1977) adapted the USDAHL to three Maryland watersheds. Results indicate that the model accurately represents the hydrology of the watersheds. They believed that the model is a valuable tool for studying changing land use.

Molnau and Yoo (1977) and Perrier et al. (1977) compared the USDAHL model with other runoff models. Molnau compared three models: the Tennessee Valley Authority runoff model (TVA), the Kentucky Watershed Model (KWM), and USDAHL. Three years were used in the study: 1961, 1962, and 1963. 1961 was a dry year while the other two were wet. All models simulated the dry years more accurately than the wet. The TVA model was simplest in terms of required parameters and the complexity of watershed representation. Runoff potential is determined by subtracting interception from precipitation. The runoff potential is then divided into direct runoff and infiltration where a portion of the infiltration water makes its way back to the stream due to ground water movement. The TVA model also has a modified snow melt routine. The KWM is a widely used lumped parameter model. All precipitation is subject to interception capacity, may infiltrate immediately, or be stored in depression or overland flow storages which are also subject to infiltration, depending on the time it takes for water to flow. The lumped parameters take into consideration all of these processes. The USDAHL is the most complex in terms of model complexity. It attempts to describe actual watershed processes. The overall simulation by the USDAHL model was more accurate than the other two models.

The study by Perrier et al. (1977) was conducted to compare and evaluate simulated hydrologic response parameters from five existing deterministic mathematical simulation models. An additional, and more important purpose was to determine which model is best suited for incorporating chemical washoff alogrithms for water quality studies. The models are Hydrocomp Simulation Package (HSP), Stanford Watershed Model (SWM), Streamflow Synthesis and Reservoir Regulation (SSARR), Flood Hydrograph Package (HEC-1), and USDAHL. These models are termed lumped systems. The dynamic equations governing their behavior are not position dependent. All except HEC-1 are continuous models, where the physical variables representing input and output are continuous functions of time. HSP is the largest and most complete simulation of the watershed. SWM in its simplicity allows adaptation to specific modifications. SSARR has a generalized watershed model for runoff, a river system model for routing streamflows, and a reservoir regulating model. HEC-1 is a single event storm model using the Muskingum method for streamflow routing. USDAHL has the most complete description of the watershed characteristics and is comparatively small and easily modified. One of the major drawbacks found in using a particular simulation package is the user's manual. In most cases they are misleading and create confusion for exact definitions of various terms. They are often not up to date with current programming changes. The Hydrocomp Model was by far the most complete model investigated. It can output data at each of 150 reaches, thus, washoff alogrithms could be inserted to permit continuous simulation of water quality throughout a watershed. Although the USDAHL model did not lend itself to calibration of the outflow, it does give the most complete description of the watershed characteristics as input into a cascading model. The cascading concept lends itself to closer characterization of chemical washoff for eventual loading into a river system. If streamflow routing, diversions, and more seasonal parameters were added, then calibration could be expected.

Three runoff models are compared by Moore and Mein (1977): the Stanford watershed model, the Boughton model, and the Monash model. They are evaluated as to how daily runoff is predicted. The Boughton model is the most widely used digital rainfall-runoff model in Australia. Rainfall is divided into interception, upper and lower soil moisture. Eleven parameters and four estimated initial moisture states are used in the Boughton model. Two versions to the Monash model are available, one operating on a daily cycle, and the other operating on a daily cycle with an hourly cycle superimposed during rainfall events. The first version was used in this comparison. The watershed can be subdivided into four areas with different parameter sets. The parameter sets contain information describing interception, depression, and soil moisture storages. The soil moisture capacities are fixed, while ground water storage has an unlimited capacity. The Stanford watershed model has seen many applications in the U.S. It consists of four storages: water, interception, upper and lower soil moisture zone, and ground water. It uses an empirical channel routing routine within one catchment. A number of different hydrologic regimes can be handled. An alteration was made from a time interval of 15 minutes to an hour. Moore and Mein arrived at the following conclusions from this study:

(1) Each of the three models has advantages over the other, depending on the catchment hydrology, the budgetary constraints (data availability and computer time), and whether daily or monthly flows are required;

(2) The Boughton model performed almost as well as the other two for monthly flow reproduction and its running costs and data requirements are considerably less. For daily flow reproduction the standard of simulation is considered poor;

(3) The Monash model and Stanford model (as modified) produce comparable results, but the former requires less computer and user time;

(4) The baseflow routines of the Stanford model give it an advantage on catchments where baseflow is important;

(5) The catchment routing routine of the Monash model gives it an advantage on large catchments;

(6) The use of daily input data and a daily time increment do not permit peak daily flows to model well;

(7) The Stanford model requires a considerable amount of operator experience if good simulation is to be achieved;

(8) Given familiarity of the user with the operation of the models, the parameters of the Monash model are easiest to optimize; and

(9) No one objective function, as a basis for parameter optimization, proved adequate over the whole range of flows.

Shanholtz and Lillard (1971) used the Stanford watershed model on two small watersheds in Virginia with five years of calibration data and another five years for testing. Runoff results were reasonably good, along with peak estimates.

A report by Gwinn and Ree (1975) presents a method for determining what size reservoir will produce a dependable supply of water for periods when no surface runoff occurs. Minimum streamflows were emphasized because a dependable water supply was desired. The results will be conservative, so very little risk is encountered.

As previously mentioned, a continuous flow runoff model is most desirable for predicting watershed runoff into a potential reservoir site for irrigation purposes. The model needs to be fairly simple to use, yet it must represent the watershed. Haan's model proved to be most desirable. The portion which controls the hydrology of the watershed can easily be made into a subroutine to incorporate with other models. The complex portion of Haan's model is in optimizing the four parameters. Once the model has optimized these parameters, the optimization section is no longer used. Haan's model can be used in its complete form initially to optimize the four parameters to be used as input values. An additional important factor was that Haan was available for personal consultation, which proved invaluable for adaptation and usage of the model.

CHAPTER III

SYSTEM DESCRIPTION AND BASIC ASSUMPTIONS

In simulating the economics of supplemental irrigation for corn, an important objective for the simulation model is that it be flexible and adapt to varying climatic and regional conditions. The components essential for the simulation are: (1) crop growth function, (2) water supply function, (3) reservoir sizing function, (4) supplemental irrigation function, and (5) economics function.

Based on the review of available models, the Duncan SIMAIZ model was selected as the crop growth function, and the Haan Water Yield Model was selected as the water supply function. The reservoir supply, supplemental irrigation, and economics functions were developed as part of this research effort.

All of the components are combined into one model in this report, which is used to simulate the economics of supplemental irrigation. The title of the model is known as IRrigation ECONomics Simulator (IRECONS).

Incorporating daily weather information into a crop growth function allows daily growth predictions to be made and final yield to be predicted. The soil water-holding capacity, daily evapotranspiration, and precipitation are used to adjust the soil water available for crop development. When soil water is deficient, plant available water is restricted, resulting in crop stress and reduced growth. Irrigation is a component dependent upon water supply. Consequently, the availability of water supply for irrigation must also be determined. Since many sub-humid areas, such as Central Kentucky, rely on streamflow as the major source of water supply, a watershed runoff function must be incorporated. When unreliable or inadequate water supply is available from streamflows, a reservoir sizing routine is needed for storing irrigation water. Site characterization is necessary for predicting the model's response at specific locations. Crop variety, watershed topography, and soil conditions are just a few of the variables which must be able to be input, enabling the model to be adapted for different locations. Climatic simulation, whether actual weather data, calculated based on other climatic variables, or statistically simulated, must represent the site being analyzed to accurately make predictions.

The inputs to the Duncan SIMAIZ model are used to adjust the model to the variety of corn being simulated and to the soil type. The variables used in the Haan runoff model define a given watershed. In the sizing of a storage reservoir, additional important inputs concerning the topography of the reservoir site are needed. The pond area at incremental elevations allows the volume of the reservoir to be determined for varying dam heights. This also allows direct evaporation from the reservoir site to be calculated along with direct precipitation into the reservoir for varying dam heights. The centerline width of the proposed embankment at incremental elevations allows geometry to be used for determining the volume of fill necessary to construct the dam. Knowing the volume of fill for the dam, construction cost can be determined. The centerline width is also needed to calculate seepage losses through the dam.

Daily climatic information, consisting of maximum and minimum temperature, precipitation, and cloud cover, are supplied from a 25-year data tape.

To obtain the needed climatic information on one tape, data from two separate National Weather Service data tapes were combined. Because of the unavailability of long-term solar radiation data and its importance in crop growth functions, monthly regression equations were developed for Kentucky which relate known extraterrestrial radiation and cloud cover to solar radiation. In addition to daily climatic information, average daily potential evapotranspiration for each month, as predicted by the Thornwaite equation, is used to predict evaporation from the reservoir surface and in the watershed runoff model.

SIMAIZ

The model which will be used to predict plant growth, yield, and water requirements is SIMAIZ, a corn simulation model developed by Duncan (1974). SIMAIZ describes plant development and grain yield in response to environmental factors. In the model development it was assumed that agronomic practices do not limit growth; i.e. fertilizer application, weed control, and pest control were optimum. This would typically be the case for operators that would consider investment in supplemental irrigation.

In using SIMAIZ, one can vary both environmental and physiological factors and observe the resulting changes. A few examples of these physiological factors are photosynthetic rate, number of ears per plant, length of filling period, silk-period stresses, and plant available water. A complete list of data inputs and the commonly used values can be found in Appendix A. These factors allow SIMAIZ to adjust for different varieties and geographic locations and be site specific, which is important when evaluating irrigation economics.

Conceptual Basis of SIMAIZ

In simulating field conditions, the climatic information used must be easily obtainable. SIMAIZ uses maximum and minimum temperatures, rainfall, solar radiation, and when available, pan evaporation. This climatic information is used to calculate evapotranspiration and the daily photosynthetic rate for plant growth. SIMAIZ consists of a main routine which reads in and initializes important factors, and then directs and controls several subroutines which are responsible for the majority of the calculations.

The subroutines are called: WATERX, PHZDAZ, LAILEF, PTOTAL, QPVEG, TASSEL, KERNOZ, GRAINZ, and DRYING. WATERX is based on Ritchie's (1972) row crop evapotranspiration model. Figure 3-1 is a flow diagram of Ritchie's model and Table 3-1 explains the terms used. In addition to calculating ET, the model determines a water stress factor used to take into account the effects of soil water deficit on plant growth. PHZDAZ was designed to calculate a parameter defined as a physiological day which is used as a predictor of the morphological development of corn. One physiological day is equal to the average number of growing degree days accumulated in one day for that climatic region. The calculation of growing degree days is based on daily maximum and minimum temperatures using the National Weather Service Modified Method. LAILEF was designed to estimate daily leaf area index (LAI) for a corn canopy. The rate of development for LAI is dependent on the stage of leaf area development, equivalent physiological days, and the water stress factor, which is established in WATERX. Leaf area growth follows a sigmoidal curve in which intital growth is exponential for a short period followed by a linear growth stage and finally a linear tapering off of growth rate. PTOTAL calculates photosynthate

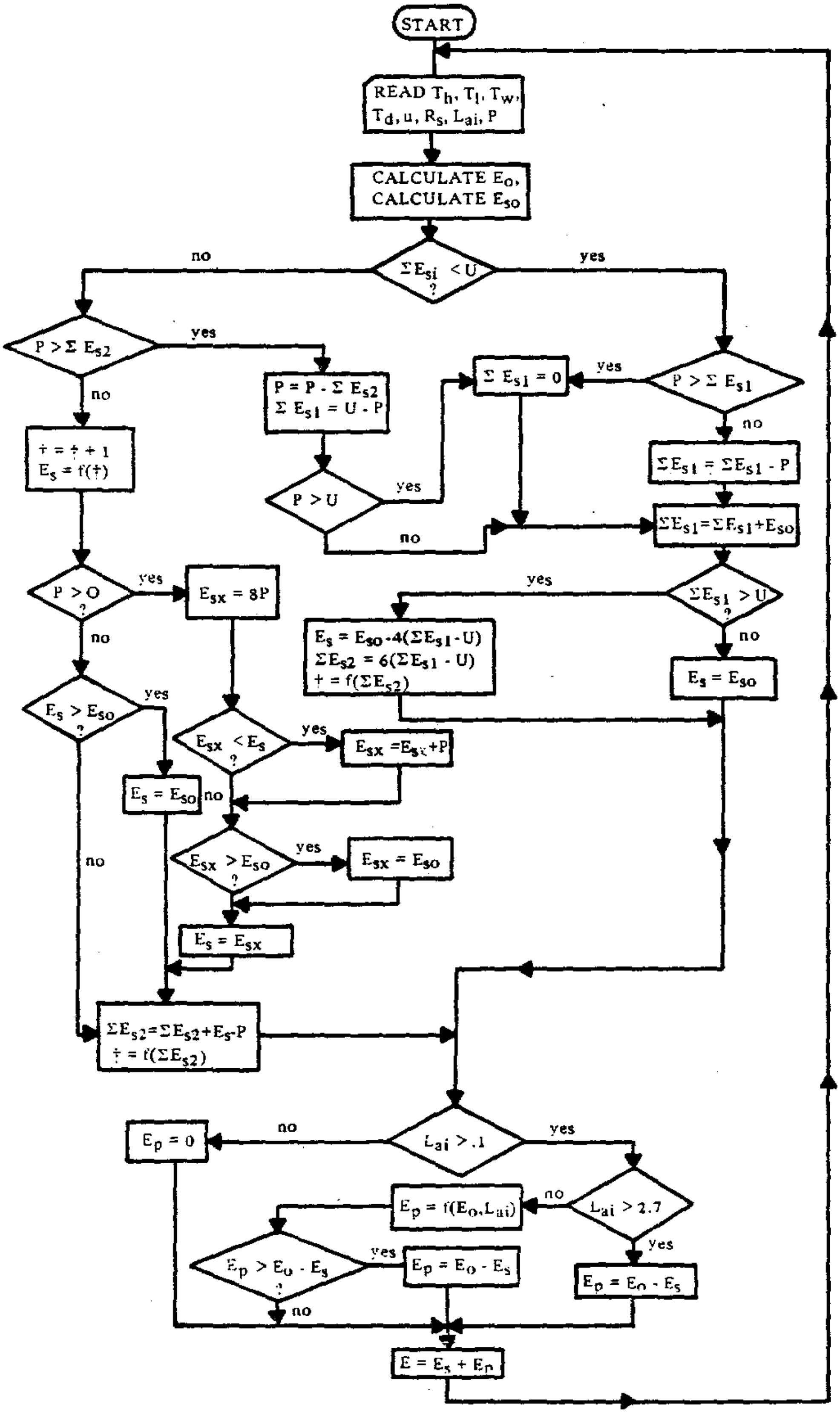

Figure 5-1. Flow diagram of the evapotranspiration model (from Ritchie, 1972).

Table 3-1. Definition of Terms for Figure 3-1, Ritchie, 1972.

E - total evaporation rate from soil and plant surfaces, evapotranspiration, millimeters per day;

E_m - evaporation rate measured with a weighing lysimeter, millimeters per day;

E_o - potential evaporation rate above the plant canopy, millimeters per day;

E_p - evaporation rate from plant leaves, transpiration, millimeters per day;

E_s - evaporation rate from the soil surface, millimeters per day;

E_{so} - potential evaporation rate below the plant canopy at the soil surface, millimeters per day;

E_{sx} - evaporation rate from the soil surface during stage 2 evaporation on a day when $P < \Sigma E_{s2}$, millimeters per day;

L_{ai} - leaf area index, dimensionless;

P - rainfall or irrigation rate, millimeters per day;

R_{no} - net radiation above the canopy (1 mm/day is equivalent to an energy flux of 59 cal cm^{-2} day^{-1});

R_{ns} - net radiation at the soil surface below the canopy, millimeters per day;

R_s - solar radiation, millimeters per day;

t - time, days;

T_d - dry bulb temperature, °C;

T_h - maximum daily temperature, °C;

T_l - minimum daily temperature, °C;

T_w - wet bulb temperature, °C;

u - wind speed, kilometers per day;

U - upper limit of cumulative evaporation from soil during stage 1 drying, millimeters;

ΣE_{s1} - cumulative evaporation from the soil surface during stage 1, millimeters;

ΣE_{s2} - cumulative evaporation from the soil surface during stage 2, millimeters.

produced (PTS) in grams of carbohydrate per day, per unit ground area, which is later used to calculate plant growth. A gross photosynthate value is interpolated from a table as a function of solar radiation and LAI. This value is for ideal soil moisture and optimum leaf temperature. Two correction factors are used to account for nonoptimum conditions. QPVEG simulates the vegetative growth of a corn plant by distributing daily photosynthate to the individual plant parts including leaf, stalk, cob, husk, and reserves. TASSEL is used to determine the time when both tasselling and silking have occurred. This is when pollination occurs and when the transition from vegetative to grain development begins. KERNOZ is entered after pollination begins, and is used to determine an initial potential grain weight based on conditions at the start of pollination, an adjusted potential grain weight after a latent period has elapsed, and maximum number of ears per plant. GRAINZ simulates ear growth after vegetative growth has terminated by distributing daily photosynthate among husk, cob, and grain. DRYING is an in-field grain drying routine, used after the corn has reached maturity. It is a rough approximation used mainly for cosmetic purposes, as all yields are calculated on a dry weight basis.

Planting date is an input to SIMAIZ, but in using 25 years of data, it was impractical to assume a planting date. Duncan[1/] suggested a planting date could be simulated based on the fact that farmers try to plant corn as early in the spring as possible. Thus, for a given location, there are normally three major considerations: (1) corn is never planted

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[1/] Duncan, W. G. (1978) Personal communication on corn growth modeling.

before a specified date (April 2 for Kentucky), (2) the soil temperature should have reached a minimum level (15°C for Kentucky); a common assumption is that soil temperature lags behind air temperature by approximately one week, and (3) the soil must be dry enough so planting equipment can enter the field. In the simulation model, the rooting zone of the soil is divided into ten layers. In the planting routine, when the first layer is 50 percent dry, the soil is ready for corn to be planted. When all three of these considerations are favorable, the model chooses that date for planting. It is understood that this method is a rough approximation, but is more accurate than any other method known to the author.

Subroutine WATERX is called before planting date and a soil moisture balance is calculated daily. Once planting date is reached, a daily loop is entered which controls growth calculations by calling appropriate subroutines when needed. Figure 3-2 shows a conceptual flow diagram of daily calculations. The first set of subroutines, WATERX, PHZDAZ, and LAILEF are entered daily regardless of the stage of corn development, The remaining subroutines PTOTAL, QPVEG, TASSEL, KERNOZ, GRAINZ, and DRYING are entered depending upon the stage of development of the corn plant, The model checks daily to see if the grain is mature. When maturity is reached, the desired moisture content for harvesting. If the grain has not matured, then subroutine PTOTAL is entered. Before both tasselling and silking have occurred, subroutine QPVEG is entered. If both tasselling and silking have occurred, then vegetative growth is complete and QPVEG is omitted from further computation, The next controlling question is, has pollination occurred? If both pollination and tasselling have occurred, then TASSEL is entered. If neither pollination nor tasselling have occurred,

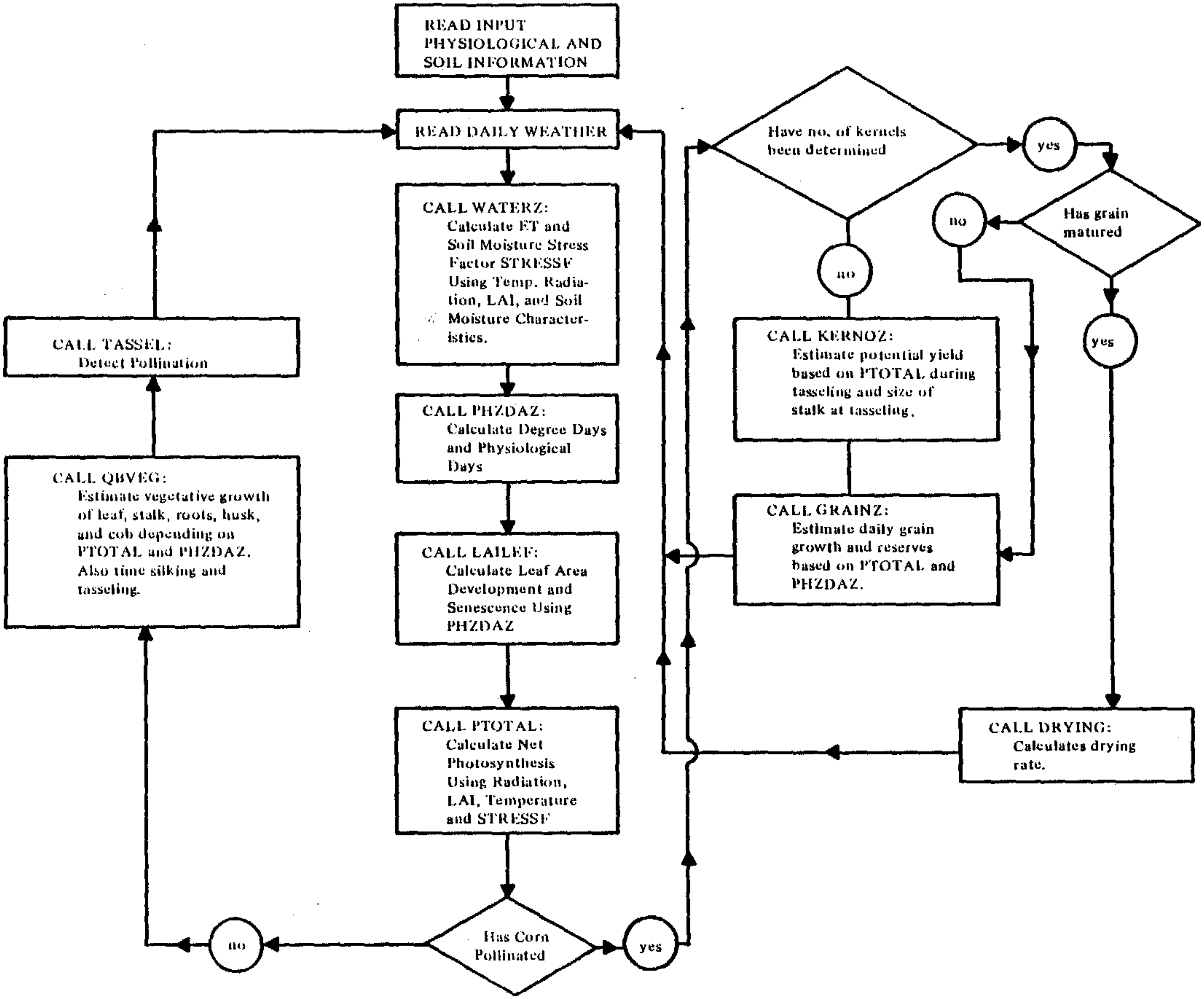

Figure 3-2. Conceptual flow diagram of Duncan SIMAIZ Model (from Barfield, 1977).

the model skips the remaining subroutines for that day's growth calculations. After TASSEL has determined when pollination occurs, KERNOZ is entered daily until a latent period has elapsed. After entering KERNOZ and before grain has matured, subroutine GRAINZ is entered daily, until grain maturity.

On attractive feature of SIMAIZ is that is is easy to modify. The fact that most of SIMAIZ's calculations are made in the subroutines allows for much easier substitutions when further experimentation and research develops more reasonable estimates of plant growth.

The ability of SIMAIZ to predict grain and dry matter yields has been tested using data from four states: Pennsylvania, Kentucky, Utah, and California. Fritten et al. (1975) used SIMAIZ to simulate both grain and dry matter yields at State College, Pennsylvania in 1974 and 1975. In the initial simulation attempts, field measured climatic parameters, field measured hybrid parameters, one parameter calculated from long-term climatic records, and other input parameter constants recommended by Duncan as being representative of corn, were used. The results are shown in Figures 3-3 and 3-4 indicate poor agreement between observed and predicted yields. Firtten et al. postulated that the primary reason for the lact of fit was due to the inability to properly evaluate a parameter defining the number of degree days per physiological day, a term calculated using long-term climatic records. Since accumulation of physiological days is used to control developmental growth of the crop within SIMAIZ, the failure of the long-term climatic data to truly represent the field conditions resulted in a poor simulation of silking date (see Figure 3-3 and 3-4). SIMAIZ was modified to more accurately represent Pennsylvania

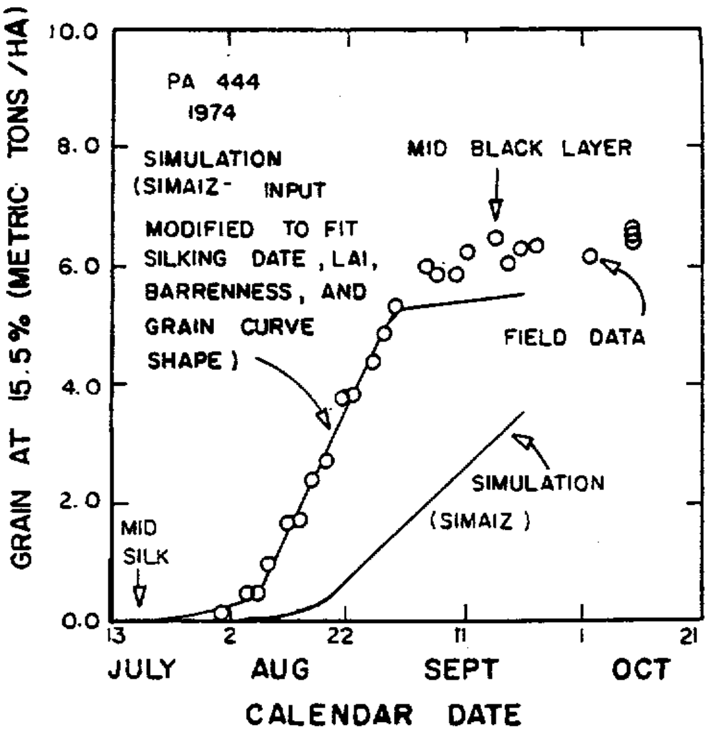

Figure 3-3. Simulated and observed grain yield for maize using SIMAIZ and a version with modified input data (Fritten, 1975).

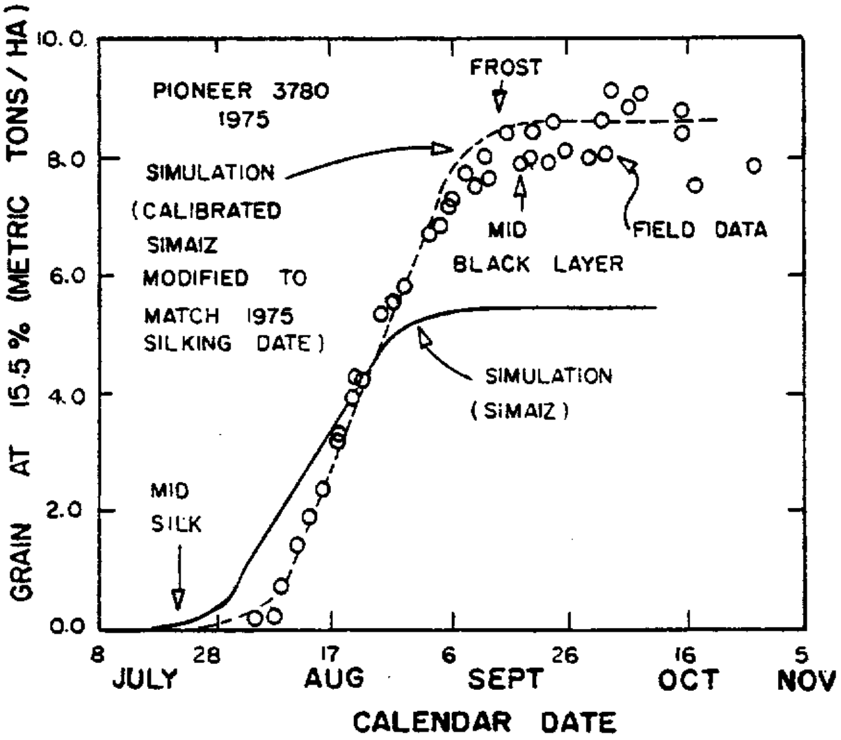

Figure 3-4. Simulated and observed grain yield for maize using a calibrated version of SIMAIZ and a version with modified input data (Fritten,

conditions and predict silking date. The modified version more accurately predicted both grain and dry matter yields, as can be seen in Figures 3-5 and 3-6.

Barfield et al. (1977) used SIMAIZ to predict grain yields for both irrigated and non-irrigated corn at Lexington, Kentucky using four years of data and three planting dates. Exact planting dates for 1964 and irrigation amounts for all the years were not known. The irrigation policy was to keep the soil moisture content at or above the 75 percent level. Since soil moisture samples were not taken, it is not possible to determine how accurately this irrigation policy was followed. For this study, SIMAIZ was programmed such that irrigation was assumed to occur when 25 percent of the plant available was depleted. Table 3-2 shows a summary of observed and predicted grain yields, and Figures 3-7, 3-8, and 3-9 show a plot of observed versus predicted yields for irrigated and non-irrigated conditions. One of the parameters which was varied is the STRESF curve. STRESF is used to account for moisture stress on both photosynthesis and transpiration. STRESF I follows an assumption from Tanner and Ritchie (1974) that there are no effects of soil moisture on photosynthesis and transpiration until approximately 80 percent of the plant available moisture is depleted. STRESF I can be seen in Figure 3-10. STRESF II is representative of conditions in Kentucky since the soil is well drained and little moisture exists below the rooting depth, as contrasted to the experiments conducted by Ritchie in which lower soil layers held considerable amounts of water into which plant roots could grow during periods of deficit. With a well drained soil it is conceivable that soil moisture stress starts well above 80 percent soil moisture depletion. To represent this, STRESF II was used to account for soil moisture stress.

Table 3-2. Summary of Observed and Predicted Corn Yields.

Planting Date	Measured Yields		Computed Yields STRESF I**		Computed Values STRESF II**		Computed Values STRESF I & II***	
	Irrig Yields	Nonirrig Yields	Irrig Yields	Nonirrig Yields	Irrig Yields	Nonirrig Yields	Irrig Yields	Nonirrig Yields
1962								
April 28	207	135	164	151	161	145	172	172
May 25	168	109	156	122	151	120	168	166
June 22	118	75	151	94	148	103	164	161
1963								
April 8	165	152	180	168	172	151	189	187
May 9	161	145	164	159	159	144	175	172
June 10	136	126	145	124	143	123	153	153
1964								
April 15*	156	103	176	77	173	75	185	180
May 15*	156	16	171	88	168	88	175	106
June 15*	112	55	162	25	158	47	171	76
1965								
April 14	144	97	177	52	170	74	185	100
May 17	172	78	152	58	150	58	161	73
June 17	126	26	155	13	149	18	166	54
Mean[1]	152	93	163	94	159	96	172	133
Mean[2]	155	105	160	104	155	104	170	137
Standard								
Error of[1]			22	31	26	27	34	52
Estimate[2]			27	22	25	16	31	44
% Error in								
4 year[1]			7.2	1.1	2.5	3.2	13.2	43.0
Average[2]			3.2	1.0	0.0	1.0	9.7	30.5

* Actual planting dates unknown.

** STRESF I or STRESF II for photosynthesis and transpiration.

*** STRESF I for photosynthesis reduction and STRESF II for transpiration reduction.

1. Averages including 1964 data.
2. Averages excluding 1964 data since 1964 planting dates were assumed.

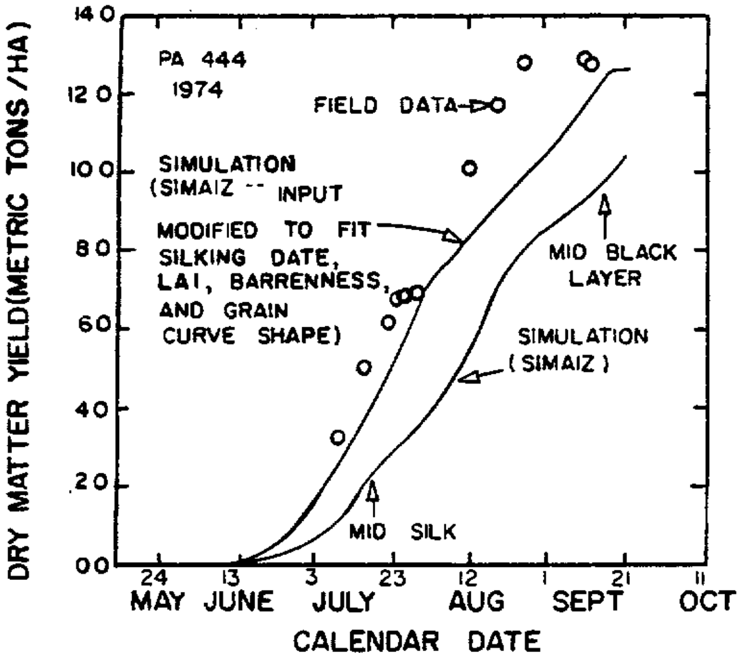

Figure 3-5. Simulated and observed dry matter yield for maize using SIMAIZ and a version with modified input data (Fritten, 1975).

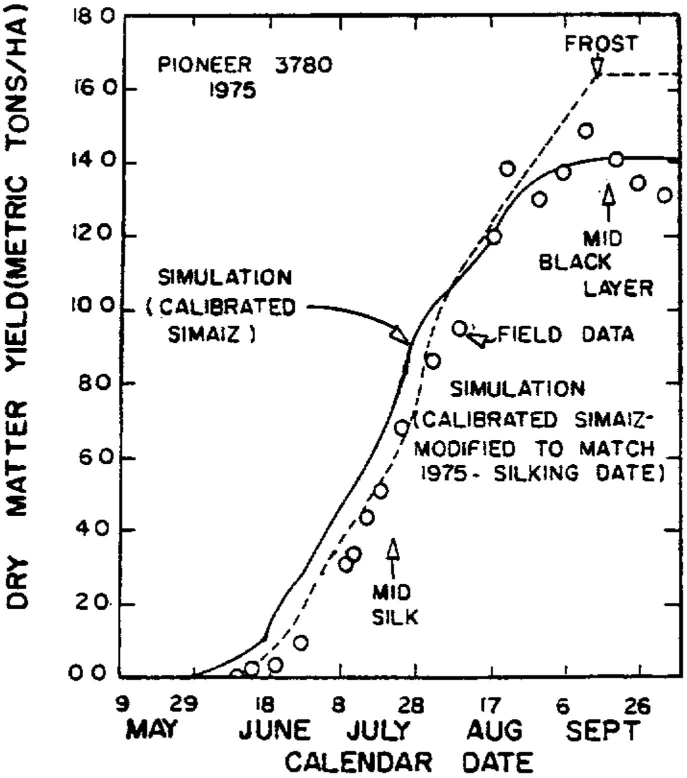

Figure 3-6. Simulated and observed dry matter yield for maize using a calibrated version of SIMAIZ and a version with modified input data (Fritten, 1975).

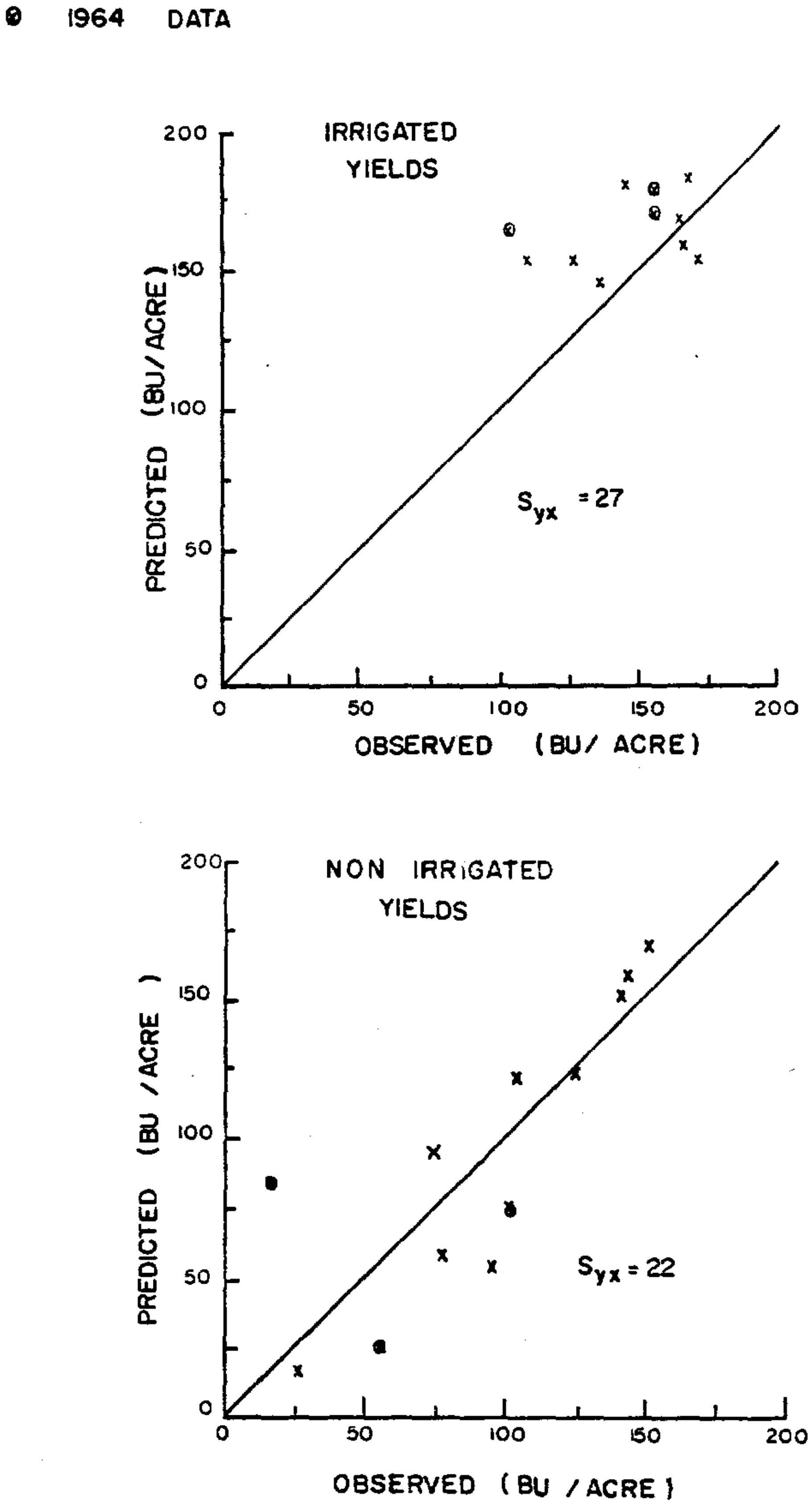

Figure 5-7. Predicted and observed yields using STRESSF I for evaporation and photosynthesis reduction (Barfield, 1977).

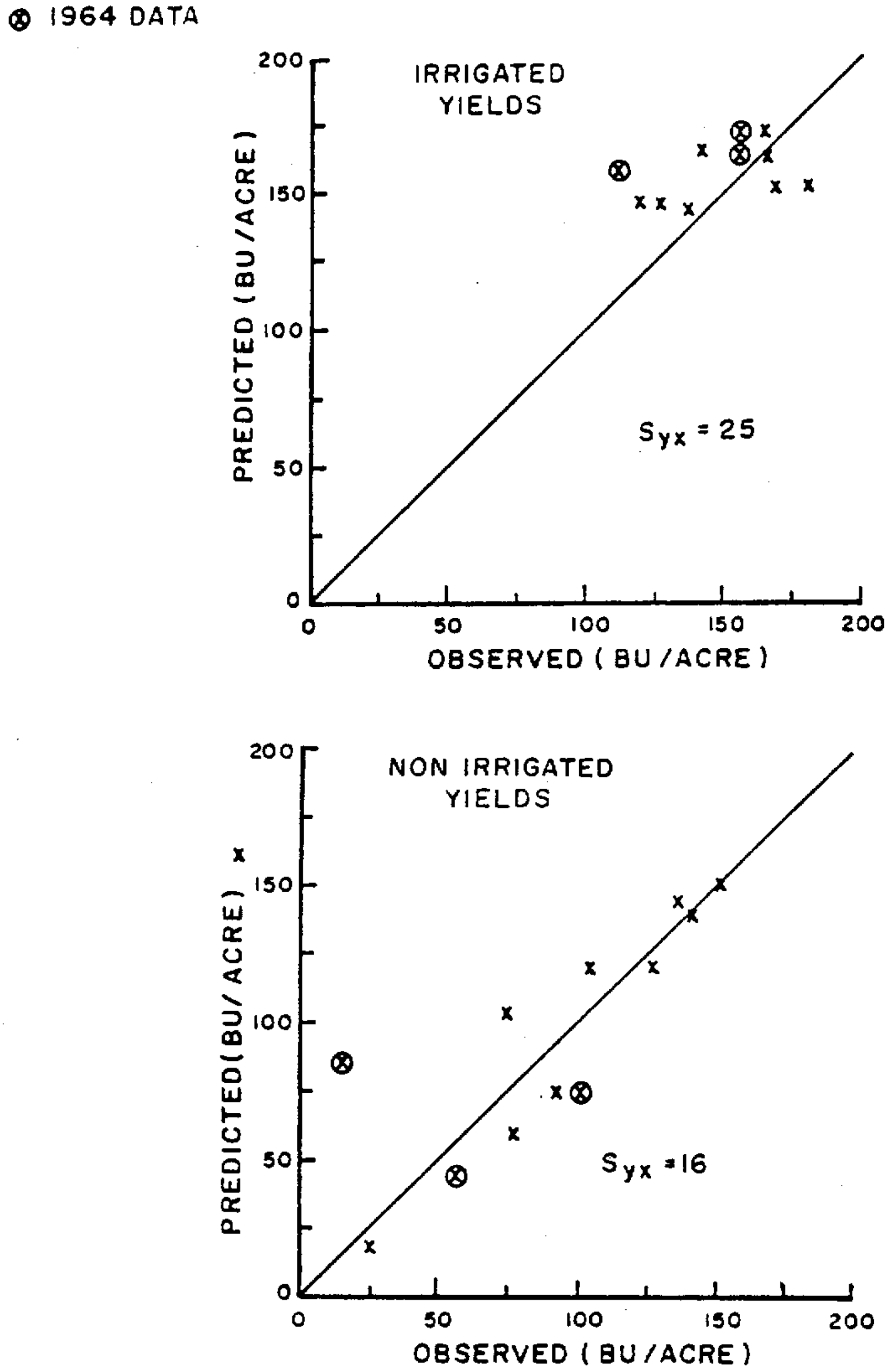

Figure 3-8. Predicted and observed yields using STRESSF II for evapotranspiration and photosynthesis reduction.

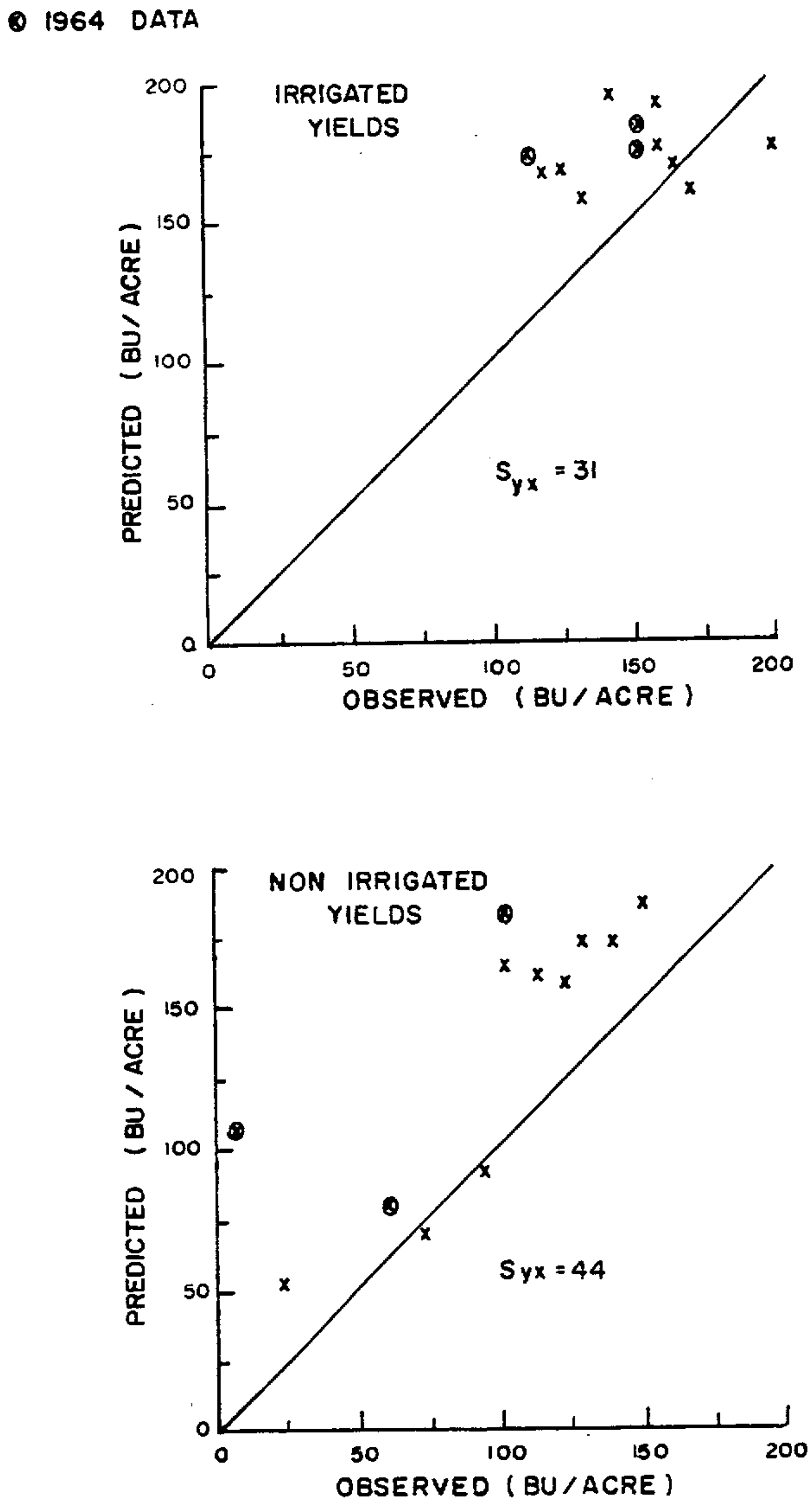

Figure 3-9. Predicted and observed yields using STRESSF II for evapotranspiration reduction and STRESSF I for photosynthesis reduction (Barfield et al., 1977).

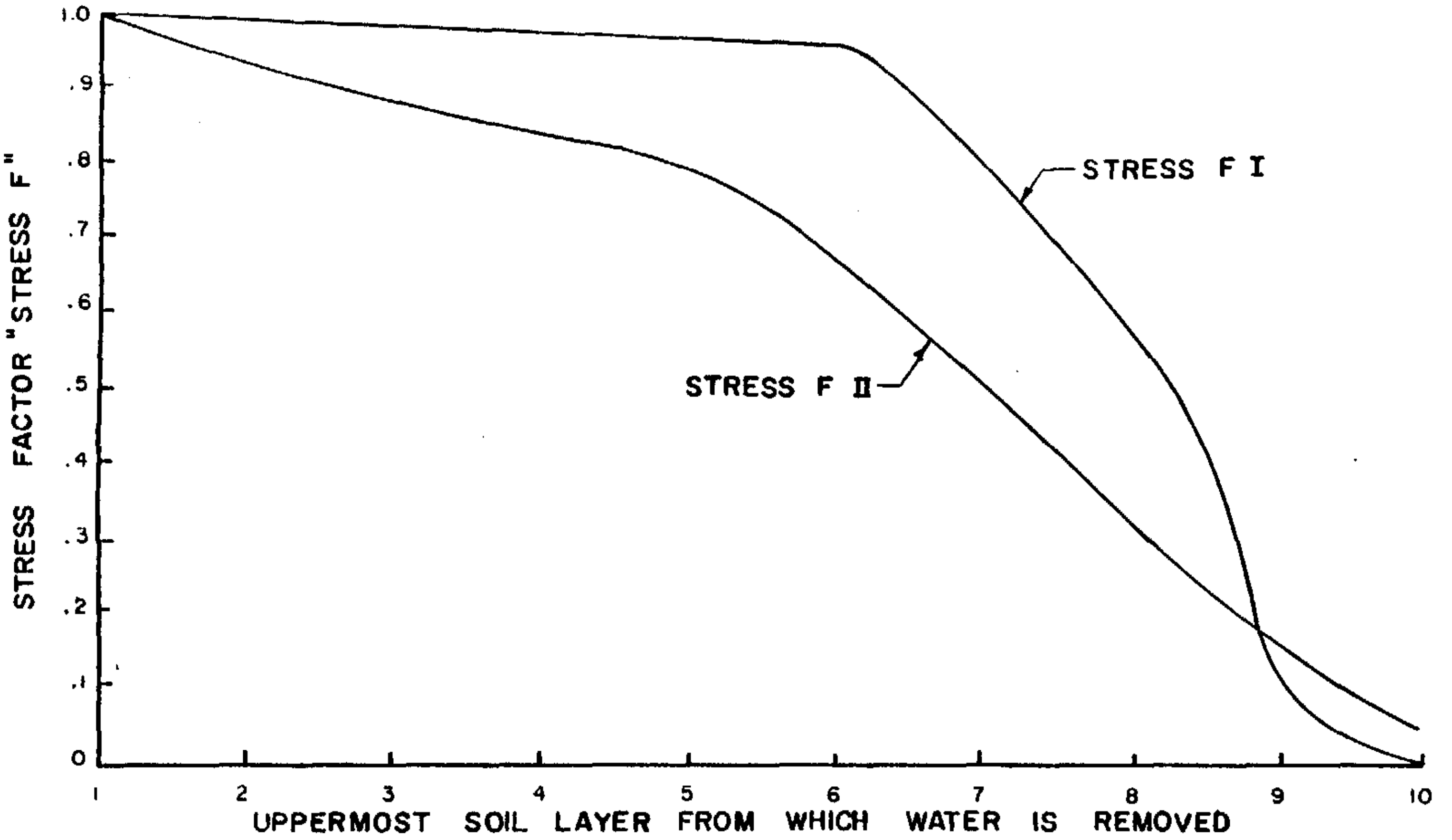

Figure 3-10. Stress factor as a function of the uppermost soil layer which has less than 60% PAW remaining (Barfield et al., 1977).

Plot studies were conducted at the University of Kentucky during 1978 on irrigated and nonirrigated corn using four planting dates. SIMAIZ was used to predict both grain and dry matter yields. Adjustments were made in SIMAIZ to produce the most representative yield results. A plot of observed versus predicted values can be seen in Figures 3-11 and 3-12. The standard error of estimate is larger than desirable. In general, the irrigated yields were under-predicted and non-irrigated yields were over-predicted making prediction of irrigation yield increases conservative.

Stewart et al. (1977) reported on a two year irrigation experiment in four Western states: California, Utah, Colorado, and Arizona. This was an extensive study in which varying amounts of irrigation water was applied on several plots. The effects of irrigation with saline water were also evaluated. Since SIMAIZ does not account for the effects of saline water, the data from these plots was not used. Because of arid conditions in the western states, the potential evapotranspiration (PET) equation used in SIMAIZ was altered to account for the effects of wind on PET using Penman's combination equation. A complete climatic record for both years was obtained for California and Utah, so SIMAIZ was used to predict both dry matter and grain yields for these states. SIMAIZ was calibrated for each site by varying the data inputs. The results, as can be seen in Figures 3-13 and 3-14, were acceptable.

Once SIMAIZ is calibrated to a specific location, reasonable results can be obtained. One of the problems in using SIMAIZ to accurately predict yields is in the timing of phenological development.

The Pennsylvania study shows that proper timing of the events leads to excellent predictions when using SIMAIZ. The timing of tasselling

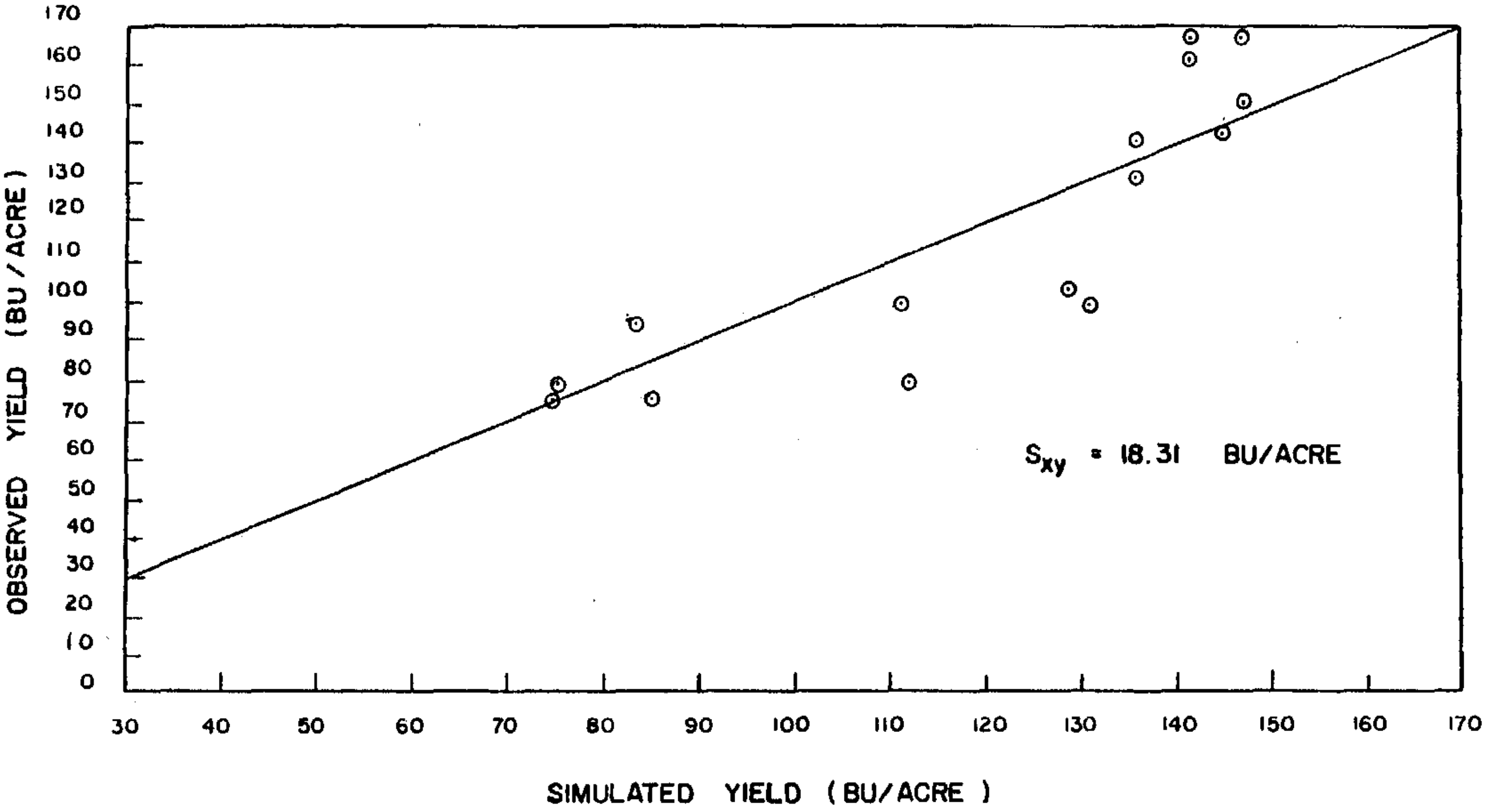

Figure 3-11. Predicted and observed grain yields for the 1978 Kentucky data.

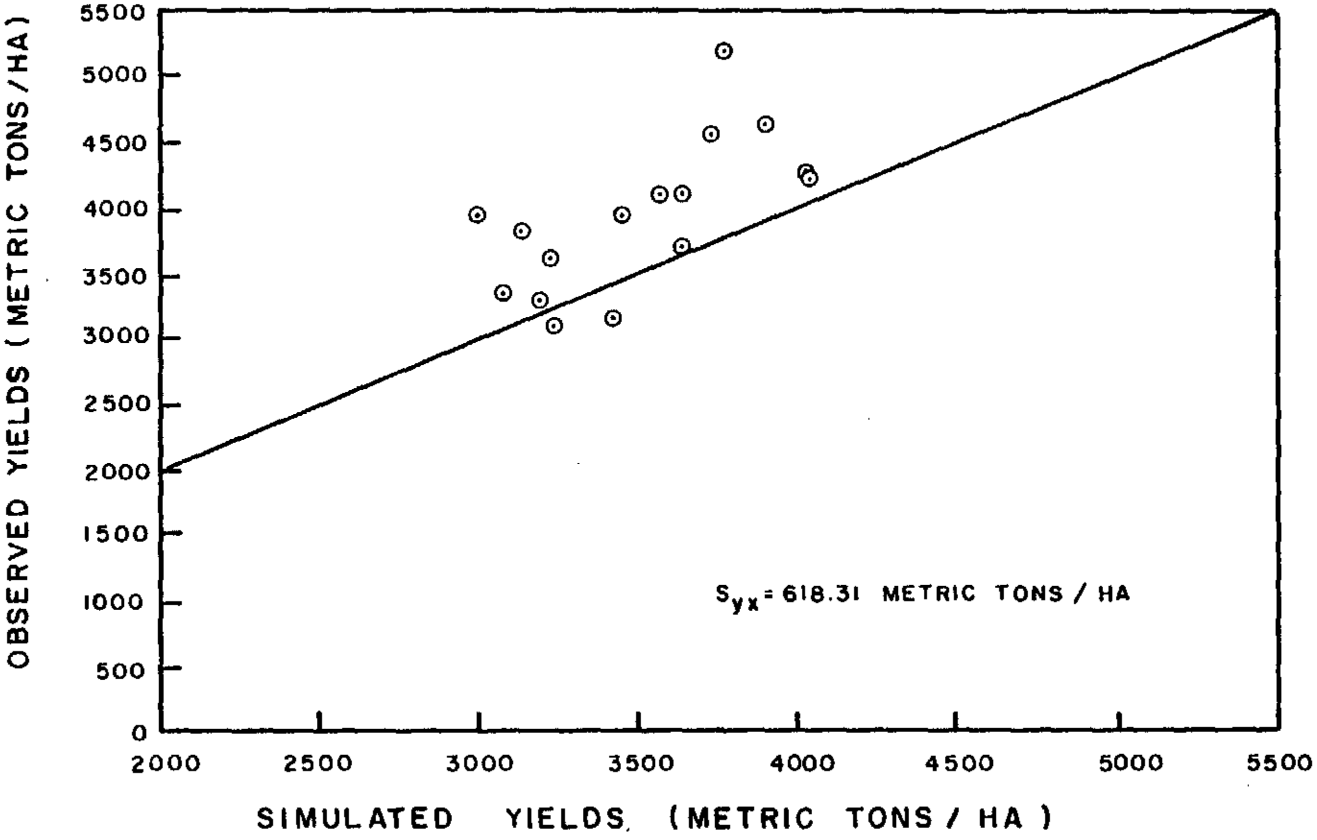

Figure 3-12. Predicted and observed dry matter yields for the 1978 Kentucky data.

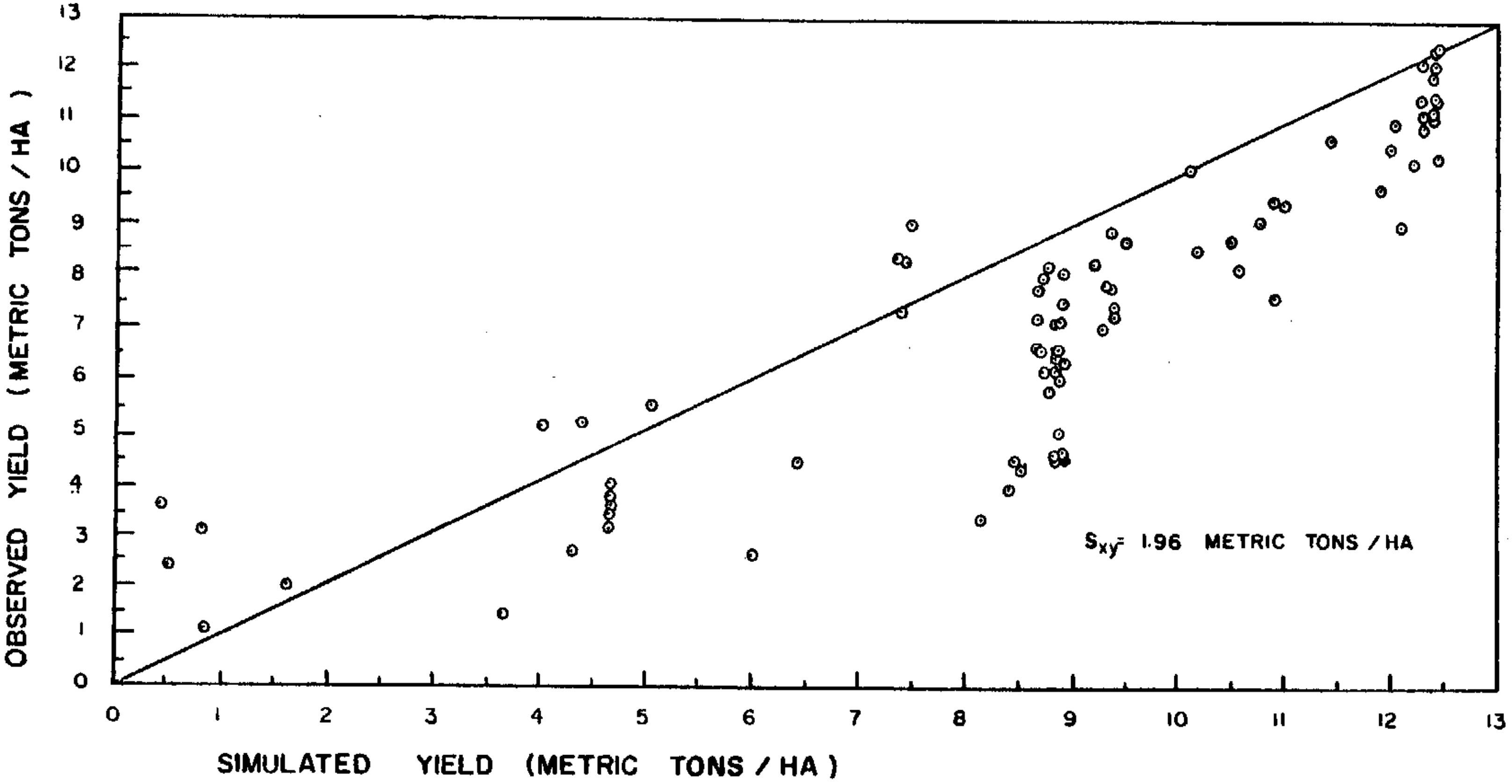

Figure 3-13. Simulated and observed grain yields for the Western U.S. data (Stewart et al., 1977).

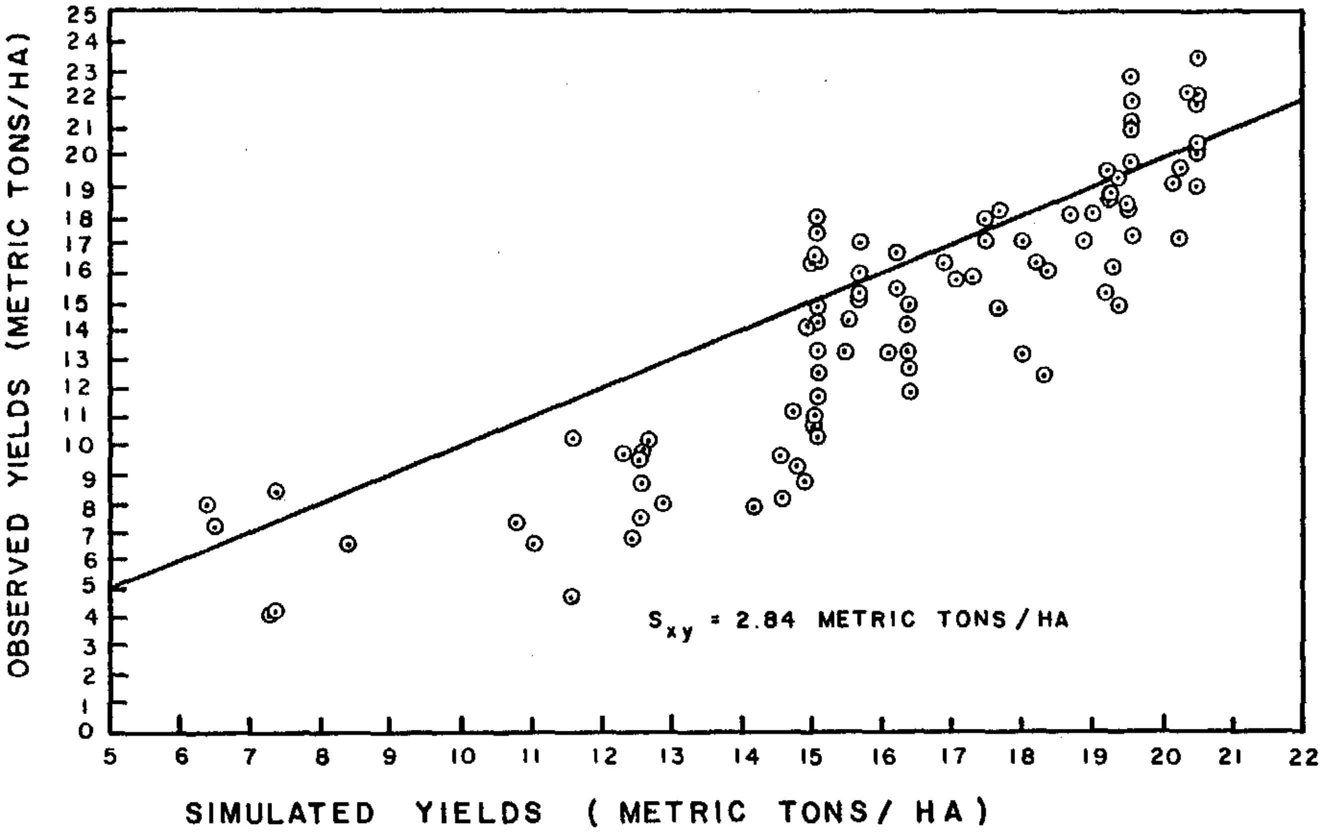

Figure 3-14. Observed and simulated dry matter yields for the Western U.S. data (Stewart et al., 1977).

was not possible in the other studies. Since the timing of tasselling controls the length of filling period, it is probable that improvements in predictions of phenological development would improve the model prediction. When better procedures become available, they can be incorporated in the model.

It would be desirable to have a more accurate model of grain yield. However, none are available at the present time that can be used to predict both irrigated and non-irrigated yields. Since yields due to irrigation are the subject of interest in this research, and since they are conservatively estimated for Kentucky data, the use of SIMAIZ to model the effects of irrigation on yields will give conservative economic values.

HAAN WATER YIELD MODEL

The model which will be used to predict daily flows into a reservoir is the Haan water yield model (Haan, 1972). This model was selected since it was developed to simulate monthly watershed runoff for small rural watersheds. Haan defines small as being less than 40 square miles. The original constraints used in the model's development were that it be simple in concept, applicable over a wide range of conditions, and require a minimum of input data. Because of these constraints, duplicating the exact hydrology of a watershed exceeds the ability of the model. For example, the infiltration parameter selected by Haan more accurately represents a combination of infiltration, interception, and surface storage. The model does, however, reasonably estimate the runoff for a given watershed from daily precipitation.

Model Parameters

The Haan Water Yield Model has four parameters which must either be: (1) optimized using estimated values and at least one, and preferably two or more years of recorded streamflow, or (2) calculated based on several measurable watershed characteristics. These parameters to be estimated represent maximum infiltration in./hr (VAR1), maximum daily seepage in./day (VAR2), maximum capacity of soil water which is less readily available for evapotranspiration inch (VAR3), and the fraction of seepage that becomes runoff (VAR4). The parameters cannot be directly measured, as they only represent the components described in characterizing the watershed.

To optimize the parameters, Haan's (1972) complete model must be used separately, as it contains an optimization section specifically designed for this purpose. Haan's model optimizes the parameters by minimizing the sum of squares between observed and simulated runoff values. When several years of recorded runoff values are available, the model initially optimizes the parameters using the first year of record, and then runoff is simulated for the remaining years of observed runoff. The two years with the poorest fit are used to again optimize the parameters. The results from the two years are averaged to obtain the final optimum parameter set. Results of using optimized parameters on seven watersheds in Kentucky, obtained from Haan (1972), are found in Table 3-3 for independent predictions. The model does an excellent job of predicting monthly runoff using optimized parameters.

When observed runoff is not available for the site in question, a method for calculating the parameters must be used. To calculate the four

Table 3-3. Water Yield Model Results Using Optimized Parameters.

Watershed	Years Used for Opt.	No. Years Simulated	Cor.[1/] Coeff.	Slope[2/]	Obs. Mean RO	Sim. Mean RO
Cane Br.	57,58	10	.96	1.02	17.25	18.11
Cave Cr.	53,61,62	16	.93	1.04	14.63	15.14
Clemson 1	64,65	6	.97	1.04	9.75	10.63
Clemson 2	64,65	6	.95	1.02	17.42	17.53
Clemson 3	65,66	5	.95	1.02	7.35	7.35
Helton Br.	57,58	12	.94	1.05	17.48	16.93
Perry Cr.	53,59,60	13	.95	1.04	13.04	12.85

1/ Correlation between observed and predicted monthly runoff.

2/ Slope of regression curve between observed and predicted runoff.

parameters, the following regression equations, developed by Jarbo (1972) and Jarbo and Haan (1974), can be used when no streamflow data is available:

(1) Maximum Infiltration (VAR1) - in./hr

$$VAR1 = 4.66 - 11.49\ VAR2 - 0.0003\ Sd\ Sb - 0.031\ A\ Hg - 0.131\ Pl\ Fc + 1.136\ Vr\ Pl \quad (4)$$

(2) Maximum Seepage (VAR2) - in./day

$$VAR2 = 0.037 + 0.002\ Wc + 0.00067\ Iw\ L - 0.0026\ Pa\ Hg + 0.00006\ Fc\ L - 0.0086\ Vr\ Hg \quad (5)$$

(3) Soil Water Less Available for Evapotranspiration (VAR3) - in.

$$VAR3 = 3.03 + 0.005\ Iw\ Sb + 0.011\ Sd\ Hg + 0.0096\ Fc\ Iw \quad (6)$$

(4) Fraction of Seepage that Becomes Runoff (VAR4)

$$VAR4 = 0.326 + 0.011\ L + 0.008\ Pl\ Sb + 0.0018\ Ps\ Sd - 0.045\ Wc\ Pl \quad (7)$$

where:

Sd = average soil depth for the watershed (inch).

Sb = slope of mainstream, which is the slope in feet per mile of the stream from the reservoir site to the point where the farthest upstream tributary enters the mainstream.

A = watershed area (acres).

Hg = hydrologic group index.

Pl = percent area of lakes or ponds.

Fc = percent area of forest cover.

Vr = volume of rock drained by stream system. This value can be calculated by multiplying the watershed area by the difference in mean elevation of the basin and elevation of the proposed dam site.

Wc = the average available water capacity for the watershed.

Iw = a water availability index obtained from U.S. Geological Survey hydrologic atlases. This is an integer value ranging from 1 to 4.

Pa = average permeability of the A horizon.

L = length of mainstream.

Ps = average soil permeability.

Results of using calculated parameters on six watersheds in Kentucky, obtained from Jarbo and Haan (1974), are found in Table 3-4. The non-optimized model has an acceptable accuracy, but is not as accurate as the optimized model. A comparison of calculated versus optimized parameters can be seen in Table 3-5.

Table 3-4. Water Yield Model Results Using Calculated Parameters (from Jarboe, 1972).

Watershed	Average Annual Obs. RO	Average Annual Sim. RO	Average Annual Dev.	Percent Error
Helton Br.	17.16	17.57	0.41	2.4
L. Plum Cr.	18.40	18.90	0.50	2.7
McGills Cr.	16.34	18.27	1.93	11.8
N.F. Nolin R.	15.71	17.11	1.40	8.9
Perry Cr.	13.45	13.21	0.24	1.8
Stillwater Cr.	19.13	16.92	-2.21	11.5

Table 3-5. Optimum and Calculated Parameter Values (from Jarboe, 1972).

Watershed	Opt. f_{max}	Calc. f_{max}	Opt. S_{max}	Calc. S_{max}	Opt. C	Calc. C	Opt. F	Calc. F
			Calibration Watersheds					
Bear Br.	3.00	3.22	0.035	0.034	7.50	8.25	0.52	0.52
Cane Br.	3.20	2.68	0.030	0.028	10.00	9.18	0.35	0.44
Cave Cr.	2.80	3.10	0.070	0.047	3.80	5.91	0.52	0.56
Flat Cr.	3.00	2.28	0.040	0.055	4.20	4.50	0.36	0.38
Green R.	3.06	2.43	0.073	0.071	4.09	4.92	0.44	0.48
McDougal Cr.	3.00	2.96	0.050	0.065	7.20	6.33	0.60	0.52
Rock Lick Cr.	2.32	1.75	0.050	0.054	5.90	5.51	0.60	0.54
Rose Cr.	2.90	3.17	0.066	0.059	4.97	4.58	0.28	0.23
S. Elkhorn Cr.	2.00	1.82	0.050	0.050	4.90	5.50	0.55	0.59
S.F.L. Barren R.	1.30	1.41	0.088	0.083	4.90	5.25	0.58	0.49
W. Bays Fk.	2.09	2.73	0.070	0.056	4.10	4.85	0.56	0.42
Wood Cr.	1.10	1.41	0.050	0.042	7.00	6.33	0.70	0.66
Obion Cr.	1.28	1.03	0.080	0.075	6.20	5.17	0.13	0.16
Bear Cr.	1.13	1.29	0.050	0.050	5.10	4.78	0.28	0.49
Pitman Cr.	0.45	0.96	0.046	0.047	6.76	6.29	0.45	0.50
Plum Cr. #4	3.20	3.24	0.040	0.041	5.30	4.22	0.49	0.49
Plum Cr.	2.00	2.15	0.040	0.037	3.84	4.09	0.52	0.46
			Test Watersheds					
Elkhorn Cr.	3.15	-3.28	0.030	-0.620	6.50	5.20	0.70	1.12
Helton Br.	2.80	3.35	0.050	0.032	9.40	8.28	0.35	0.44
McGills Cr.	1.10	2.31	0.090	0.053	5.50	5.51	0.45	0.40
Perry Cr.	0.95	3.17	0.065	0.061	4.75	5.20	0.00	0.01
Stillwater Cr.	1.80	1.93	0.043	0.058	7.00	5.58	0.75	0.53
L. Plum Cr.	2.00	2.56	0.050	0.045	2.90	4.58	0.35	0.52
N.F. Nolin R.	0.55	0.54	0.040	0.055	7.00	5.93	0.30	0.55

Conceptual Basis of Model

In addition to the four parameters, initial conditions for soil moisture should be defined. The soil moisture is divided into readily available (Mr) and less readily available (Ml) for evapotranspiration. The maximum value for Mr is one inch and for Ml is VAR3. A conceptual diagram of the runoff model is shown in Figure 3-15.

The evapotranspiration (ET) value is a function of daily potential evapotranspiration (PET) per month which depends upon soil moisture status and daily precipitation (Pd). The following relationships describes how ET is calculated:

$$ET = PET \quad \text{when } Pd = 0.0 \text{ and } 0 < Mr \leq 1.0 \tag{8}$$

$$ET = PET(Ml/VAR3) \quad \text{when } Pd = 0.0 \text{ and } Mr = 0.0 \tag{9}$$

$$ET = 1/2\ PET \quad \text{when } Pd > .01 \text{ and } 0 < Mr \leq 1.0 \tag{10}$$

$$ET = 1/2\ PET(Ml/VAR3) \quad \text{when } Pd > .01 \text{ and } Mr = 0.0 \tag{11}$$

Once ET is determined it is subtracted from soil moisture.

Deep seepage (S) is calculated daily by:

$$S = VAR2(Ml/VAR3). \tag{12}$$

The fraction of this value which returns to the mainstream as surface runoff (Vr), is given by:

$$Vr = VAR4 \times S \tag{13}$$

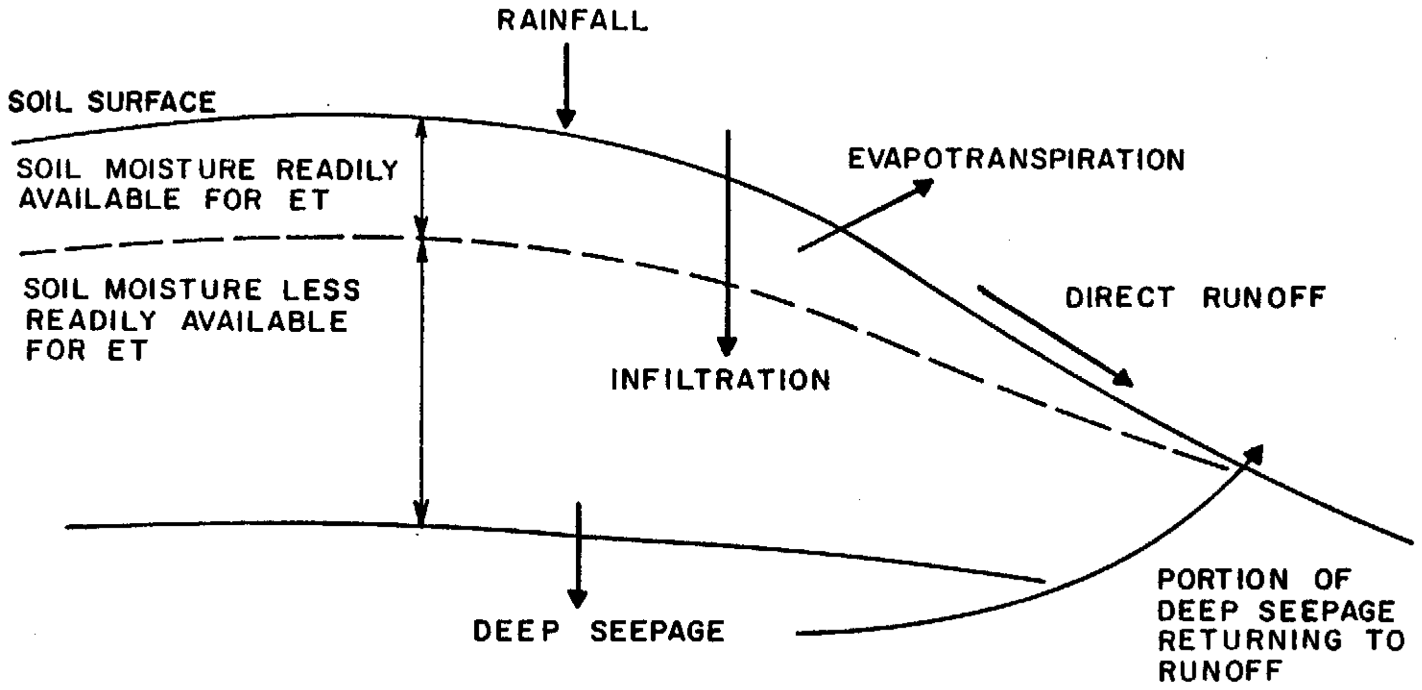

Figure 3-15. Conceptual diagram showing the hydrology of runoff.

Daily rainfall is distributed into a rainfall pattern with six minute intervals. Initially, an hourly pattern is formed using a SCS Type 1 or Type 2 distribution (Table 3-6), depending on the geographic location. This distribution was obtained from Kent (1968). The hourly rainfall is then further divided into six-minute intervals using a pattern proposed by the Soil Conservation Service National Engineering Handbook (U.S. Soil Conservation Service, 1957, Figure 21-3), as shown in Table 3-7.

Table 3-6. Distribution of Hourly Rainfall Within A Day.

	Accumulated Fraction of Daily Rainfall	
Hour	Type 1 Storm	Type 2 Storm
0-1	0.017	0.011
1-2	0.035	0.022
2-3	0.055	0.035
3-4	0.076	0.048
4-5	0.091	0.064
5-6	0.125	0.080
6-7	0.156	0.100
7-8	0.194	0.120
8-9	0.254	0.147
9-10	0.515	0.181
10-11	0.624	0.235
11-12	0.682	0.663
12-13	0.727	0.772
13-14	0.767	0.820
14-15	0.798	0.850
15-16	0.830	0.880
16-17	0.854	0.898
17-18	0.870	0.916
18-19	0.902	0.934
19-20	0.926	0.952
20-21	0.944	0.964
21-22	0.963	0.976
22-23	0.981	0.988
23-24	1.000	1.000

From Haan (1972).

Table 3-7. Rainfall Distribution Within An Hour.

Minutes	Percent Rain in Time Interval	Cumulative Percent Rain
0-6	4	4
6-12	6	10
12-18	9	19
18-24	33	52
24-30	18	70
30-36	9	79
36-42	7	86
42-48	6	92
48-54	4	96
54-60	4	100

From Haan (1972).

Given a rainfall rate (P), rainfall is distributed into infiltration (f) and direct surface runoff (Vs) in the following manner:

Infiltration

$$f = VAR1 \quad \text{when } P \geq VAR1 \text{ and } Mr < 1 \text{ or } Ml < VAR3 \qquad (14)$$

$$f = P \quad \text{when } P \leq VAR1 \text{ and } Mr < 1 \text{ or } Ml < VAR3 \qquad (15)$$

$$f = 0.0 \quad \text{when } Mr = 1 \text{ and } Ml = VAR3 \qquad (16)$$

Direct surface runoff

$$Vs = (P - f)t \quad \text{when } P > f \qquad (17)$$

$$Vs = 0.0 \quad \text{when } P \leq f \qquad (18)$$

where t is time increment.

The Haan (1972) model was designed to produce monthly runoff calculated continuously using daily rainfall. It has been shown to do an excellent job simulating monthly runoff. Daily values of runoff are taken from the continuous calculations and used for this study.

RESERVOIR SIZING ROUTINE

In areas where surface water must be stored for irrigation purposes, a system for sizing reservoirs must be employed. The proper sizing of irrigation reservoirs to minimize initial capital investments, while conserving water and energy, must start by considering all inflows and outflows, as shown in Figure 3-16. The inflows are precipitation and watershed runoff, given by:

$$Q_p = PR \times A_{reservoir} \tag{19}$$

$$Q_{ro} = RO \times A_{watershed} \tag{20}$$

where RO is the watershed runoff and PR is daily precipitation. The outflows which should be considered are evaporation, seepage, prior water rights (baseflow), and irrigation demand. The volume of water lost due to evaporation is:

$$Q_E = PET \times A_{reservoir} \tag{21}$$

where PET is potential evaporation. Seepage has two components; seepage through the dam and into the soil. Following Schwab et al. (1966), this can be calculated as:

$$Q_{s1} = (4Kh^2C)/(9L) \tag{22}$$

where Q_{s1} is the seepage discharge, K represents the hydraulic conductivity of the least permeable section, h is the distance from the impervious base

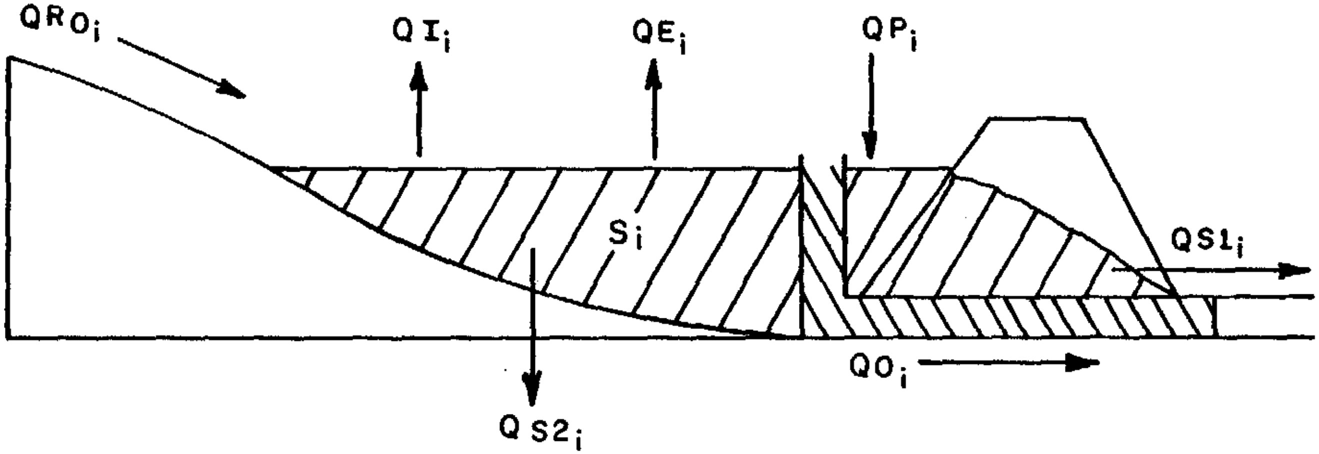

Figure 3-16. Water balance of an irrigation water supply reservoir showing all inflows and outflows.

to the present level of water in the reservoir, L is the mean length of the seepage line, and C is used to convert Q_{s1} into proper units. One assumption in equation 22 is that the downstream saturation line is at 1/3 the height of water stored. Schwab indicates that this is usually good for discharge slopes flatter than 1:1. Seepage through the bottom of the reservoir is considered to be a constant rate, Qs2. If prior water rights must be incorporated, a base flow, Qb, or full release of natural flow, whichever is least, is the most common practice. Irrigation outflow, QI, is given by:

$$Q_I = I \times A_{crop}/effs \tag{23}$$

where I is the amount of water applied, A_{crop} designates the area of irrigated land and effs is the efficiency of the irrigation system.

A daily balance incorporating these inflows and outflows can be used to calculate the daily change in storage, ΔS, or:

$$\Delta S_i = Q_{roi} + Q_{pi} - Q_{Ei} - Q_{s1i} - Q_{s2i} - Q_{Ii} \tag{24}$$

(where terms are shown in Figure 3-1). The storage at any date is given by:

$$S = \sum_{i=1}^{n} \Delta S_i \tag{25}$$

where n is the number of days since reservoir was last full.

In order to size the reservoir, an initial dam height is assumed. If the reservoir becomes dry during any year of the data set being analyzed, the model increments the dam height which increases the volume of the reservoir and returns to the beginning of that year's data set. The model will continue to increase the reservoir volume until a dam height is reached

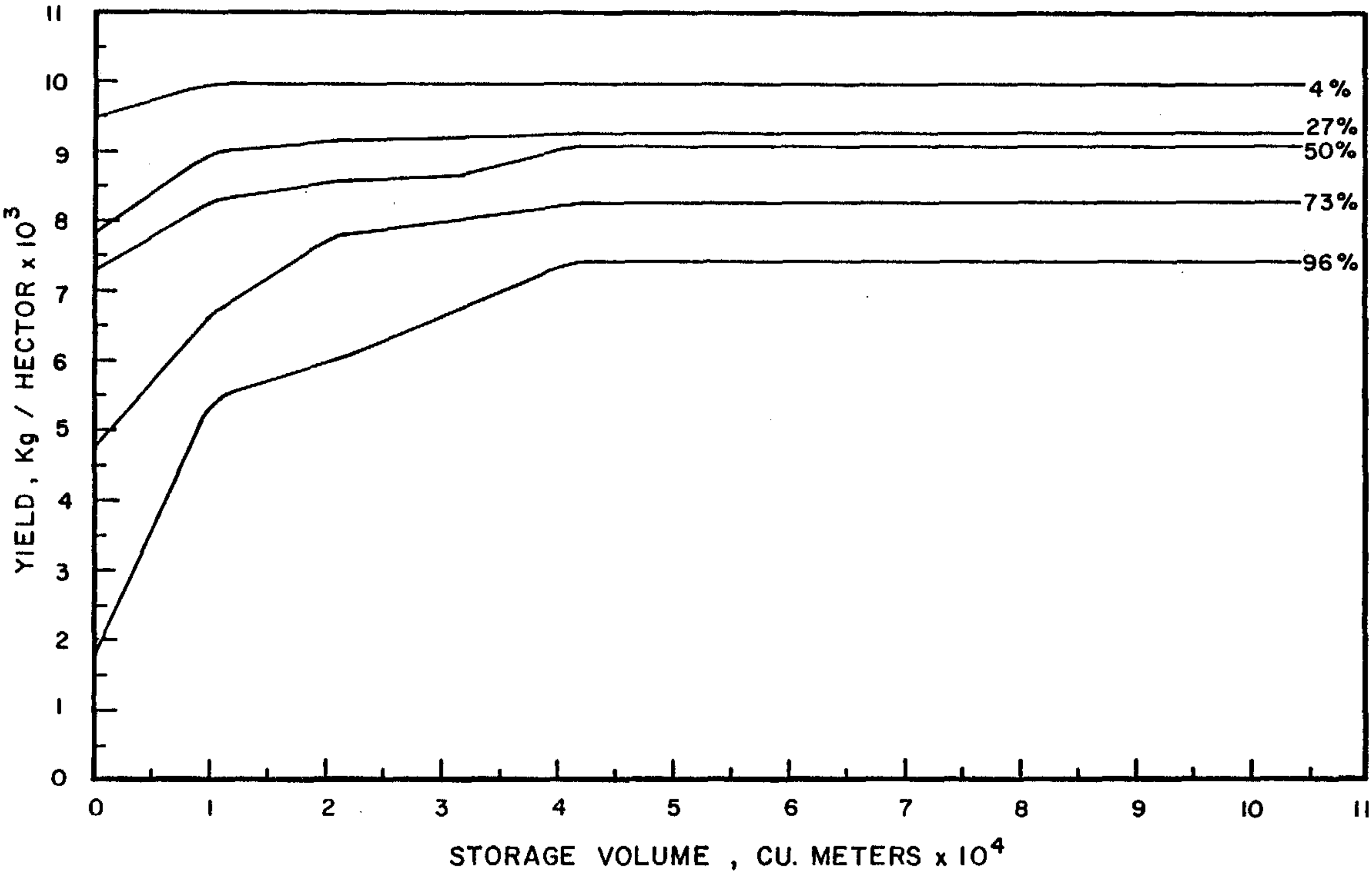

Figure 3-17. Grain yield vs. reservoir size.

which will enable the reservoir to supply irrigation water at all times for the period under study. This is called the maximum reservoir size.

The ideal reservoir size is not necessarily the maximum size since many factors other than water supply must be taken into consideration when sizing the reservoir. Some of these factors are: (1) how much can the farmer afford to invest in an irrigation system, (2) how much labor is available to set up the system, (3) how often can the irrigation system be run, (4) what yield must the farmer maintain to justify the expense of the reservoir and irrigation system, and (5) what percent risk, that the yield will be less than the maximum, is the farmer willing to accept. The next step after the maximum reservoir size has been determined is to reduce the reservoir volume by increments until a nonirrigated condition (zero reservoir volume) is simulated. Return period calculations are performed on the resulting yields for each reservoir size. These values can be plotted, producing probability curves of yields as a function of reservoir size, as in Figure 3-17. Other economic factors besides increase in yield must be considered before irrigation can be advised.

IRRIGATION MODEL

An important element for a successful irrigation operation is proper scheduling of irrigation. One typical method is to irrigate when the soil moisture has depleted to a preselected level. Several methods have been used to determine soil moisture content. One method would be to use predictive equations for evapotranspiration calculations, and actual rainfall data to calculate daily a soil water balance. This method can be periodically checked and adjusted by actually measuring the moisture content of the soil. Soil probe samples, tensiometer readings, and neutron probes are ways of directly measuring soil moisture. An irrigator with some experience can estimate the soil moisture content by feeling the soil at a given depth below the surface. This is a simple on-site way of determining moisture content.

Another method for scheduling irrigations would be to irrigate at regular intervals, depending on the stage of development of the crop. This method works fine in arid regions where rainfall is insignificant throughout the growing season, but is impractical for supplemental irrigation scheduling because rainfall occurs sporadically throughout the growing season.

Irrigating when the soil reaches a given moisture content is the most desirable for supplemental irrigation and is also easily incorporated into SIMAIZ. SIMAIZ calculates evapotranspiration daily and performs a mass balance on the soil moisture. When the soil moisture reaches a certain level, irrigation can be signaled.

A subroutine is incorporated into the overall model which controls irrigation. The user defined variables for this subroutine are potential plant available water (will vary with individual farms, H2OCAP), amount of water which must be depleted from the soil profile before irrigation begins (H2ODEF), and the amount of water to be applied when irrigation is performed (H2OIRR). A daily check is made to see if the difference between potential and actual (H2OPRO) plant available water is less than H2ODEF. When

$$(\mathrm{H2OCAP} - \mathrm{H2OPRO}) < \mathrm{H2ODEF} \qquad (26)$$

the subroutine adds H2OIRR to the rainfall term for that day. The actual demand of water, in inches per acre, from the reservoir is:

$$\text{DEMIRR} = \text{H2OIRR/EFFS} \tag{27}$$

where EFFS is the efficiency of the irrigation system in conveying water.

By varying H2ODEF and H2OIRR for a given situation, several irrigation scheduling patterns can be considered. H2ODEF enables the user to vary the moisture content of the soil which signals irrigation. H2OIRR can equal H2ODEF or it can be less than this value so the soil moisture would not be completely replenished. This would allow less actual rainfall to be wasted due to a recent irrigation completely refilling the soil profile.

Once a reservoir volume has been determined which will supply water at all times, the reservoir volume is incrementally reduced. Calculations for all the years are made for each reservoir size. Consequently, there will be times when not enough water will be available in the reservoir for the desired irrigation application. When this occurs, the model will irrigate with the amount of water that is available, given it is above a minimum amount. To prevent the model from irrigating with an insignificant amount of water, a value (H2OLIM) is defined which prevents irrigation from occurring when the current volume falls below this value. In reducing the reservoir volume, it is possible that a situation will exist where, even when the reservoir is full, the volume of water is insufficient to meet the minimum requirement for irrigation. When this situation arises, the irrigation subroutine redefines the H2OLIM term to be 95 percent of the potential volume of the reservoir. The results from varying H2OIRR and H2ODEF is contained in the sensitivity analysis.

ECONOMICS MODEL

In an economic analysis, all cash flows are evaluated at some reference time. With the calculations performed in the previously discussed models, a yearly cash flow can be determined for pumping irrigation water, labor for running the irrigation system, yearly maintenance, and additional income from increased grain yield. In addition to yearly values, the cost of the irrigation water supply can also be determined. These values allow the operating costs, water storage costs, and benefits from irrigation to be known. An area neglected is the cost for the irrigation system itself (i.e. pipes, pump, and sprinklers). Arriving at a cost for the irrrigation system is a complicated procedure and varies considerably, depending on the type system and where and how it is purchased. Since this is the only value not considered, the results from an economic analysis would indicate the amount of capital available to invest in the irrigation system. This is the predicted parameter in the economics routine.

Two water supply sources are considered; a well and a storage reservoir. The well is assumed to have an adequate water yielding capacity so that water supply is not a problem. This enables the grain yields, which resulted when the maximum reservoir size was determined, to be used for the well economics. The cost of constructing the well is an input, WELCST, dependent upon the required depth of the well. Pumping costs are increased by adding the additional head, WELHED, from the well to the total dynamic head term, TDH, in the pumping equation, given in equation 30. The well maintenance is a yearly expense figured as a percentage, PERCM, of the construction cost.

$$\text{MANTCS} = \text{WELCST} \times \text{PERCM} \tag{28}$$

The labor costs and increased grain yield are the same as was calculated for the maximum reservoir size.

To calculate the cost of the dam, it is necessary to know the volume of fill. Knowing the reservoir site topography, a relation between volume of storage water and dam size is made. The length of the dam can also be measured from the topographic map. Hence, the total volume of earth to be moved in constructing the dam can then be calculated allowing a means of determining reservoir construction cost in relation to reservoir volume.

Reservoir cost was calculated from:

$$\text{Reservoir Cost} = (\text{Volume of Dam}) \times (\text{Fill Price}) + \text{DAMCST} \qquad (29)$$

Fill price is an input which may vary for different locations. A value of \$2.00/CuM was recommended by the Soil Conservation Service in Kentucky as reasonable for small earth dams. DAMCST is used when additional expenses such as sealing problems and special outflow structures are encountered. Reservoir maintenance cost is figured as a percentage of the reservoir cost, which is an input to this model.

Pumping costs are calculated knowing the volume of water pumped and the total dynamic head by:

$$\text{Pumping Cost} = \text{CKWH} \times \text{TDH} \times \text{H2OAD*AREAIR*.085308/(EFFP} \times \text{EFFM)} \qquad (30)$$

where CKWH is the cost per kilowatt hour ¢/kilowatt hour; TDH is the total dynamic heat in feet, which will vary with the site; H2OAD is the total volume of water pumped from the reservoir during each season in inches; EFFP is efficiency of pump; EFFM is efficiency of motor; and AREAIR is the area irrigated.

The labor cost for system operation must also be estimated. This value will vary with different type systems and is an input to the model. To calculate total labor cost for the irrigation season, the labor cost for system operation is multiplied by the number of times irrigation was performed.

The value of the increased yield is calculated from:

$$\text{Value of Increased Yield} = \text{Yield difference} \times \text{GRPR} \tag{31}$$

where GRPR is the price of grain and yield difference is the difference in yield for a given year due to irrigation.

A present worth method of analysis was chosen using the cash flows previously described in order to account for the interest factor in investment. By using a present worth anaysis, a value is obtained allowing the farmer to determine the total amount of money he/she can invest in an irrigation system. Another advantage to using a present worth analysis is that a separate constant inflation rate can be incorporated for each yearly cost value. If the farmer wants to see what would happen if labor costs inflated at a higher rate than corn prices, this is possible. Of course this would only serve to answer the question, "what if", as inflation is essentially impossible to predict and is almost never constant for any length of time. Prices could just as easily enter a period of deflation as increased inflation.

To account for yearly inflation (f) on a yearly cost (A), the following relationship is formed:

Cost in year 1 would be A

Cost in year 2 would be $A(1+f)$

Cost in year 3 would be $A(1+f)(1+f)$

Cost in year n would be $A(1+f)\ (n-1)$ (32)

This method was also used by Chu (1980) to inflate yearly costs.

To project each yearly cost (B) back to the present from year n, using an interest rate (i), the following equation is used:

Present worth = $B(1+i) - n$ (33)

Combining equations 32 and 33, and summing over the life of the system N years, we have:

$PW = A(1+f)(n-1) \times (1+i)\ (-n)$ (34)

where PW is the present worth value of yearly cost A. By combining all costs and benefits in their present worth value, the total present worth of the system is known.

By calculating a present worth of the system for each year of simulation and each reservoir size, an average return on investment could be calculated over the period of simulation. To make this analysis mentioned above, the following steps need to be taken:

(1) Calculate the yield increases due to irrigation and expenses of irrigating on a yearly basis;

(2) Calculate the average present worth of the increased yield minus the increased annual cost due to irrigation (not including equipment amortization) over the period of simulation;

(3) Subtract the cost of the reservoir construction (or well construction) from the value obtained in (2). This will be the average cash available for investment in an irrigation system (CAIS).

An example is shown in Figure 3-18 for an irrigation system with a 10-year life. The characteristics of the watershed, crops analyzed, and investment costs are found in Appendix A

To use the analysis system described above, cost and return decisions must be based only on the long term average values for return on investment without information on the level of risk involved on an annual basis, or over the life of the system. To develop information on the level of risk involved, one would need to simulate a large number of values (30 to 40) for each point on the curve shown in Figure 3-18 and do a return period analysis on the results. Such a simulation would require either 300 to 400 years of adequate weather records or the use of a technique to simulate daily maximum and minimum temperatures, and incoming solar radiation. Neither of these methods is presently feasible.

An alternative approach would be to use the present worth values as outlined below:

(1) On a yearly basis, calculate the yield increases, irrigation set up times, and volume of water pumped for each reservoir size evaluated;

(2) Calculate the present worth of the yield increase minus the annual cost of irrigation for each year and reservoir size;

(3) The capital available for investment in an irrigation system will be the amount figured in (2) above, minus the cost of the reservoir (or well);

(4) Rank capital available for investment in an irrigation system for each reservoir size and calculate the associated probability of occurrence.

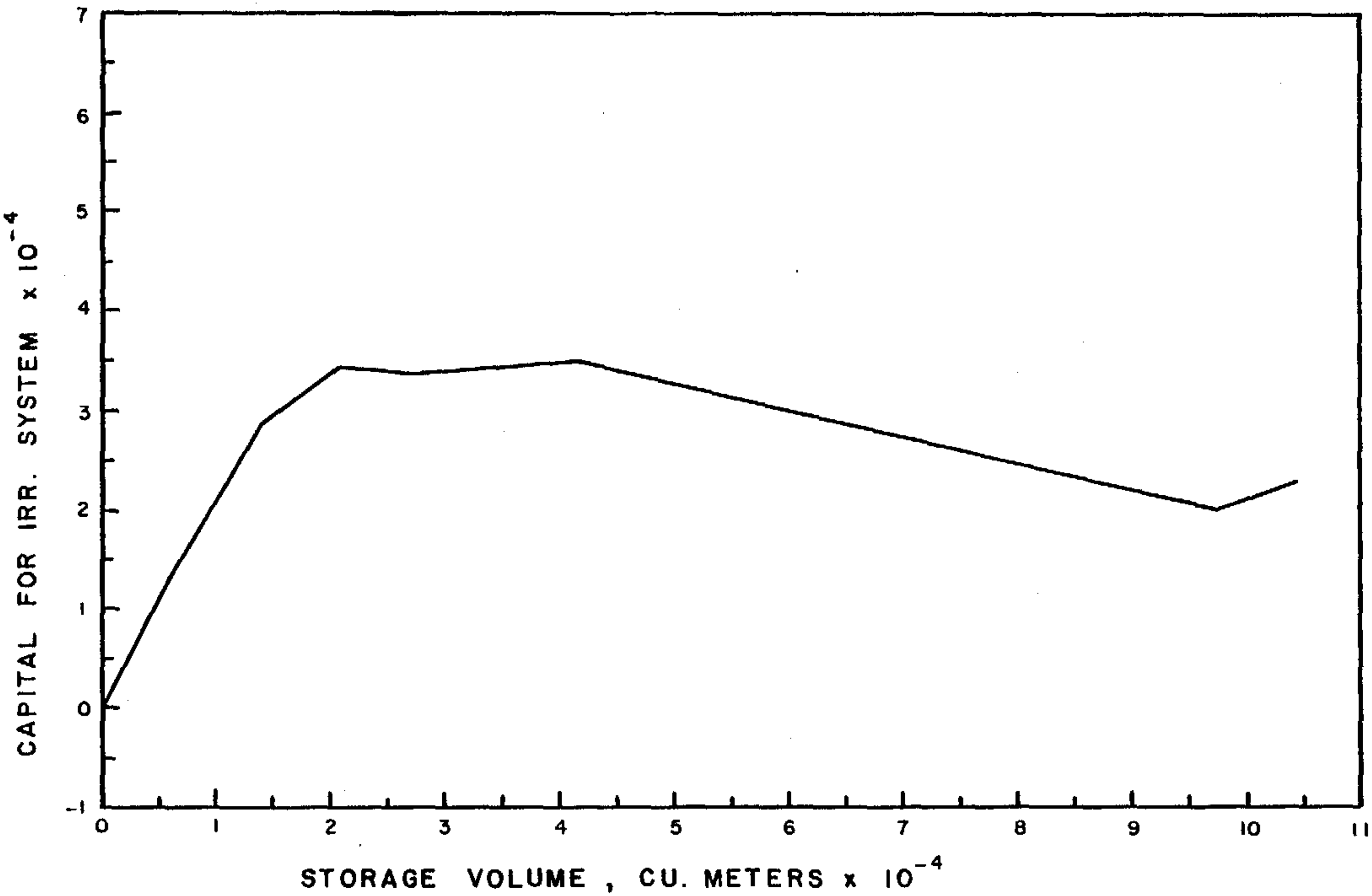

Figure 3-18. Average capital available for investment in irrigation system vs. reservoir size.

An example of the output, for reservoir sizing, using this method outlined, is shown in Figure 3-19 for the example farm and watershed. If a reservoir of 40,000 cu meters was constructed for this site, in 50 percent of the years (point A) one could expect to have a return on investment if $13,000 or less were invested in the irrigation system itself (pipes, sprinklers, and pump). The calculated average value, from Figure 3-18, for a given reservoir size is considerably different from the 50 percent curve in Figure 3-19, which represents the mean value. The distribution of the curves in Figure 3-19 can explain why the mean and average values would differ so greatly. The interval between the 50%, 73%, and 96% curves is much less than the interval between the 50%, 27%, and 4% curves. The distribution also indicates that in many years the farmer would lose money due to an investment in irrigation while some years the profits will be very high, thus offsetting the loss experienced in the other years.

In more humid areas, the rainfall is often adequate to meet the evaporative demands of the crop. Because of this, the farmer who irrigates has to expect that irrigation will not always produce significantly higher yields compared to the farmer who does not irrigate. The major benefits from irrigation are realized during drought years. During these years the farmer who irrigates can expect the same high yields experienced during a good growing season, while the neighboring farmer who does not irrigate will have disasterously low yields. This is indicated in Figure 3-19, in 73 percent of the years (point B) if one were paid $13,500 to take an irrigation system they would break even or make money. On the other hand, in 27 percent of the years (point C), one could afford to invest $70,000 in an irrigation system and break even.

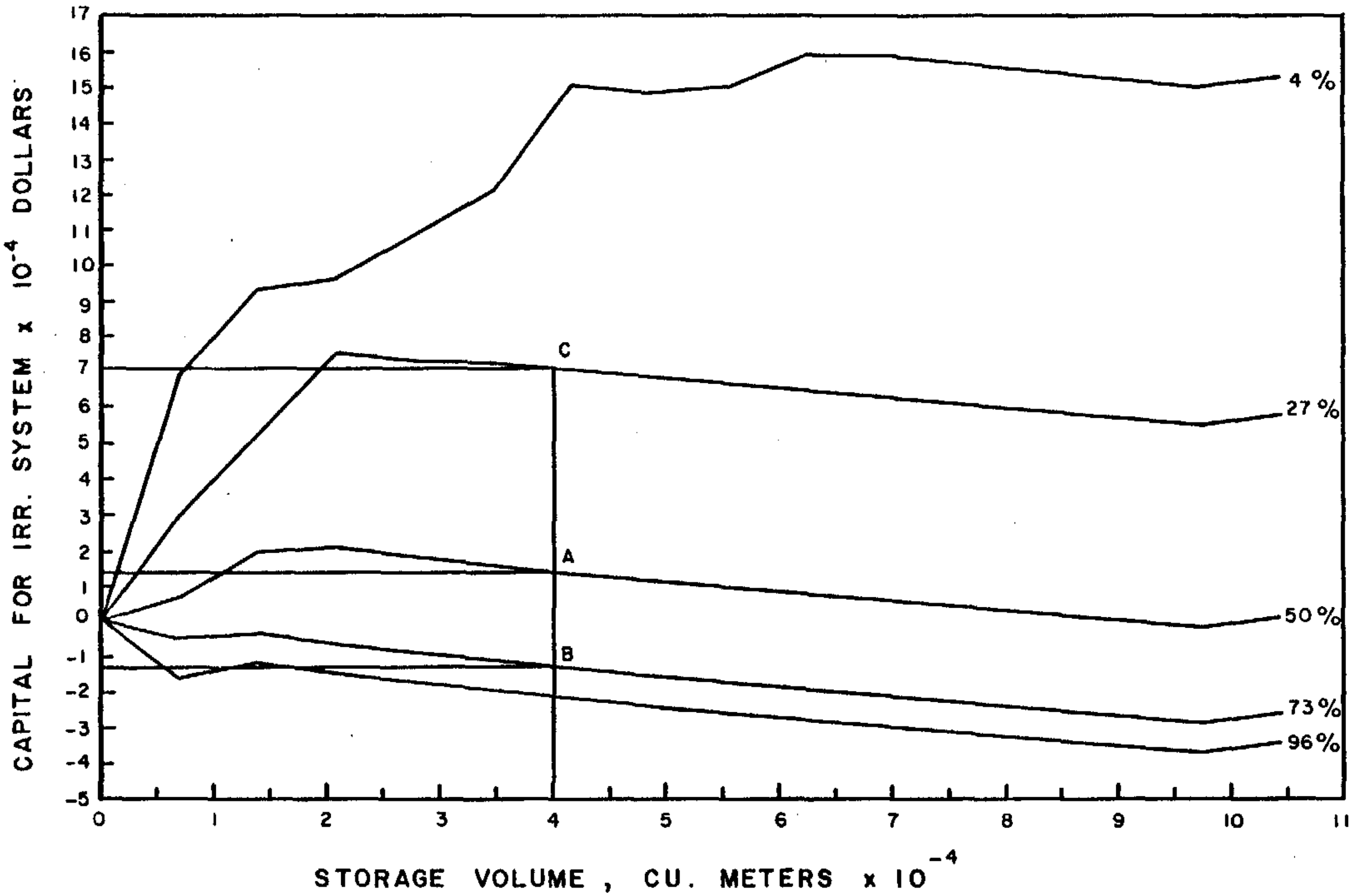

Figure 3-19. Capital available for investment as a function of reservoir size for various probability levels based on annual values.

This type analysis could be used to offer farmers additional information to help them decide whether to invest in an irrigation system; however, it essentially tells the investor the probability of recovering enough return on one's investment in any given year to meet the payment on the system at a given interest rate. Information is still needed on the level of risk over the life of the system.

An approach to the analysis of risk over the life of the system can be developed using the Central Limit Theorem. The probabilities of the present worth values for a given reservoir size in Figure 3-19 were calculated from a return period analysis on N years of record (25 in this case). These present worth values have a mean μ_{CAIS_i} (estimated by $\overline{CAIS_i}$) and a standard deviation of σ_{CAIS_i} (estimated by S_{CAIS_i}) where the subscript i on CAIS refers to the estimation made based on annual values for a given reservoir size. Based on the Central Limit Theorem, it can be shown that the present worth, based on an average over m years of return, will be normally distributed with a mean of:

$$\mu_{CAIS_m} = \mu_{CAIS_i} \tag{35}$$

and standard deviation of

$$\sigma_{CAIS_m} = \frac{\sigma_{CAIS_i}}{\sqrt{m}} \tag{36}$$

Using this fact and the standard normal curves, the risk (probability) levels can be developed for values of cash available for investment in an irrigation system based on an m year life ($CAIS_m$).

The values in Figure 3-19 are transformed this way and plotted in Figure 3-20. A comparison of Figures 3-19 and 3-20 can be made for any specific reservoir

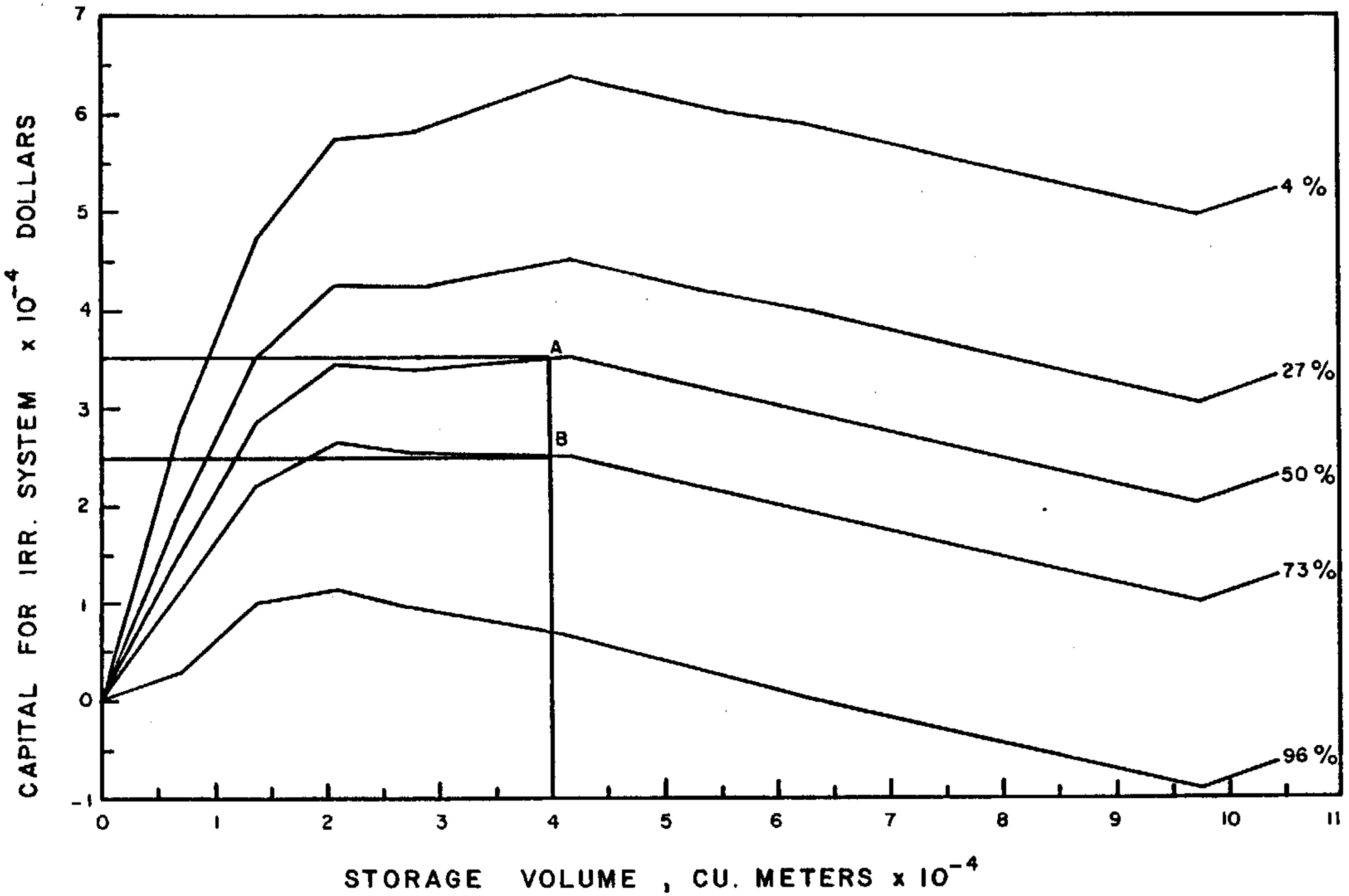

Figure 3-20. Capital available for investment as a function of reservoir size for various probability levels, based on averages over life of system (10 years in this case).

size. We will use the example of 40,000 cu meters and look at the 50 percent level. One could expect the increased return on investment of $13,000 in an irrigation system to more than meet the annual payment in 50 percent of the years and be 50 percent sure of a return on investment of $35,000 (point A) amatorized over a life of 10 years. Looking at the 73 percent curve (Figure 3-19) one would have to be paid $13,500 to take an irrigation system to more than meet the annual payment in 73 percent of the years; however, one can be 73 percent sure (Figure 3-20) of a return on an investment of $25,000 (point B) in an irrigation system amatorized over the 10 year life. The difference in the two values is due to the fact that the annual return on investment more than meets the annual payment in most of the years.

A comparison based on a given potential investment is a more appropriate way of using Figures 3-19 and 3-20. For example, if one were considering investing in an irrigation system that cost $6,000, and constructing a 40,000 cu meter reservoir, Figure 3-20 would indicate a better than 96 percent chance of making a return on the investment over a 10 year system life. Figure 3-19 indicates that approximately 55 percent of the years will have an increased return on investment equal to or greater than the annual payment required for the money invested. Therefore, using Figure 3-20, the investor can determine the risk of obtaining a return on investment over the life of a system, and by using Figure 3-19, an estimate can be made of the probability of obtaining a return in any one year. The use of Figure 3-19 would only be important when cash flow is a problem and the investor is not willing to accept a high risk of no return on investment in any one year. Further examples of varying different parameters will be discussed in another chapter.

CHAPTER IV

SENSITIVITY ANALYSIS

SENSITIVITY ANALYSIS FOR SURFACE WATER SUPPLY

A sensitivity analysis is needed to evaluate the sensitivity of the economic output to the more important model inputs. The majority of inputs required for SIMAIZ were left constant, as they describe a typical variety of corn for the area simulated. Appendix A contains a complete listing of all the necessary data inputs from which 29 were selected for a sensitivity analysis. Table 4-1 shows each variable and the range of values used. In the sensitivity analysis, standard conditions were used for all conditions except the one being varied. The standard value selected is typical of that parameter in Kentucky. The high and low values were selected to include the range of conditions which might be expected in the midwest.

First, the results from the reservoir economics will be examined. The average curve, as in Figure 3-18, is used in comparing the sensitivity of each input. The average curve for high, standard, and low values for each variable were plotted together and can be seen in Figures 4-1 through 4-26. The results are categorized in four groups. Those in which the economic output was: very sensitive, Figures 4-1 - 4-3; moderately sensitive, Figures 4-4 - 4-9; sensitive only for very small reservoir sizes otherwise not sensitive, Figures 4-10 - 4-14 (this group contained values which affected runoff); and mildly sensitive, Figures 4-15 - 4-26. Table 4-3 shows a tabulation of how each variable affected the output.

Table 4-1. Range of Values Used in Sensitivity Analysis.

Variable[1/]	Low	Standard	High
(1) Water Yield Parameters			
VAR1	.35	.53	.70
VAR2	.02	.05	.08
VAR3	3.75	5.86	10.00
VAR4	.20	.44	.70
AREARO	100.00	300.00	600.00
(2) SIMAIZ Parameters			
POPNOI	18000	24000	30000
AREAIR	50	100	200
U	6	12	18
ALPAA	3	5	7
(3) Reservoir Parameters			
QDSEP	.05000	0.00000	.2000
CK	0.00001	0.00004	0.0001
Reservoir Shape	Res. A	Standard	Res. B
(4) Scheduling Parameters			
H2OIRR	1.1	1.93	2.75
H2OCAP	3.0	5.50	8.00
H2ODEF	1.1	2.75	3.85
(5) Economic Parameters			
FCOST	0.00	.06	.12
FGRAN	.06	0.00	.12
XINT	.06	.11	.18
WELHED	50.00	100.00	200.00
WELCST	800.00	950.00	1350.00
PERMC	.005	.02	.05
TDH	100.00	200.00	300.00
EFEP	.28	.53	.75
CKWH	.03	.045	.06
FillPR	1.00	1.50	3.00
GRPR	2.00	3.00	5.00
EXTDPR	0.00	2000.00	4000.00
ALABOR	50.00	266.7	500.00
LIFE	5.00	10.00	15.00

[1/] See Table 4-2 for definition.

Table 4-2. Brief Definition of Important Parameters for Sensitivity Analysis.

VAR1	Maximum infiltration (inch/hour).
VAR2	Maximum possible seepage rate (inch/day).
VAR3	Maximum capacity which is less readily available for evapotranspiration (inches).
VAR4	A constant defining the fraction of seepage that become runoff.
AREARO	Area of watershed, units acres.
POPNOI	The population density for nonirrigated corn.
AREAIR	Area of corn to be irrigated, units acres.
U	Amount of water that must evaporate from bare soil before it ceases to act as a free water surface (mm).
ALPHA	Soil water conductivity.
QDSEP	Deep seepage through the reservoir (inch/day).
CK	Hydraulic conductivity of the material comprising the least permeable section of the dam (feet/min).
Reservoir	Shape - Accounts for different reservoir topography.
H2OIRR	Amount of water in inches to be added at each irrigation.
H2OCAP	Available water held in soil to rooting depth, in inches.
H2ODEF	Water deficit below field capacity at which irrigation is started if no rain occurs that day (inches).
FCOST	An inflation rate for the irrigation expenses.
FGRAN	An inflation rate for the price of corn.
XINT	Interest rate on capital.
WELHED	The depth water must be pumped from if using a well (feet).
WELCST	The cost of constructing a well.
PERMC	A factor used to determine maintenance cost for the reservoir based on the cost of the reservoir.
TDH	Total dynamic head (feet).
EFFP	Efficiency of pump.
CKWH	Cost per kilowatt hour ($/kilowatt hour).
FILLPR	Fill price used to determine the cost of constructing the reservoir based on the volume of soil moved in cubic years ($1.50/cu yd).
GRPR	Average price of grain ($/bu).
EXTDPR	Used when additional expenses are encountered for dam construction.
ALABOR	Labor costs assumed for setting up the irrigation system for use.
LIFE	Expected life of the system used for economic calculations (years).

Table 4-3. Sensitivity to Inputs.

Very Sensitive (≥ 63%)	Moderately Sensitive (62% - 14%)*	Partially Sensitive (see text)	Mildly Sensitive and Insensitive (14% - 0)*
AREAIR	FGRAN	AREARO	VAR1
GRPR	LIFE	QDSEP	Reservoir Shape
H2OCAP	FILLPR	VAR4	H2OIRR
	XINT	VAR3	POPNOI
	H2ODEF	VAR2	CK
	U		ALPHA
			FCOST
			CKWH
			TDH
			ALABOR
			PERMC
			EXTDPR

Percent change from standard condition.

As expected, the area irrigated, AREAIR, had a significant effect on the economic output and maximum reservoir size, as can be seen in Figure 4-1. The values used for the sensitivity analysis were 50 acres for low, 100 acres for standard, and 200 acres for high. The maximum reservoir size for irrigating 200 acres was over 170,000.0 cu meters. This was not plotted to keep the scale of the curves uniform. No other condition produced such a large reservoir. Obviously the more acres a system can irrigate, the more economical irrigation becomes.

The price of corn, GRPR, had a significant effect on the economic output, as can be seen in Figure 4-2. The values used were $2.00 per bushel for low, $3.00 per bushel for standard, and $5.00 per bushel for high, as compared to standard and low. The results appear to be somewhat linear, The potential plant available water, H2OCAP, plays an important role in the economic output, as shown in Figure 4-3. The values used were 3.0 inches for low, 5.5 inches for standard, and 8.0 inches for high. In this case, the 8.0 inches corresponds to the lowest curve in Figure 4-3. At this value, the soil is able to store enough water to supply the crop with water during most drought periods, whereas with only 3.0 inches, irrigation is needed at more frequent intervals and the increase in yield, as compared to nonirrigated conditions, is much greater. Consequently, the benefits from irrigation are much greater.

An inflation factor for the price of grain, FGRAN, had a moderate affect on available capital, as shown in Figure 4-4. In this case, the standard condition was 0.0 because, traditionally, grain prices have not inflated at the same rate as the expenses of irrigation. The low value is .06 (6%) and the high value is .12 (12%). The results are as expected, with the standard being lowest and the increases being uniform for all reservoir sizes. This again shows how important grain price is in irrigation economics.

The economic life over which the system is evaluated, LIFE, has a moderate affect on the economic output, as shown in Figure 4-5. The low, standard, and high values are 5 years, 10 years, and 15 years, respectively. As can be seen, as the years increase, the increased benefits on economic output become less.

The interest rate on money, or cost of money used in the economic analysis, XINT, has a moderate affect on economics, as shown in Figure 4-6. The values used were 0.6 for low, 0.11 for standard, and 0.18 for high. The benefits were uniform throughout the reservoir size.

The amount of water which must be depleted before irrigation begins, H2ODEF, had a moderate affect on the economic output, and also affected the maximum reservoir size, as shown in Figure 4-7. The value used for low was 1.1 inches, which is a 20% depletion in plant available water; standard was 2.75 inches, or a 50% depletion; and high was 3.85 inches, or a 70% depletion. In this instance, the standard condition proved to be most economical. When 3.85 inches needed to be depleted before irrigation began, a smaller maximum reservoir size was needed. This is probably due to the longer duration between irrigation, allowing runoff to replenish the reservoir and also allowing rainfall to replenish the soil profile somewhat before irrigation is needed. The lower value of 1.1 inch depletion resulted in more frequent irrigations and a larger maximum reservoir size was needed. Also, the more frequent labor costs began to be significant. The amount of water which must evaporate before the soil no longer acts as a free water surface, U, has a moderate affect on the economic output, as shown in Figure 4-8. The values used were 6 mm for low, 12 mm for standard, and 18 mm for high. This value affects the rate of soil evaporation. The higher the U value, the longer water will evaporate at a higher rate.

The cost per cubic yard of fill for constructing the reservoir, FILLPR, has a moderate affect on the economic output, as shown in Figure 4-9. The values used were: $1.00/cu yd for low, $1.50/cu yd for standard, and $3.00/cu yd for high. The value of $1.50/cu yd was recommended by the Soil Conservation Service in Kentucky as a reasonable value for small earth dams.

The area of the watershed which contributes to runoff, AREARO, affected the volume of runoff, but did not have a large affect on CAIS, as shown in Figure 4-10. The values used were: 100 acres for low, 300 acres for standard, and 600 acres for high. The high value did result in a smaller maximum reservoir size which cannot be seen in the figure because the curves overlap beyond a 60,000.0 cu meter reservoir volume. The area of the watershed did have a mild affect on the economics for very small reservoir volumes. The amount of water lost from the reservoir due to deep seepage, QDSEP, had only a mild affect on the economic output for the smaller reservoir sizes and had no affect on the larger reservoir sizes, as shown in Figure 4-11. The values used were: 0.05 in./day for low, 0.0 in./day for standard, and .2 in./day for high.

The variables in Haan's runoff model were varied to determine their effect on the economic output. The values were obtained from a study done for several watersheds in Kentucky (Haan, 1975). Each variable was averaged to determine the value. The high and low values were determined by observing the range of values used and selecting reasonable values from those used in the study. The fraction of deep seepage that becomes runoff, VAR4, affects the volume of runoff from the watershed, but does not have a large affect on CAIS, as shown in Figure 4-12. The values used were: .2 for low, .44 for standard, and .7 for high. The high value required a smaller maximum reservoir size than did the other two values. This is difficult to see in Figure 4-12 due to the overlapping of the curves for reservoir sizes greater than 50,000 cu. meters. VAR4 did have a mild affect on the economics for reservoir volumes less than 50,000 cu meters. Two of the other variables for Haan's model had similar effects on the economic output, VAR3, Figure

4-13, and VAR2, Figure 4-14. VAR3 represents the maximum soil moisture capacity which is less readily available for evapotranspiration. The values used were: 3.75 inches for low, 5.86 inches for standard, and 10.0 inches for high. VAR2 represents the maximum possible deep seepage rate. The values used were: 0.2 in./day for low, .05 in./day for standard, and .08 in./day for high. For both VAR3 and VAR2, the high values required a smaller maximum reservoir volume. The final value for Haan's model was VAR1, which represents maximum infiltration, and showed no variation in results (Figure 4-15). The values used were: .35 in./hr for low, .53 in./hr for standard, and .7 in./hr for high.

The cost of constructing the reservoir, as was explained in an earlier section, is based on the amount of fill required for the dam itself. The information needed from a topographic map is the pond area and width of the proposed dam site for incremental elevations. The standard values were obtained from the Soil Conservation Service for a reservoir site in Kentucky they were studying. The other two reservoir topographies were artificially generated to represent extremes, one being a very narrow dam for the volume contained in the reervoir (Reservoir B), and the other has a very wide dam for the volume of water contained in the reservoir (Reservoir A). The effects of different topographic sites had only a mild affect on the economics, as shown in Figure 4-16. Also shown are the stage storage curves for each reservoir shape. This result indicates that a detailed map of the reservoir site is not highly crucial to the analysis.

The amount of water applied during each irrigation, H2OIRR, had only a mild affect on economics (Figure 4-17). The values used were:

1.1 inches for low, which is 40% of what was depleted; 1.93 inches for standard, which is 70% of what was depleted; and 2.75 inches for high, which is 100% of what was depleted.

The plant population density for irrigated and nonirrigated conditions are inputted separately. The irrigated population density was set at 30,000 plants/acre, while the nonirrigated population density was varied. A population of 18,000 plants/acre was used for low, 24,000 plants/acre was used for standard conditions, and 30,000 plants/acre was used for a high value. Varying population density had a mild affect on economics, as shown in Figure 4-18. Therefore, it is not crucial to have an exact estimate of plant population. The hydraulic conductivity of the material comprising the least permeable section of the dam, CK, had no affect on the economic output, as shown in Figure 4-19. The values used were: .00001 ft/min. for low, .00004 ft/min. for standard, and .0001 ft/min. for high.

ALPHA is used to calculate soil evaporation during stage 2 drying and is dependent on the hydraulic properties of the soil. The effects of varying ALPHA had only a mild affect on the economic output, as shown in Figure 4-20. The values used were: 3 for low, 5 for standard, and 7 for high.

The remaining variables had a direct affect on the yearly expenses of irrigation. Only a mild affect resulted on the economics, which can be seen in Figures 4-21 through 4-26. FCOST is a factor which allows irrigation expenses to inflate at a separate rate than grain price. A 0.0 inflation rate was used for low, .06 (6%) for standard, and 0.12 (12%) for high. Standard conditions for inflating grain price was 0.0, the reason for this is that, traditionally, the price of grain has not maintained the same inflation rate as farming expenses. CKWH is the cost per kilowatt hour used in calculating energy usage for pumping. Most farm energy usage is not calculated, based only on the kilowatt usage. Generally, a graduated cost is figured, depending upon the total usage. A base cost is usually charged during the off season when the irrigation system is not in use. The standard price of 4.5¢/kilowatt hour was arrived at based on a study by Griffiths[1/], where the total electrical costs for a year were divided by the kilowatt hours used for that year. This was also the average price the local electric company used. The low of 3¢/kilowatt hour and high of 8¢/kilowatt hour were a reasonable range for a Kentucky condition. The values for total dynamic head, TDH, also used for calculating pumping expenses, ranged from 100 ft for low, 200 ft for standard, and 300 ft for high. The total labor cost for irrigation is based on the number of times during the season irrigation was needed and the cost of operating the system. The cost of operating the system, ALABOR, was also obtained from Griffiths[1/], in which he quoted the cost of labor per acre for the growing season with six irrigations needed during the season. A hand-moved system was considered high. For 100 acres this would be $500.00 per irrigation. A semi-automatic system was considered standard. For 100 acres this would be $267.00 per irrigation. A fully automatic center pivot was considered low. For 100 acres this would be $50.00 per irrigation. The annual reservoir maintenance expense is based

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[1/] Griffiths, Richard (1980) Personal Communication, Extension Irrigation Engineer, Utah State University.

on a percentage of the reservoir construction cost, PERMC. Values used for this were: .005 for low, .02 for standard, and .05 for high. The last expense considered, EXTDPR, accounts for any extra expense encountered when constructing the reservoir such as special outflow structures or sealing problems which may exist. Values used for this were $0.0 for low, $2,000.00 for standard, and $4,000.00 for high.

SENSITIVITY ANALYSIS FOR GROUNDWATER SUPPLY

The average values from the sensitivity analysis for pumping from a well is tabulated in Table 4-4. Only one well was assumed to be required, which may be a problem with large acreages. The number of wells needed for an individual farm will vary depending on the pumping capacity of the well and the size of the farm. This would be known when evaluating a specific farm.

Two additional variables must be defined which affect the economics of irrigation when using groundwater. These variables are: WELCST and WELHED. WELCST is the cost of constructing the well or wells. Costs determined from well drillers as typical of Kentucky are: $6.50/ft for low, $8.00/ft for standard, and $12.00/ft for high drilling costs. In all cases it also cost $7.50/ft for 20 ft of casing for the well. WELHED is the depth of the well and is added to the total dynamic head of the irrigation system when calculating pumping cost. The values used were: 50 ft for low, 100 ft for standard, and 200 ft for high.

The results of the sensitivity analysis on well economics are tabulated in Table 4-4. The table value is the cash available for purchasing the irrigation system, pumps, and pipes after all other costs are considered.

Table 4-4. Average Values for Sensitivity Analysis of Well Economics.

Variable	High	Standard	Low
FGRAN***	93459	53597	70672
FCOST**	46398	53597	58107
XINT**	42785	53597	63751
H2OIRR*	52978	"	51837
PERMC*	53433	"	53677
WELCST*	53152	"	53765
WELHED*	50914	"	56280
EFFP*	55959	"	45211
H2ODEF**	47279	"	33356
GRPR***	98391	"	31201
CKWH*	50915	"	56280
H2OCAP***	14664	"	112045
AREAIR***	108249	"	26273
LIFE*	65310	"	33581
ALABOR*	49669	"	57247
POPNOI*	59828	53597	55681

*** strong effect

** moderate effect

* mild to no effect

It can be observed from Table 4-4 that FGRAN, GRPR, H2OCAP, and AREAIR had the most significant effect on well economics. FCOST, XINT, and H2ODEF had a moderate affect on well economics, as shown in Table 4-4; and the remaining seemed to have only a mild affect on well economics.

The sensitivity analysis indicated that some inputs were more sensitive than others. The more sensitive inputs for both the well and reservoir economics were: AREAIR, the area irrigated acres; GRPR, the price of grain $/bushel; H2OIRR, the amount of water applied during one irrigation; FGRAN, the inflation rate for grain price; LIFE, the economic life of the system; XINT, the interest rate on capital; H2ODEF, the amount of water which must be depleted before irrigation begins; and U, the amount of water which must evaporate from the soil surface before the soil ceases to act as a free water surface. Great care should be observed when defining these inputs. If the user is unsure of the exact value for any of the above inputs, a range of values can be simulated indicating the expected range of results. Definitions and standard values for all inputs are found in Appendix A.

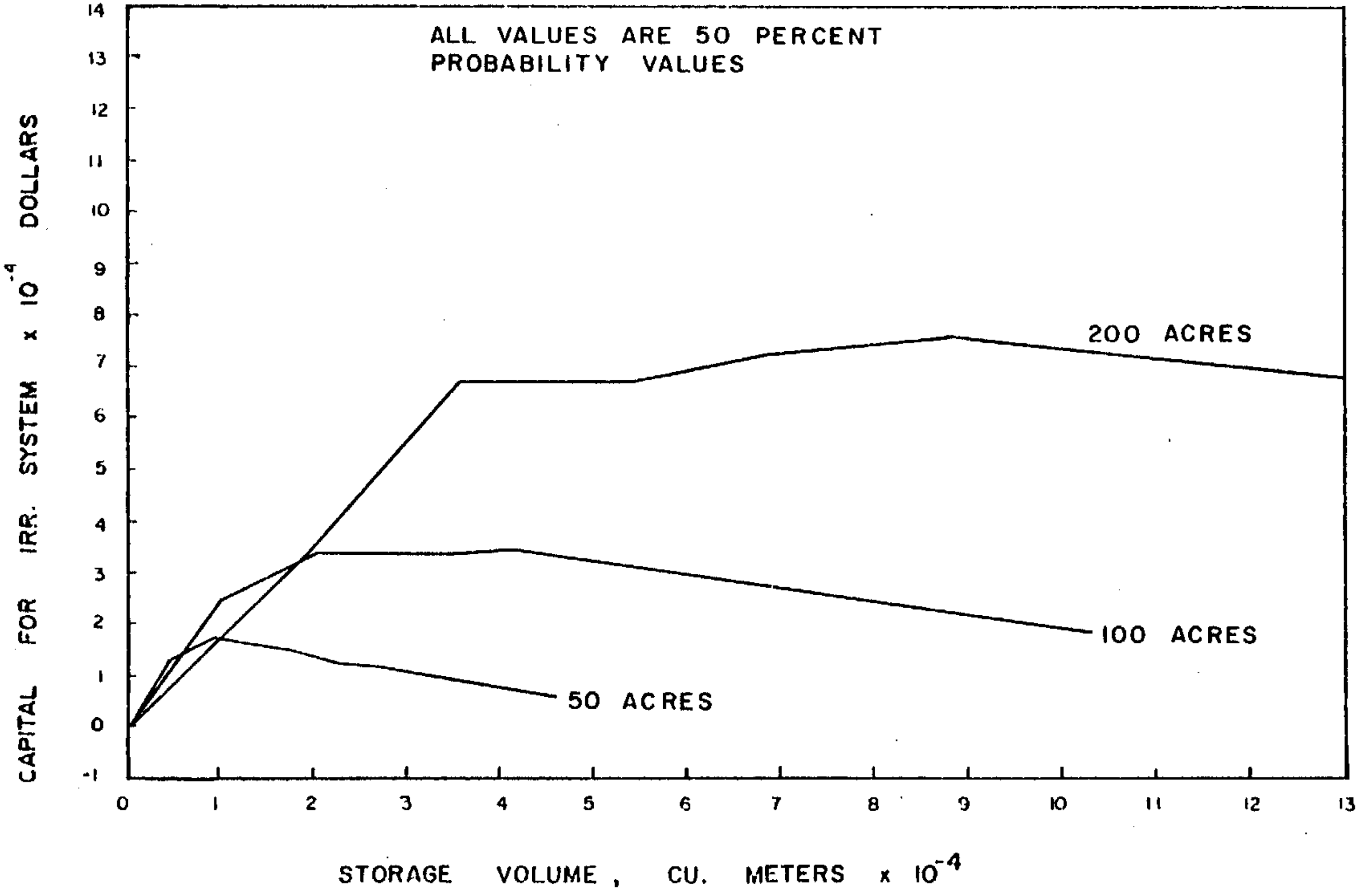

Figure 4-1. Sensitivity of CAIS to area of corn being irrigated (AREAIR).

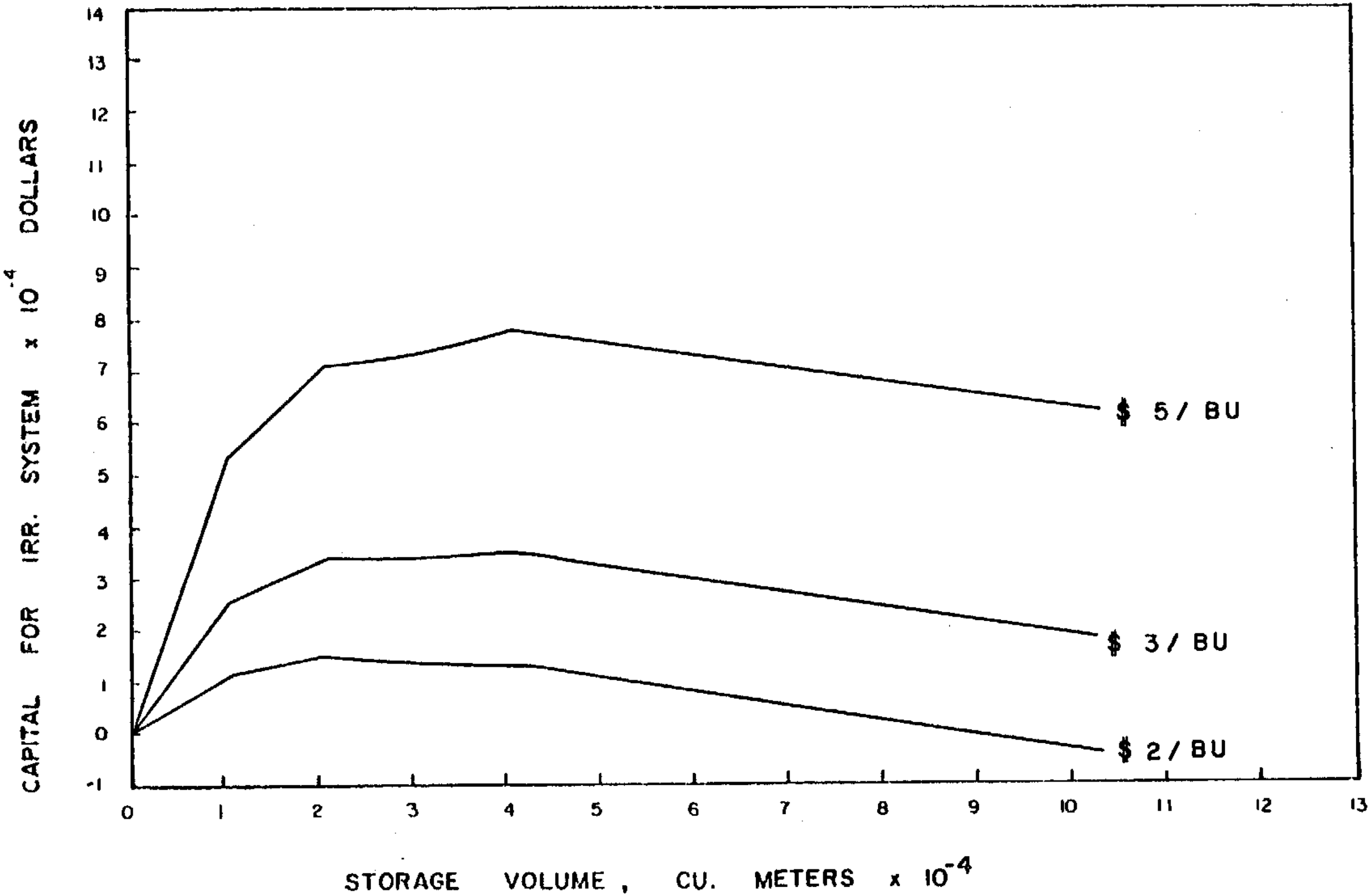

Figure 4-2. Sensitivity analysis of the effects of grain price (GRPR) and CAIS.

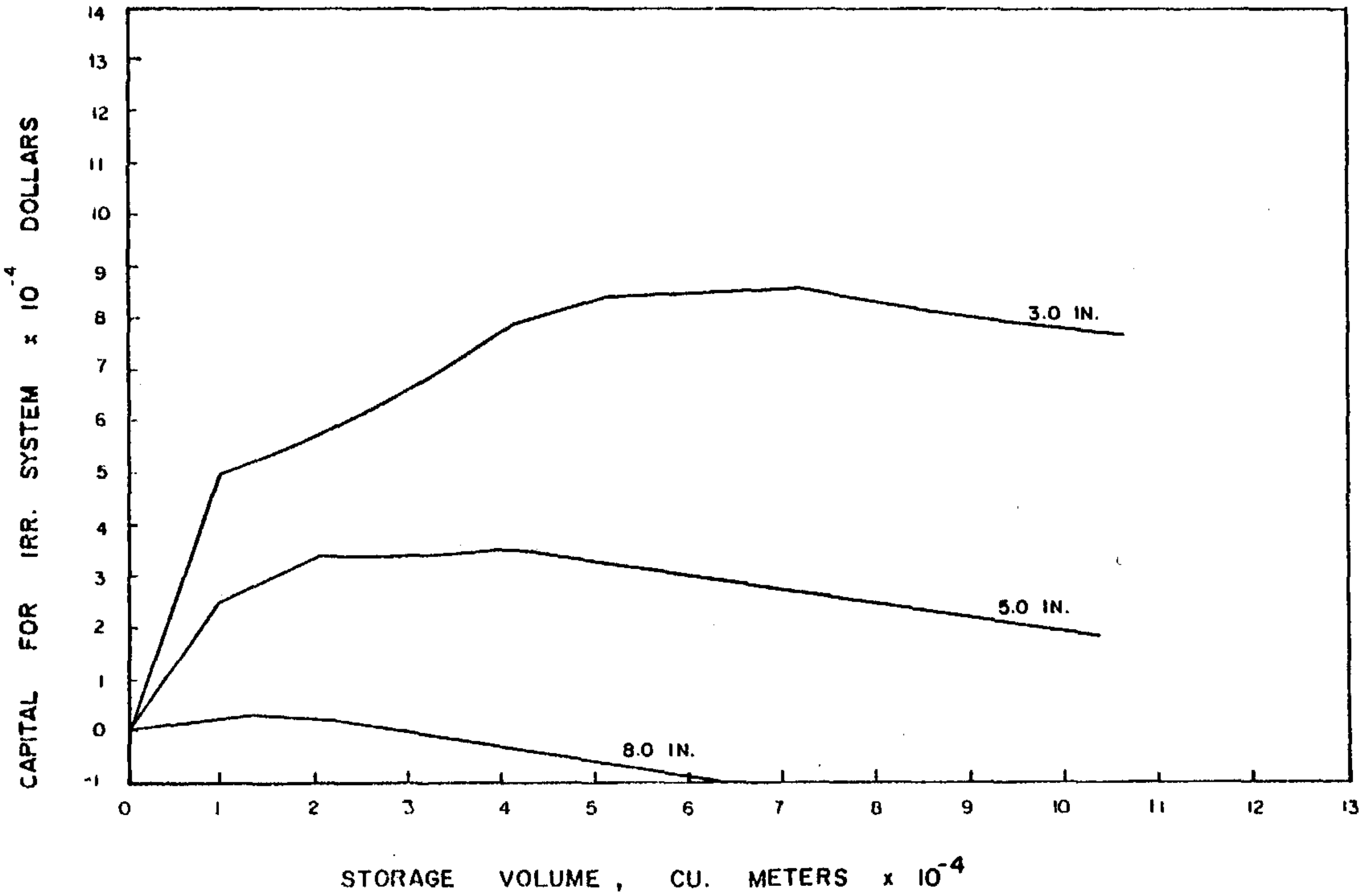

Figure 4-3. Sensitivity of CAIS to plant available water (H2OCAP).

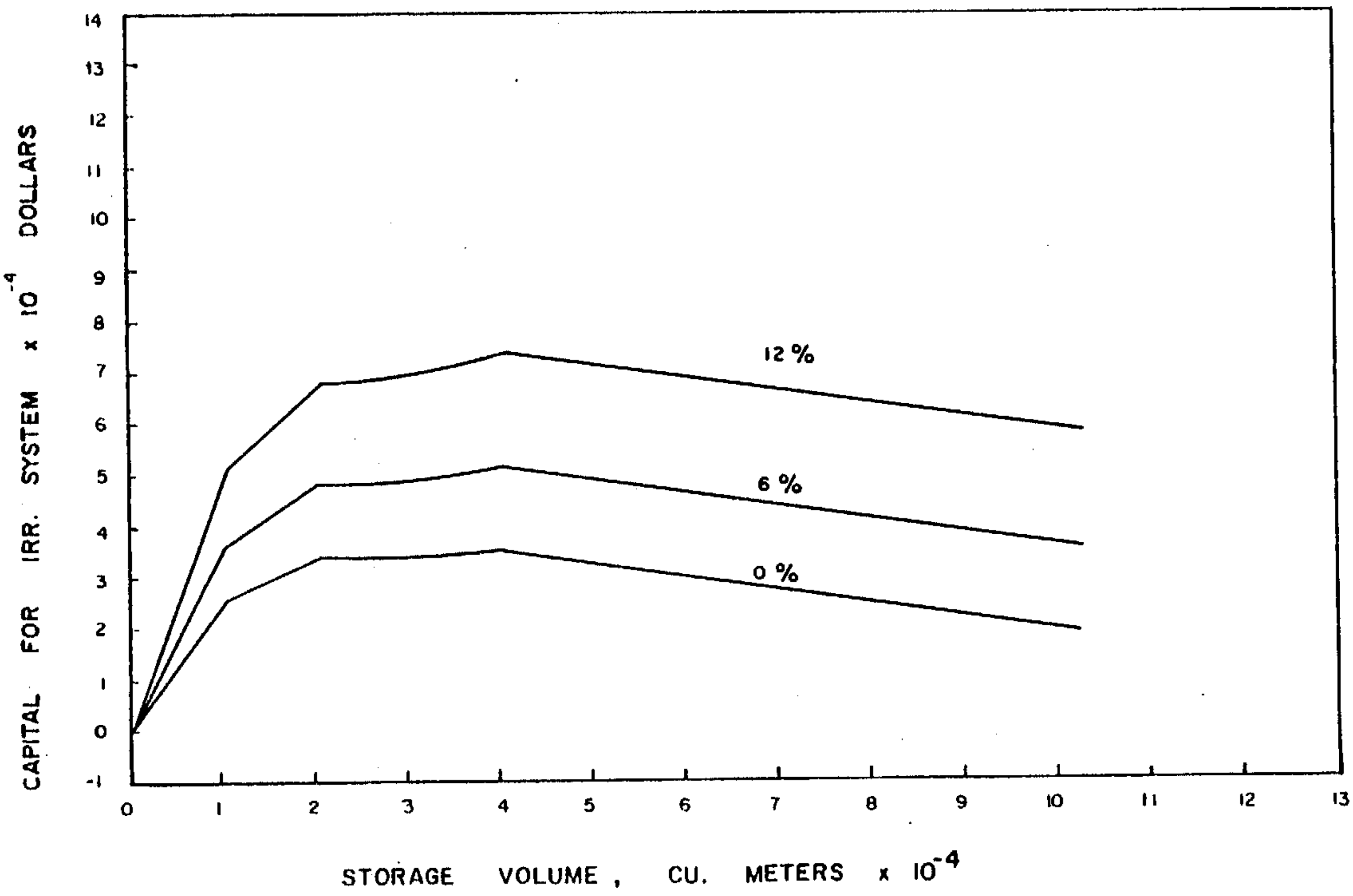

Figure 4-4. Sensitivity of CAIS to inflation rate of grain (FGRAN).

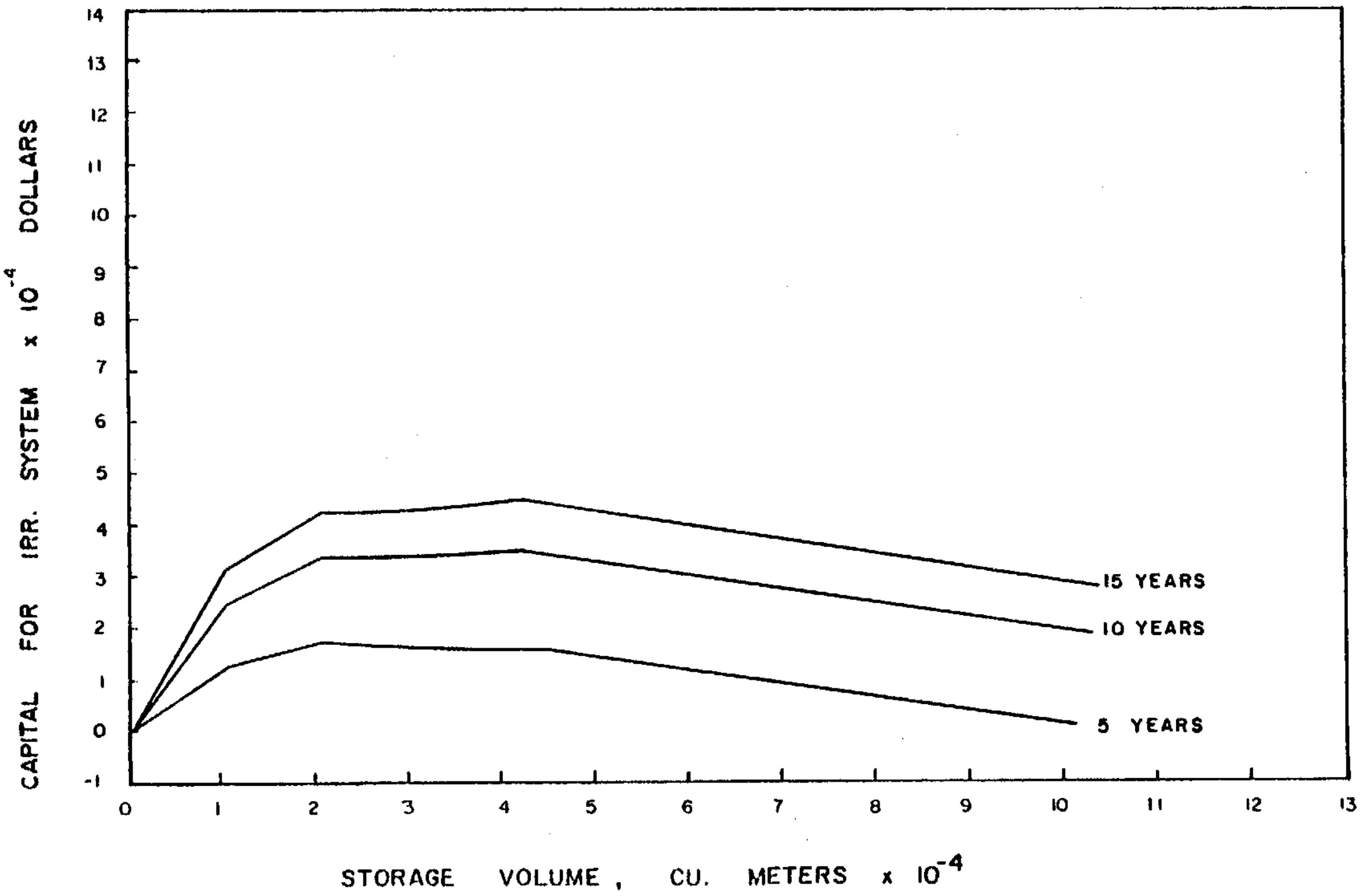

Figure 4-5. Sensitivity of CAIS to economic life of system (LIFE).

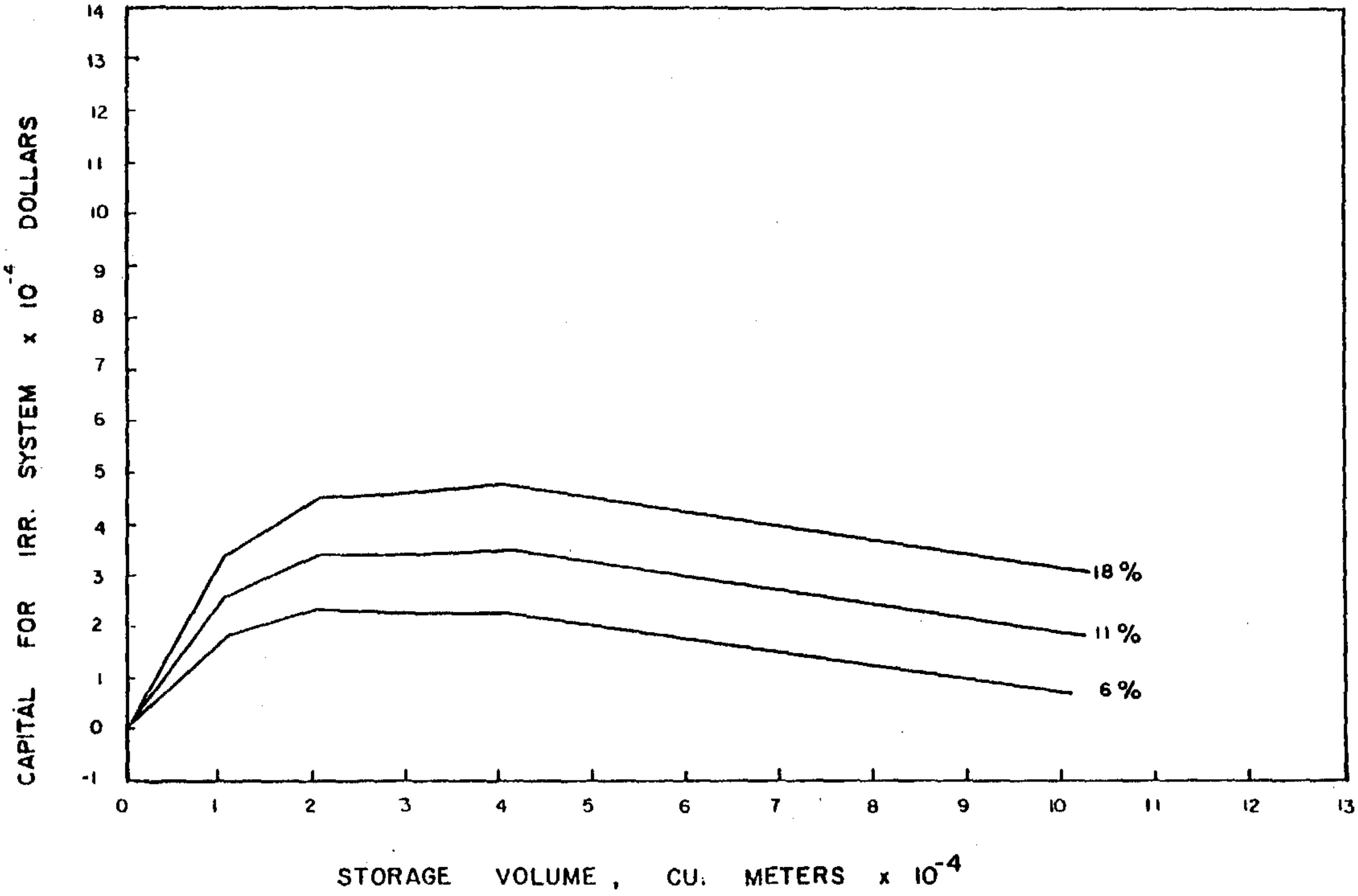

Figure 4-6. Sensitivity of CAIS to interest rate.

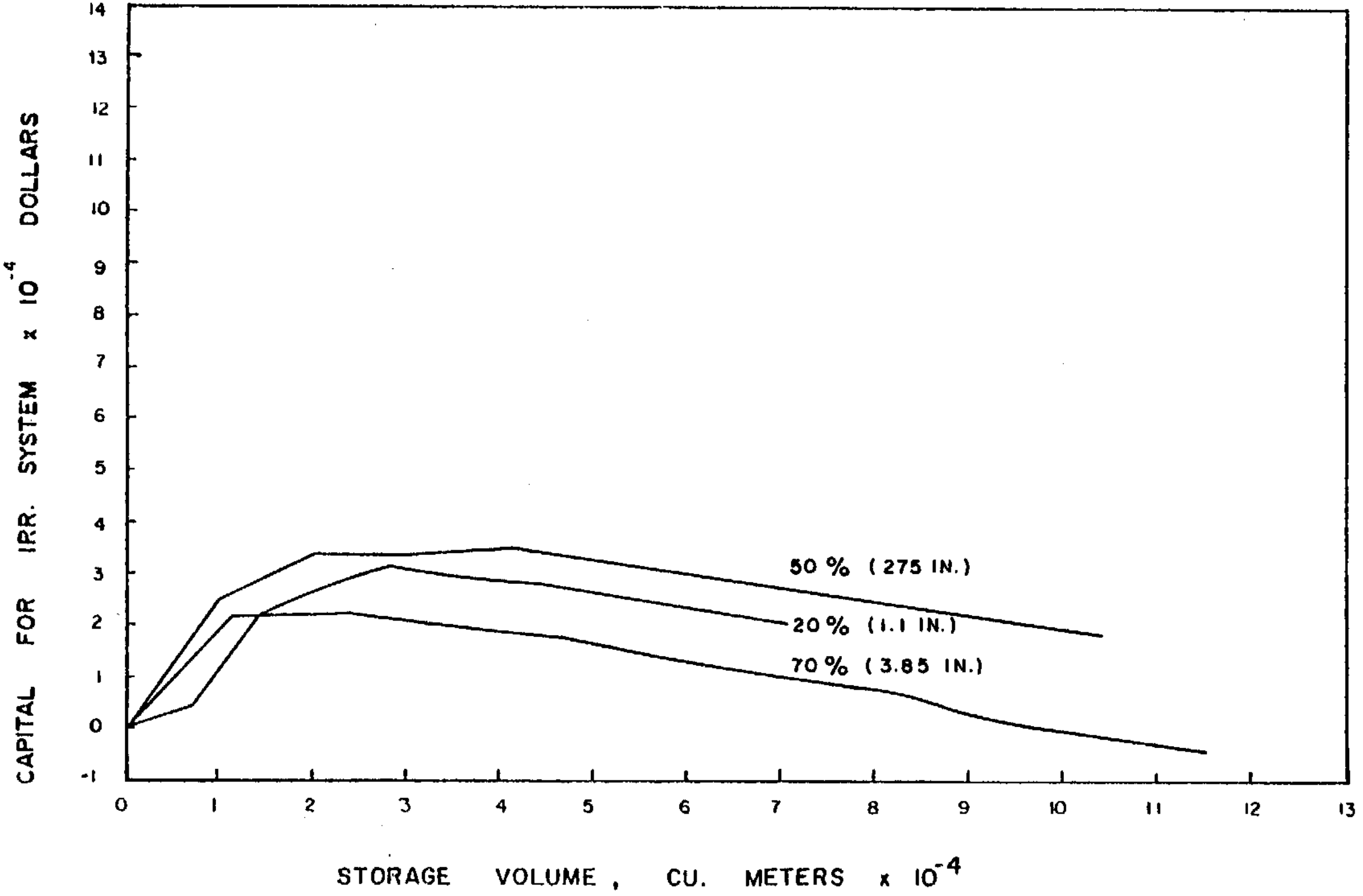

Figure 4-7. Sensitivity of CAIS to the soil water deficiency at irrigation (H2ODEF).

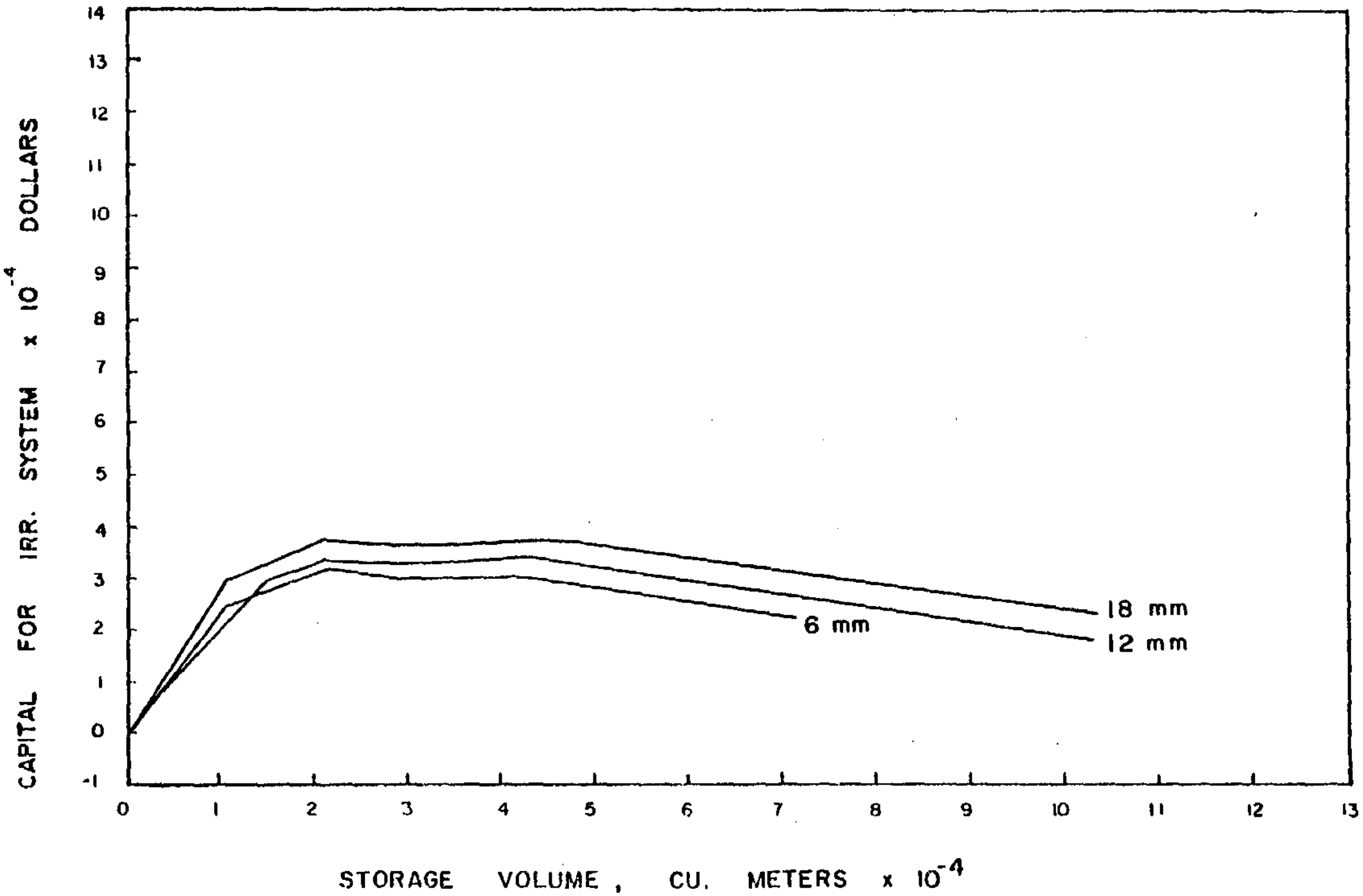

Figure 4-8. Sensitivity of CAIS to U, the amount of water which must evaporate before the soil no longer acts as a free water surface.

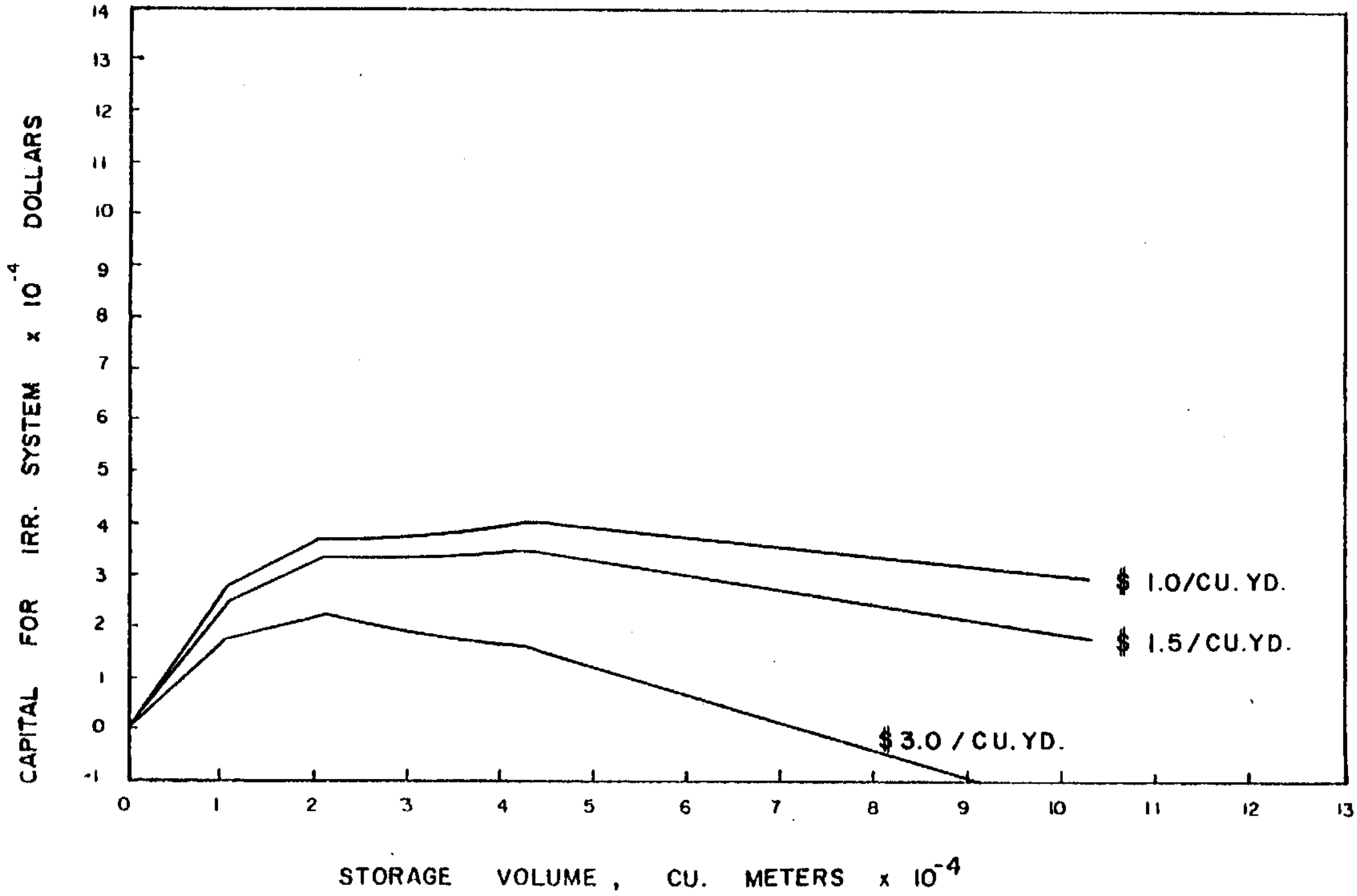

Figure 4-9. Sensitivity of CAIS to the fill price for constructing the dam.

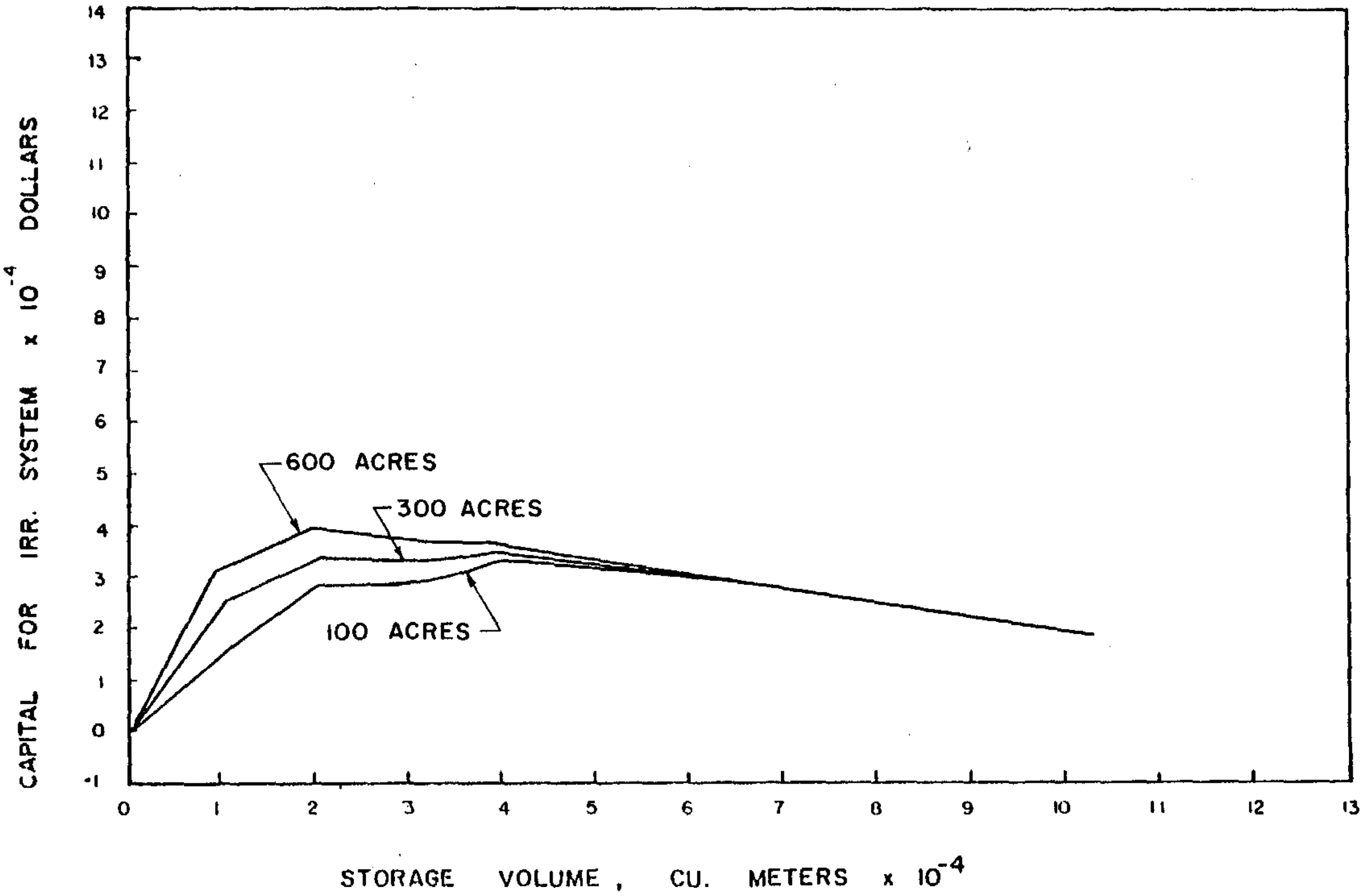

Figure 4-10. Sensitivity of CAIS to area generating runoff (AREARO).

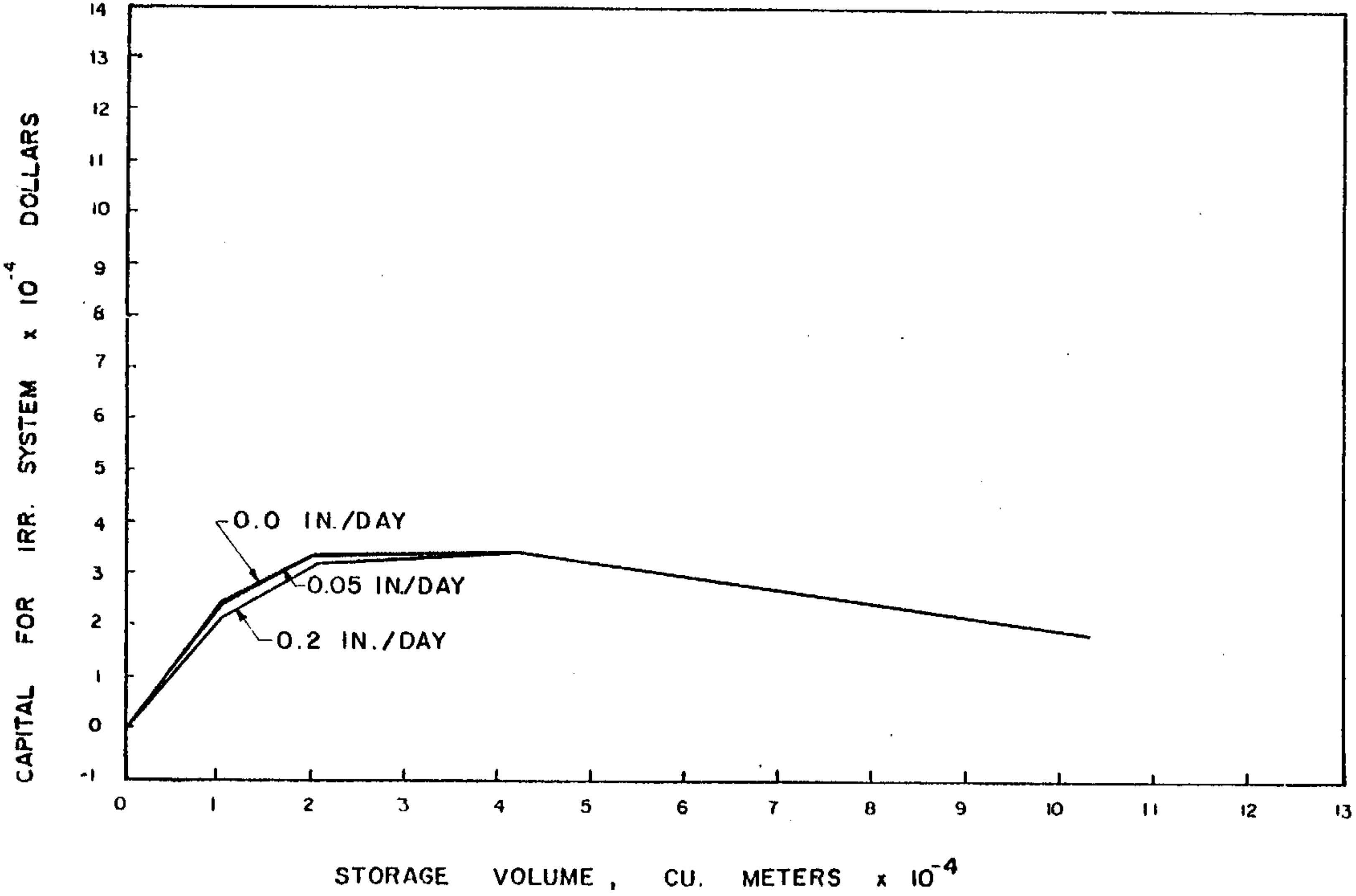

Figure 4-11. Sensitivity of CAIS to deep seepage through the reservoir.

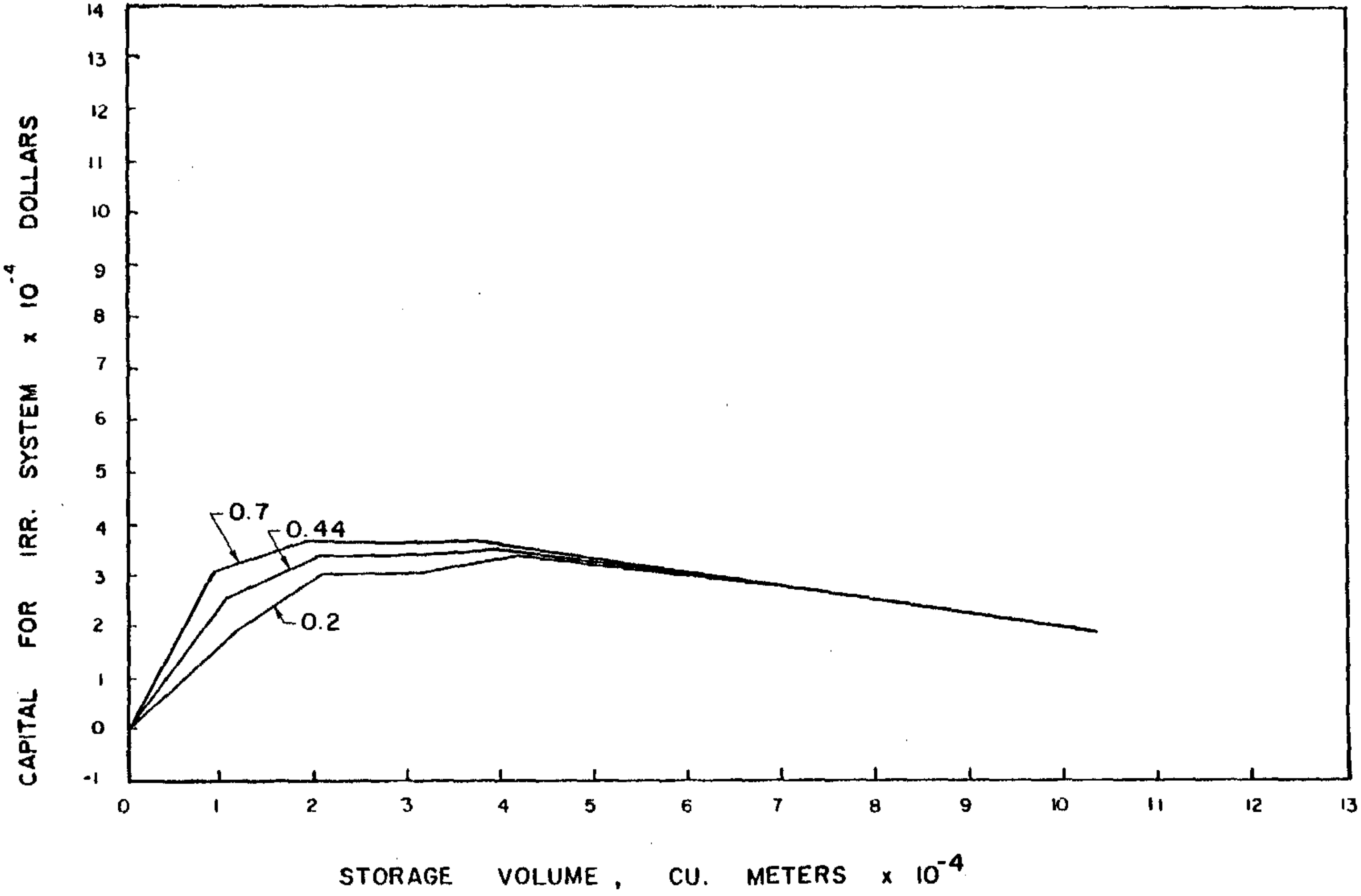

Figure 4-12. Sensitivity of CAIS to the fraction of deep seepage that becomes runoff (VAR4) in Haan's model.

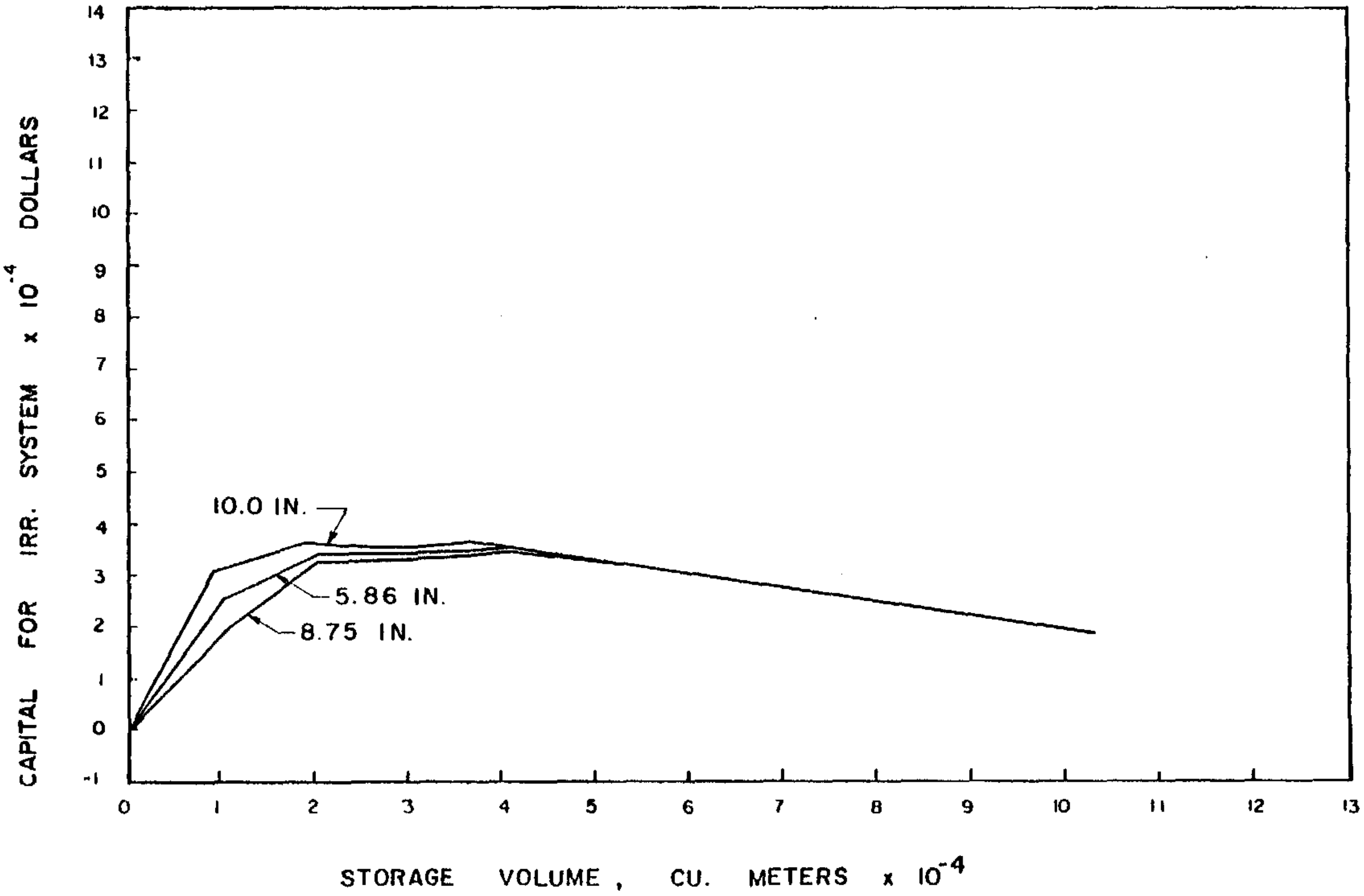

Figure 4-13. Sensitivity of CAIS to maximum soil water holding capacity less readily available for evapotranspiration (VAR3) in Haan's model.

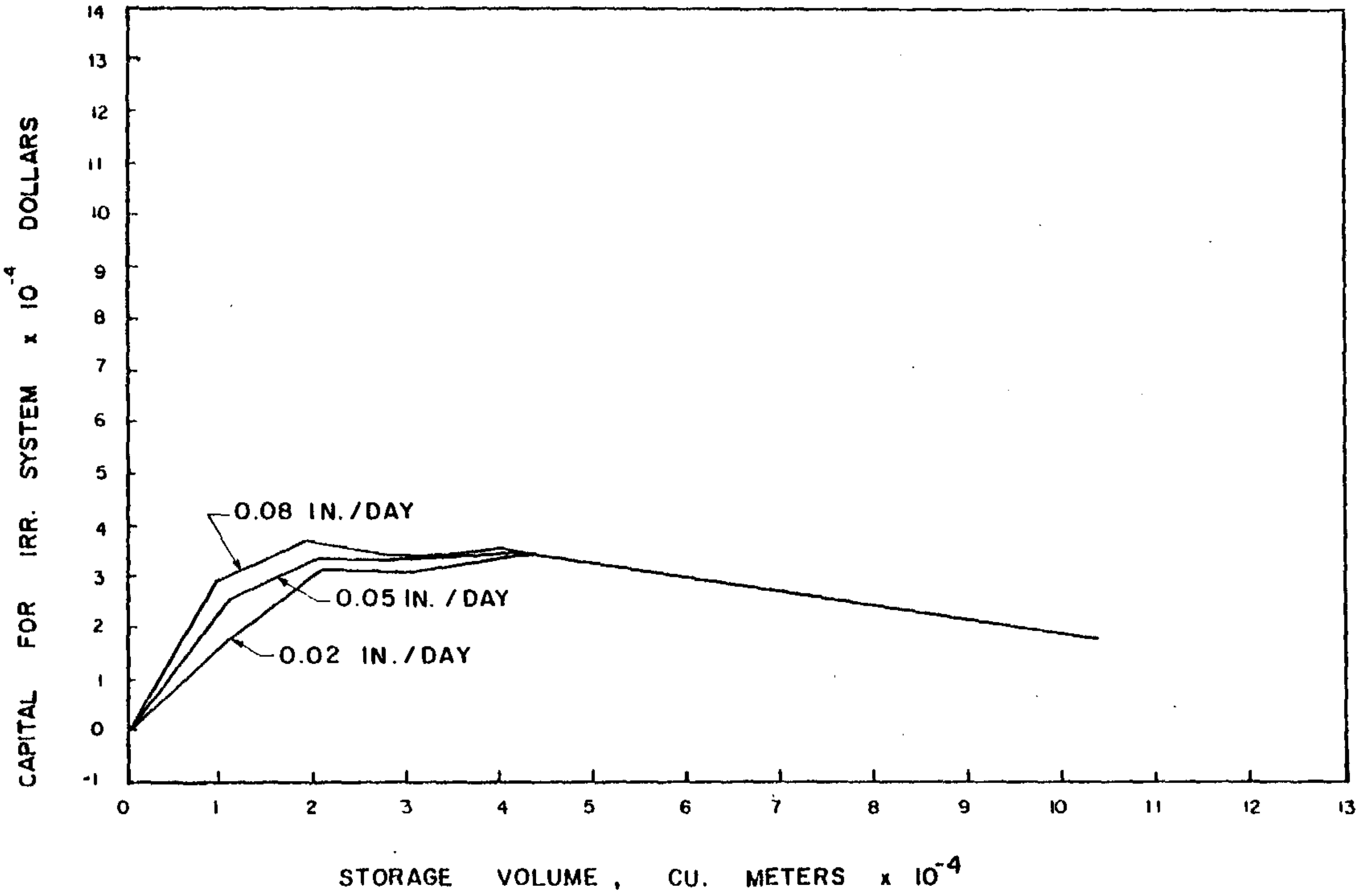

Figure 4-14. Sensitivity of CAIS to infiltration which becomes deep seepage (VAR2) in Haan's model.

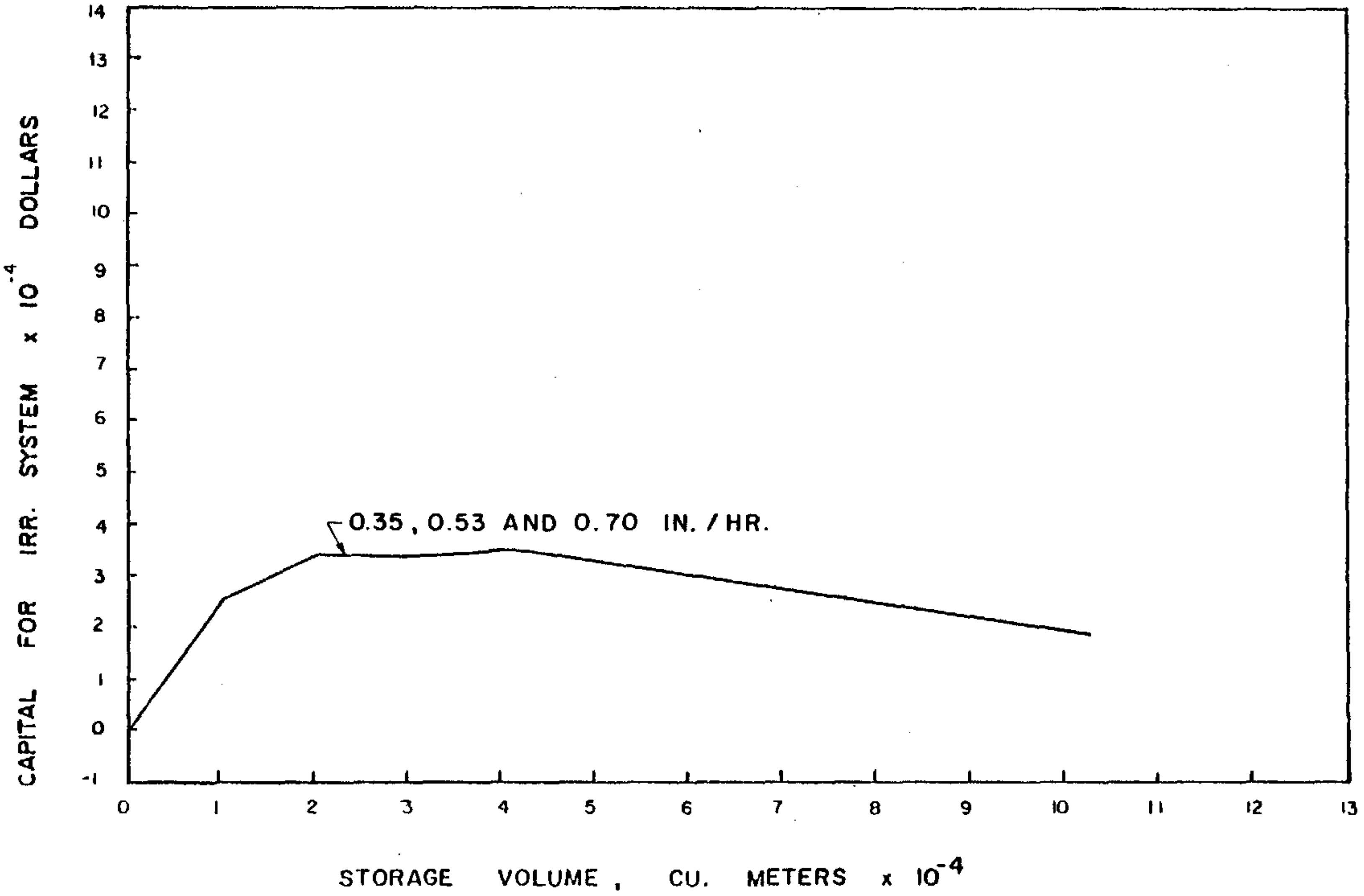

Figure 4-15. Sensitivity of CAIS to maximum infiltration (VAR1) in Haan's model.

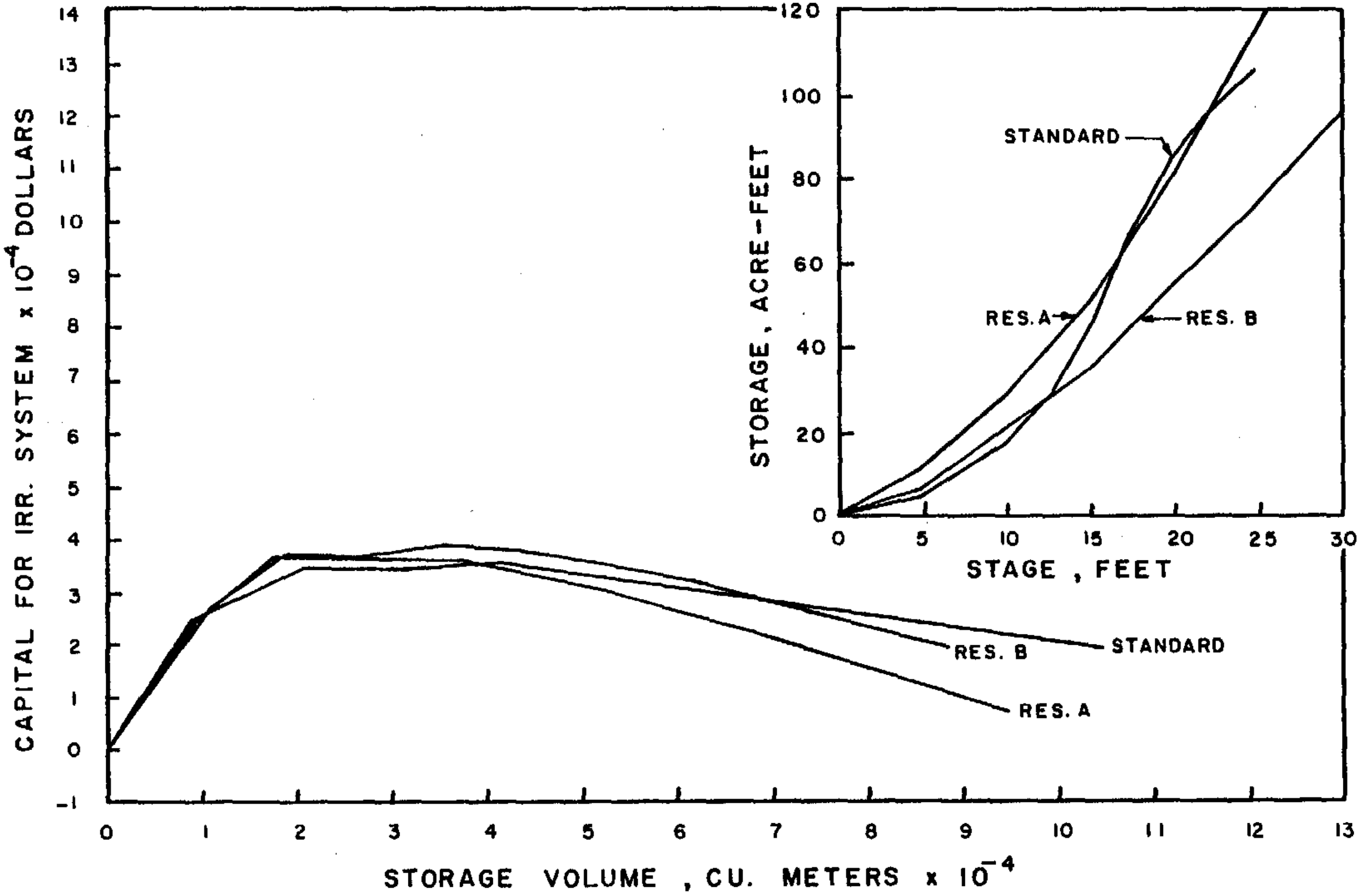

Figure 4-16, Sensitivity of CAIS to reservoir shape.

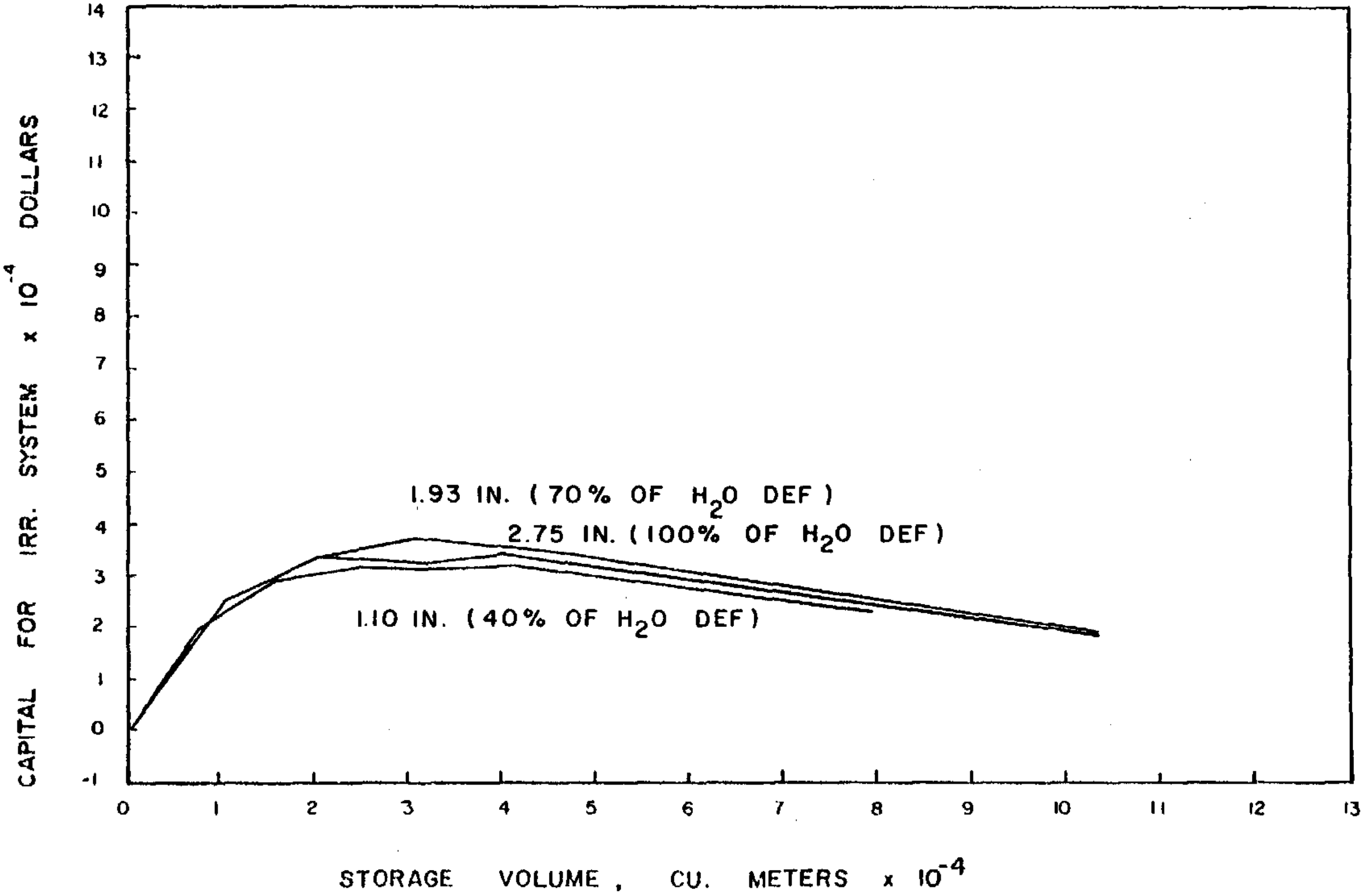

Figure 4-17. Sensitivity of CAIS to amount of H2ODEF which is replenished by irrigation (H2OIRR).

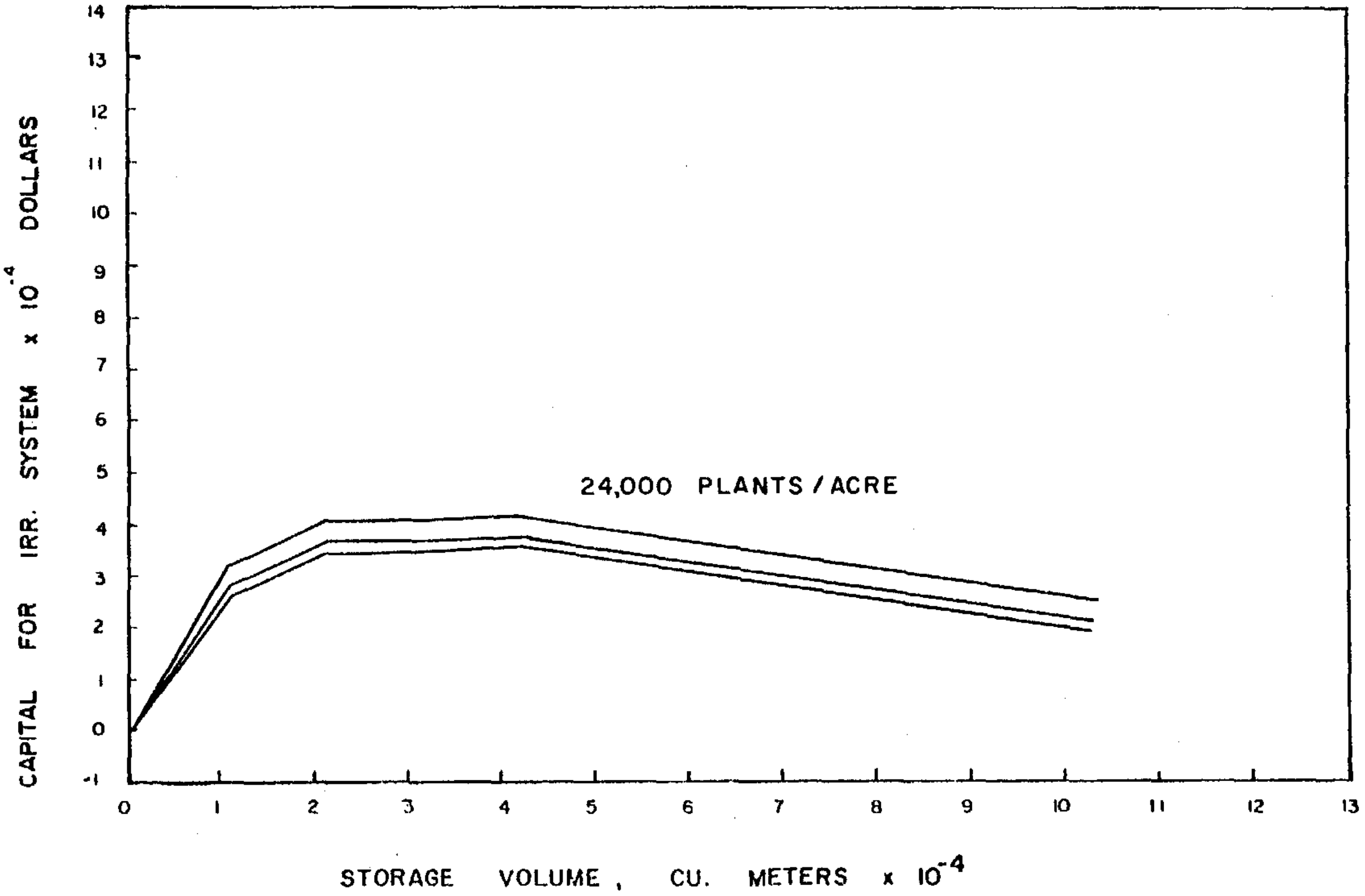

Figure 4-18. Sensitivity of CAIS to plant population for non-irrigated case (POPNOI).

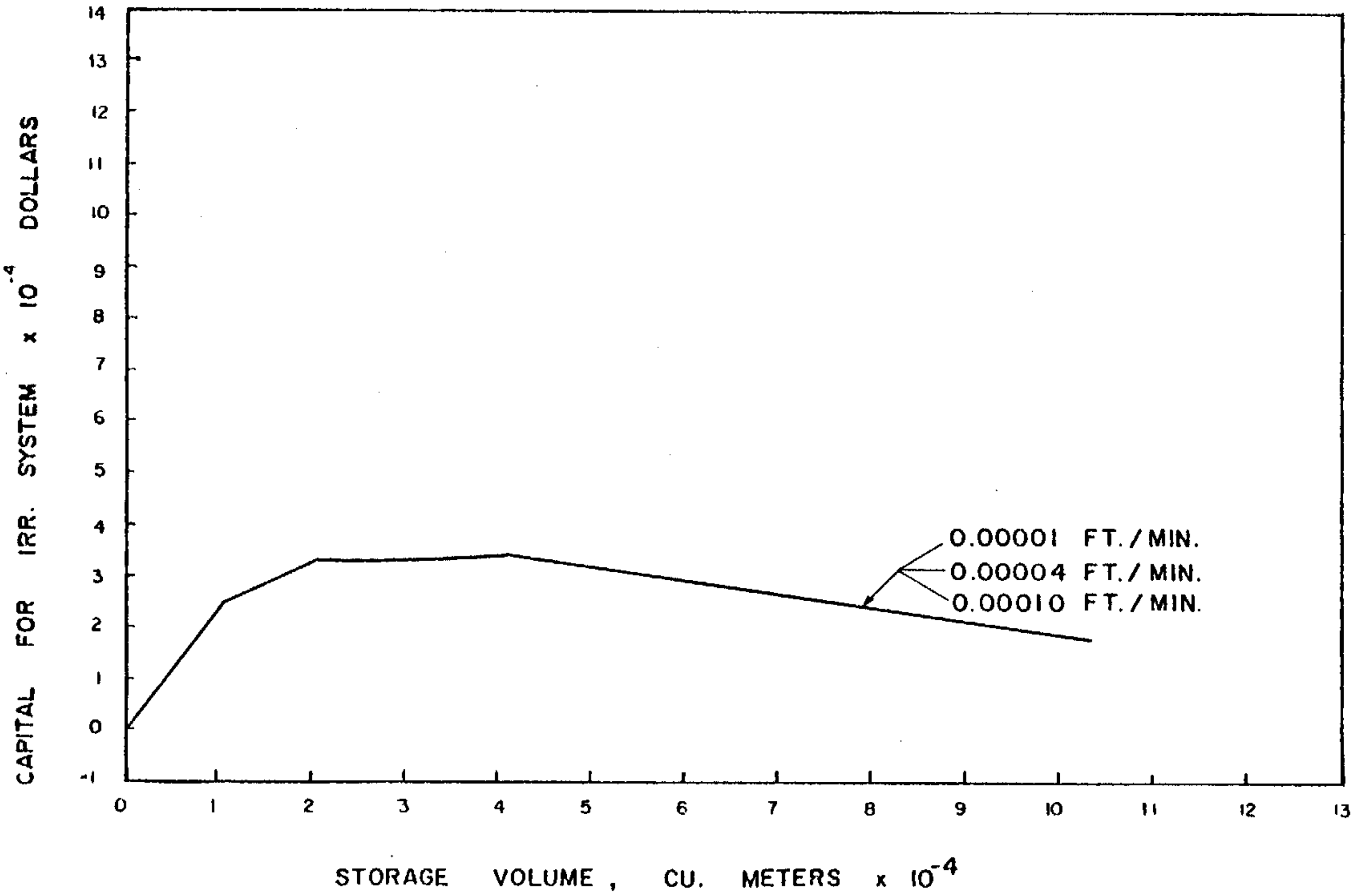

Figure 4-19. Sensitivity of CAIS to the hydraulic conductivity of the material comprising least permeable sections of the dam.

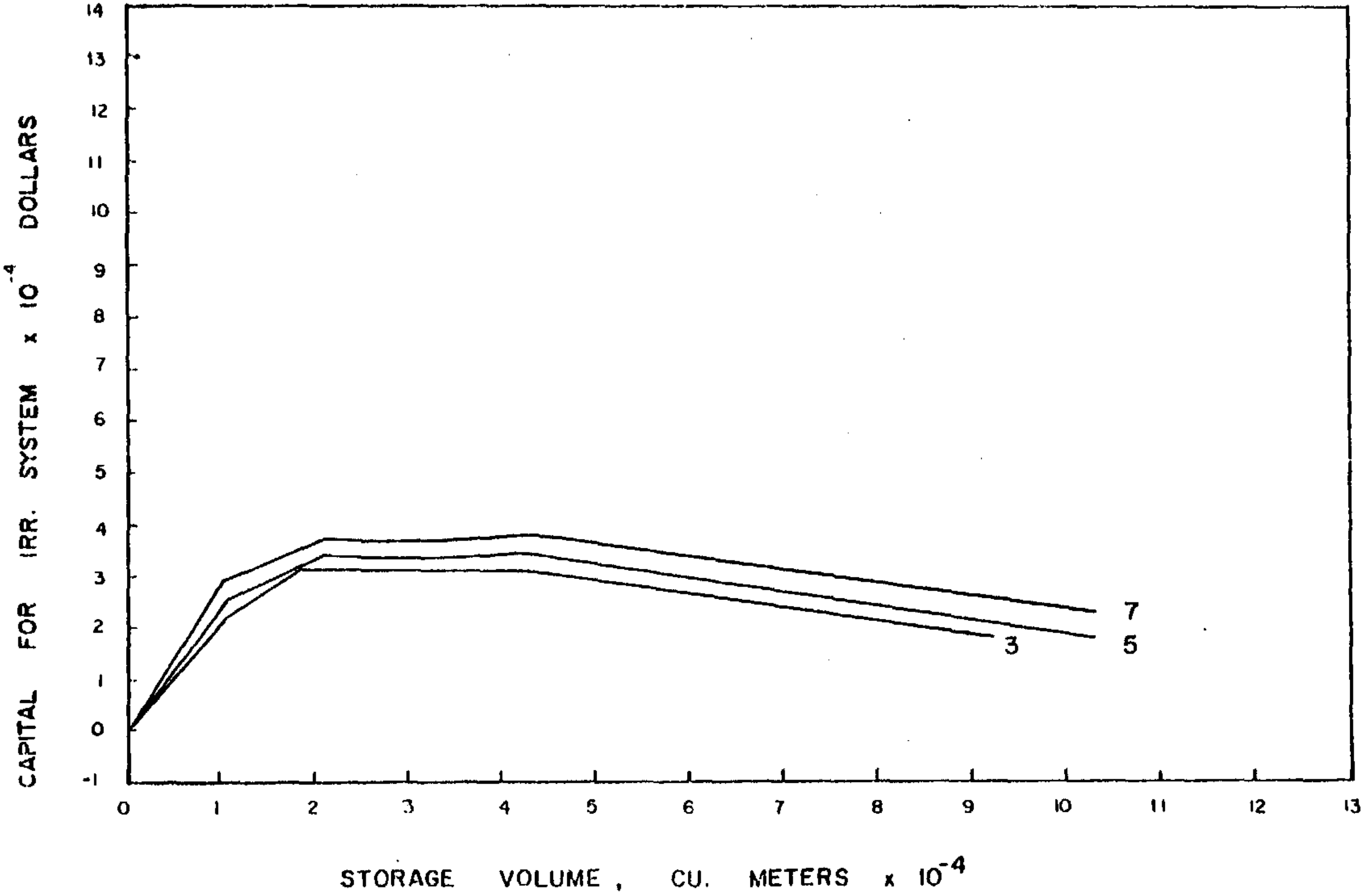

Figure 4-20. Sensitivity of CAIS to ALPHA, a constant used in Stage 2 soil drying.

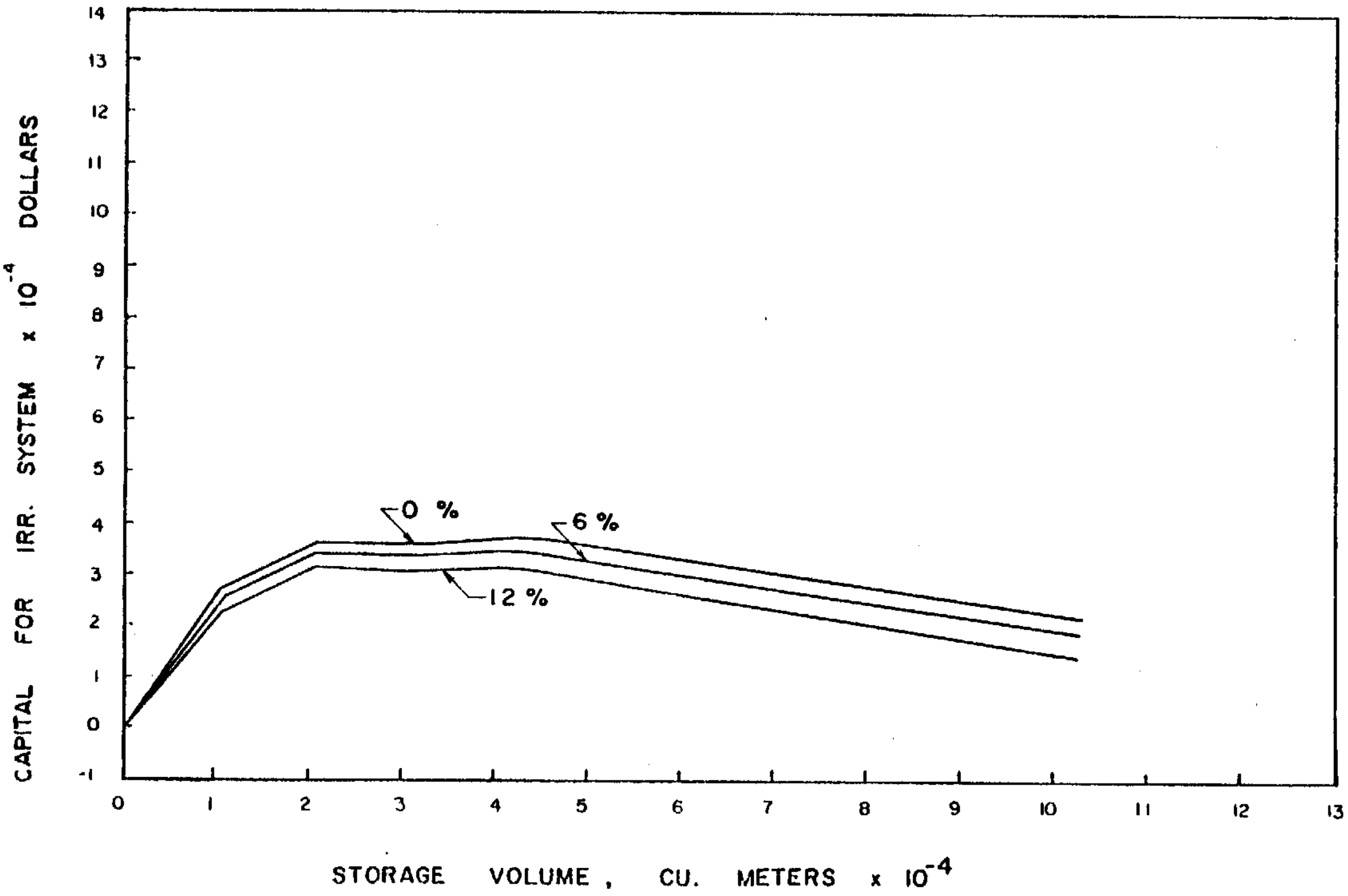

Figure 4-21. Sensitivity of CAIS to inflation rate of other irrigation costs (FCOST).

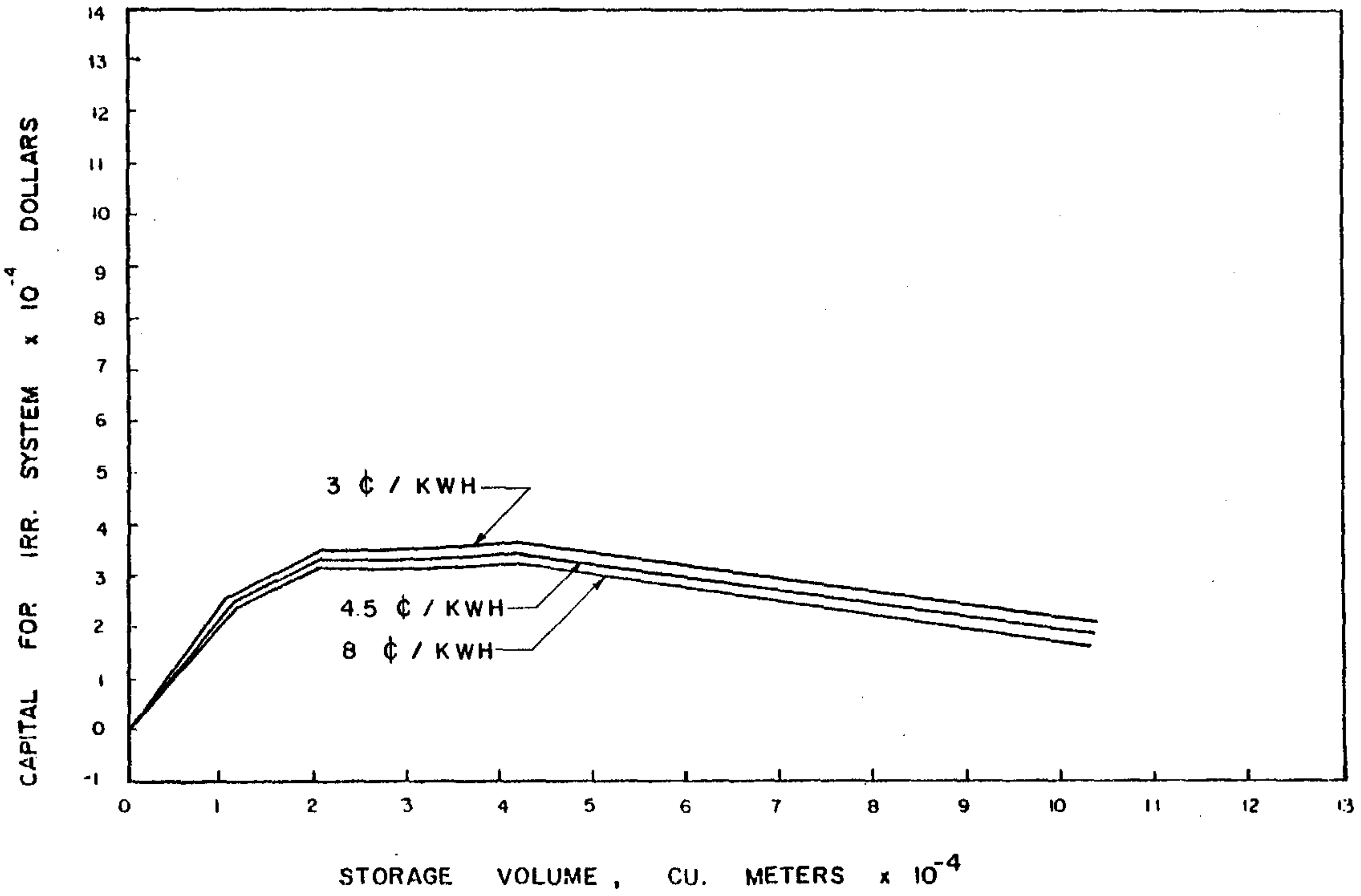

Figure 4-22. Sensitivity of CAIS to pumping energy costs (CKWH).

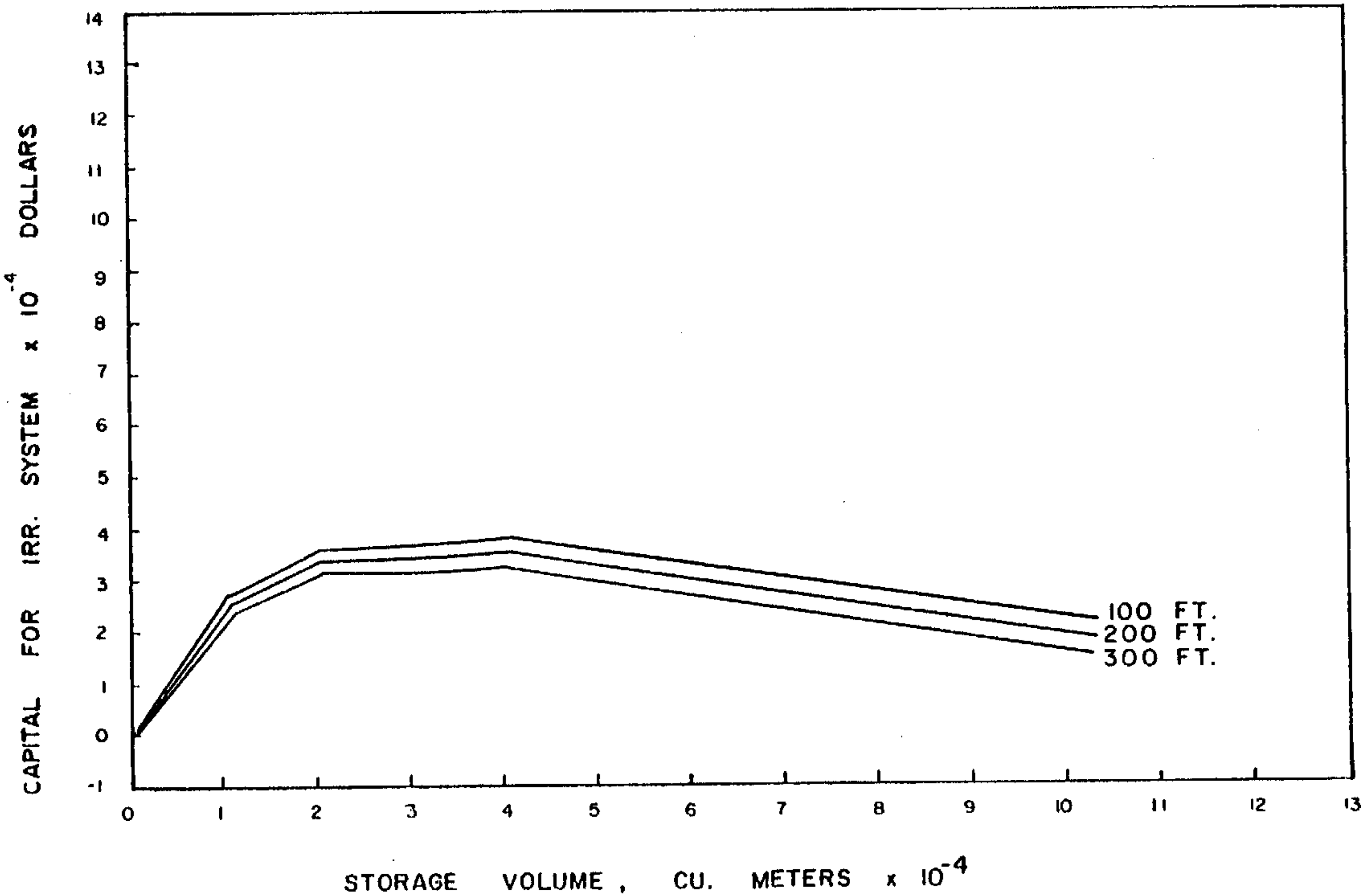

Figure 4-23. Sensitivity of CAIS to total dynamic pumping head.

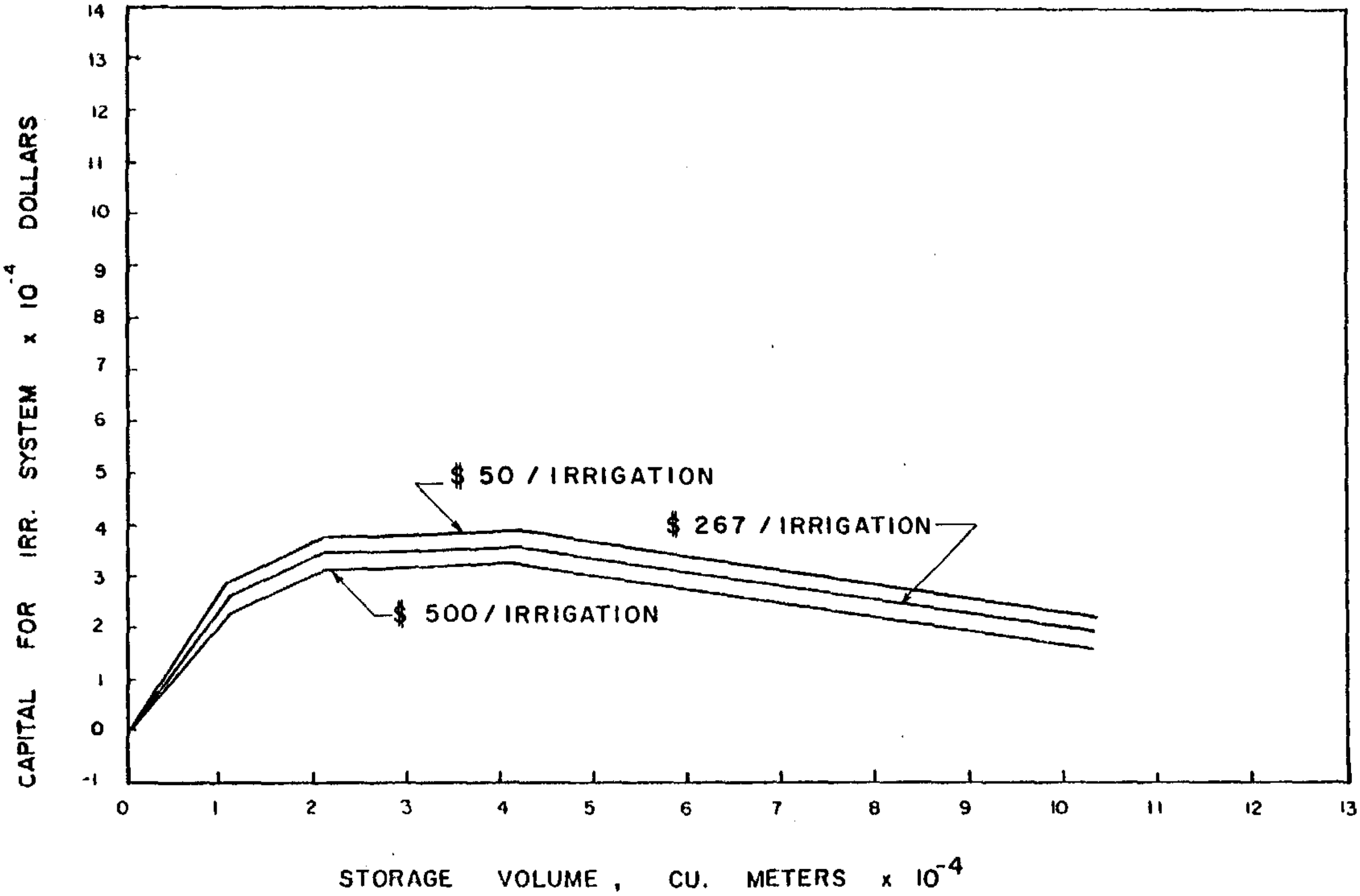

Figure 4-24. Sensitivity of CAIS to labor costs per irrigation (ALABOR).

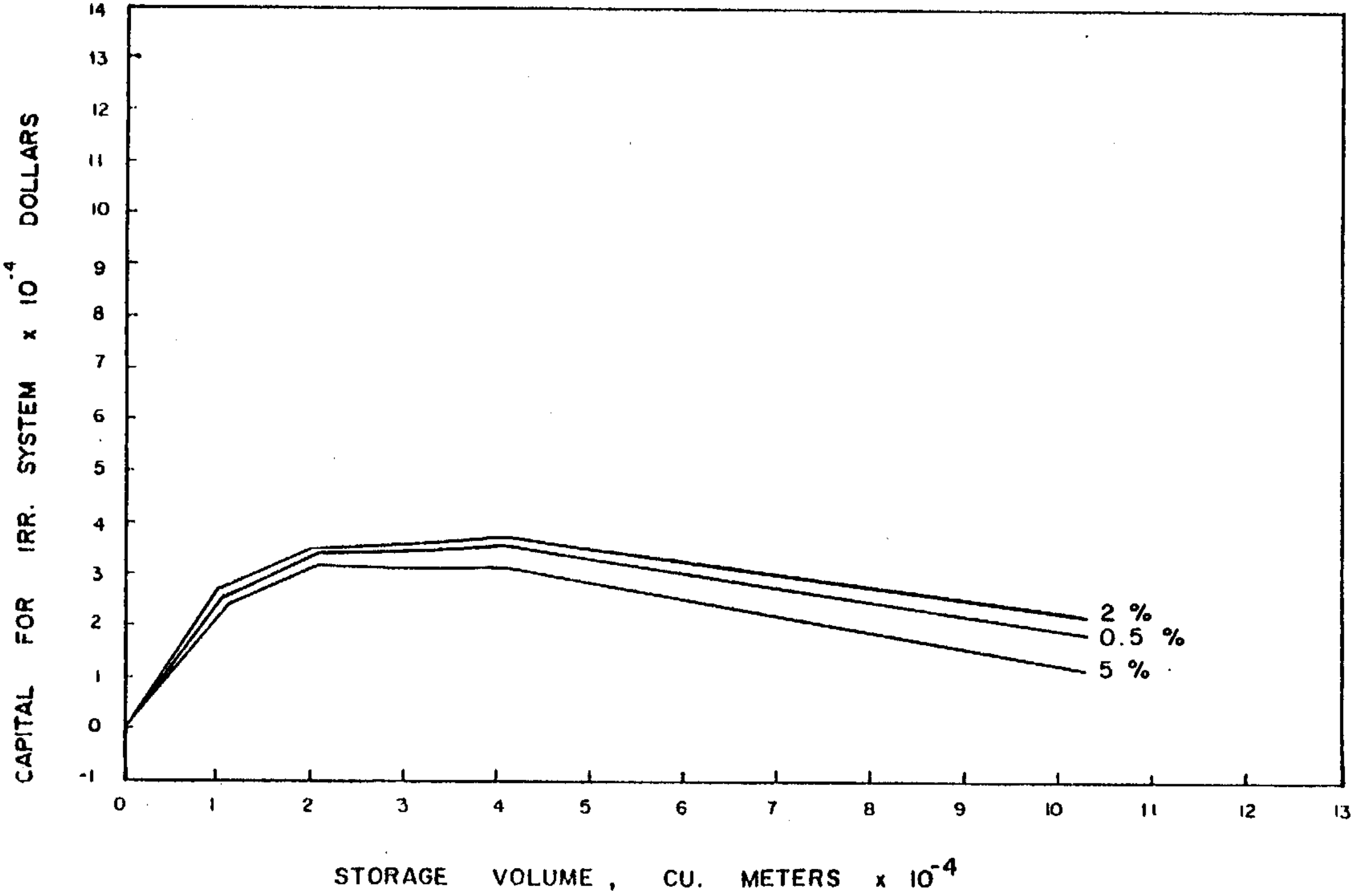

Figure 4-25. Sensitivity of CAIS to annual reservoir maintenance cost as a percentage of construction cost (PERMC).

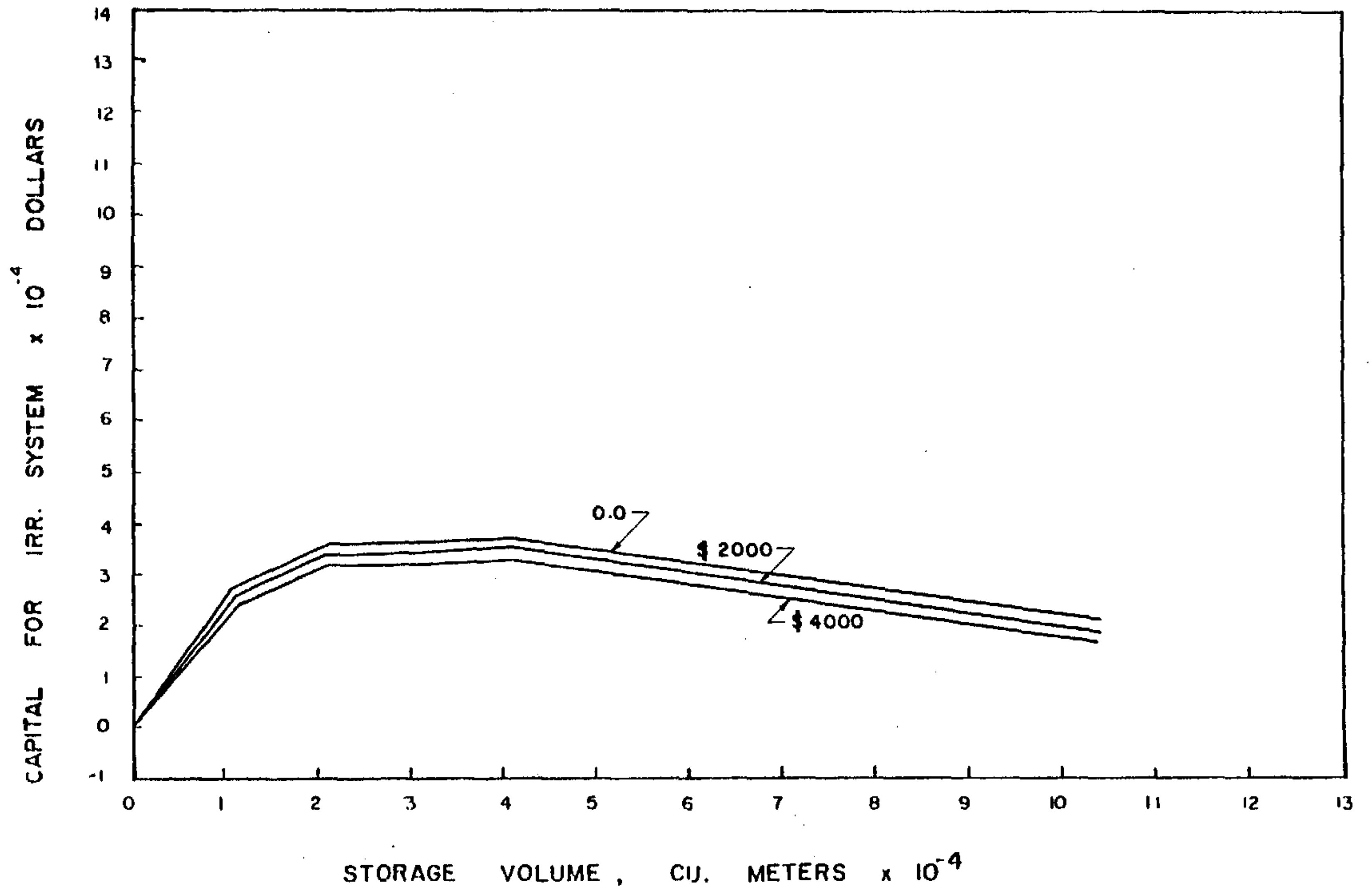

Figure 4-26. Sensitivity of CAIS to other reservoir costs (EXTDPR).

CHAPTER V

RECOMMENDED PROCEDURES FOR MODEL USAGE

The model presented in this report can be used as a tool for examining different irrigation alternatives for corn and assist the farmer in the investment decision. The farmer who is considering investing in an irrigation system, or who wants to consider different irrigation management systems, could describe the farm, the variety of corn used, and the water supply; and use the model to examine the expected economic results from irrigating. By varying the data set, different irrigation strategies and financial situations can be simulated.

It was shown in the sensitivity analysis that some variables are much more important than others under Kentucky conditions. Table 4-3 shows the distribution of the variable sensitivity. The variables, which were very sensitive, should be determined much more carefully and as accurately as possible. If this is not possible, then a range of values should be used before a final decision of whether or not to invest is made.

In the sensitivity analysis, only the average curves were considered. Although these curves do help in determining the amount of capital available for investment in an irrigation system, they do not indicate the level of risk involved in the investment. Curves should be generated which illustrate the level of risk associated with the investment in irrigation. In Chapter III curves were generated which show the probability of making enough money in any one year to make the payment on the irrigation system (Figure 3-4) and the probability of breaking even on the irrigation investment over the life of the irrigation system (Figure 3-5). These curves should be generated for each alternative which is simulated. Before the simulations are made, the farmer must decide which management considerations and economic conditions to evaluate. One point which must be kept in mind is the cost of running the simulation model. At the present time, it costs approximately $25.00 to make one simulation. It is also important to know what type of irrigation systems are practical for the type of land and available labor. The type of system will influence the labor expense, the number of acres that can be irrigated, amount of water applied during one irrigation, and the total dynamic head of the system. When using IRRICON, the following steps should be taken:

(1) Determine what type of water supply will be used; either pumping from a well or storage reservoir. If pumping from a well, the water yielding capacity and depth must be known so the total number and cost of wells can be determined along with the additional head used for calculating pumping costs. If a reservoir is needed, then the volume of water flowing into the reservoir must be known. Haan's water yield model is used in IRRICON to calculate volume of flow. Ideally, a couple of years of gaged runoff will be available, so the variables to Haan's model can be optimized as described in Chapter III. Or, if no gaged streamflow is available, the variables can be calculated from measurable watershed characteristics as described in Chapter III. In the sensitivity analysis, the variables to Haan's model were only partially sensitive to economic out-

put when varied; therefore, only a reasonable estimate is necessary.[1/]

(2) Once a water supply has been decided upon, a description of the site is needed. Assuming a reservoir is to be constructed, a topographic survey is needed for the site to determine the pond area and the centerline width of the embankment for incremental elevations (MIS). Additional site descriptions would be: watershed area contributing to the runoff, AREARO (PS); acres to be irrigated, AREAIR (VS); plant available water to the rooting depth in the field to be irrigated (VS); and Ritchie's (1972) parameters ALPHA and U (MIS and VS). ALPHA and U can be determined for the soil in the field by conducting a soil drying test as indicated in Chapter III, and as described in Ritchie (1972).

(3) Information on the proposed dam must be gathered. The vertical distance from riser to the top of the dam, ZZ (IS), in feet; the angle formed by downstream and upstream faces of the dam and the ground surface, ANG (IS); the hydraulic conductivity of the material comprising the least permeable section of the dam, CK (IS), ft/min.; and the top width of the dam, W (IS), ft. Default values are assumed in the model when zeros are used.

1/ In further discussion of input parameters, the terms are labeled as very sensitive (VS), moderately sensitive (MOS), mildly sensitive (MIS), partially sensitive (PS), and insensitive (IS), depending on sensitivity of the economic output to parameter variation. Careful consideration should be given to the VS and MOS parameters, reasonably correct estimates are sufficient for MIS and PS parameters, and rough estimates are sufficient for IS parameters.

The default values are: ZZ = 5 ft, ANG = 3, CK = .00004 ft/min., and W = 12 ft.

(4) Additional terms which should be defined for dam construction are DAMCST and FILLPR. DAMCST (MIS) allows for additional expenses for special outflow structures or sealing problems. FILLPR (MOS) is the fill price used to determine the cost of constructing the reservoir based on the volume of soil in cubic yards needed in constructing the reservoir. The value used for calculating deep seepage through the reservoir, QDSEP (PS), must also be defined, depending upon the material comprising the reservoir site.

(5) Once the physical characteristics of the site are defined, the values for the corn model must be defined. Ideally, a few years of recorded yields are available so that the model can be calibrated to the site in question. If this is not possible, reasonable values should be assigned. In Appendix A, after the definition of each term, values recommended by Duncan are given, and at the end of the definition, the values used in calibrating the model to Lexington, Kentucky; Logan, Utah; and Davis, California are given. This should assist the user in assigning values.

(6) The next step is to define the type of irrigation system, management strategy, and economic considerations. The terms directly affecting the irrigation system are: total dynamic head from the reservoir to the sprinkler head, TDH (MIS); efficiency of the pump, EFFP (MIS); and efficiency of the motor, EFFM.
The terms directly affecting the management strategy are: amount

of plant available water in the soil profile, H2OPRO (VS); the water deficit below field capacity which signals irrigation, H2ODEF (MOS); amount of water in inches to be added at each irrigation, H2OIRR (MIS); lower limit for irrigation application amount, H2OLIM (MIS); and term used to signal saving a volume of water in the reservoir until pollination begins, IRPLAN. The terms affecting economic considerations are: interest rate on capital, XINT (MOS); inflation rate for labor, FLAB (MIS); inflation rate for pumping cost, FPUM (MIS); inflation rate for maintenance, FMAN (MIS); inflation rate for grain price, FGRAN (MOS); the anticipated price for grain, GRPR (VS); labor expense for setting up and running the irrigation system, ALABOR (MIS); a factor to determine reservoir maintenance cost, PERMC (MIS); and the expected life of the system for economic calculations, LIFE (MOS). Since it is impossible to forecast inflation rates and interest rates, it is desirable to make simulations using several rates and make a decision based on a comparison of the results.

(7) The final set of inputs which must be considered is the climatic variables. For Lexington, Kentucky, a weather tape has been generated which has 25 years of daily maximum and minimum temperatures, precipitation, and cloud cover. A solar radiation term is needed which is calculated using cloud cover as explained in Chapter III. If a climatic data set must be generated, be sure the above climatic values are defined.

Once all the data has been accumulated, the simulations can be run.

An example of how the different alternatives can be examined is given. In this case, variations considered are the amount of water depleted from the soil profile when irrigation is signaled. Values of 1.1 in. and 3.85 in. are used. For each case, two sets of curves are generated, as explained in the economic section in Chapter III.

In Figures 5-1 and 5-2, a value of 1.1 was used for H2ODEF, and in Figures 5-3 and 5-4, a value of 3.85 was used for H2ODEF. Initially, it can be seen that a smaller maximum reservoir size was determined for the 3.85 in. soil water depletion. Irrigation would not be as frequent and the reservoir would have more time to fill up in between irrigations. For each case, the maximum CAIS value (capital available for investment in irrigation system) occurred for about a 30,000 cu meter reservoir. For a 30,000 cu meter reservoir, the CAIS values are higher for both the annual value curves and the average over the life of the system. Based on these curves, it could be recommended that a 30,000 cu meter reservoir be constructed and irrigation should be initiated when 3.85 inches of plant available water has been depleted.

These curves can be generated for a variety of conditions, enabling the user to visually compare the results from different simulations. It must be remembered that this model should be used as a tool and that good management judgement must be made before any final decision is made.

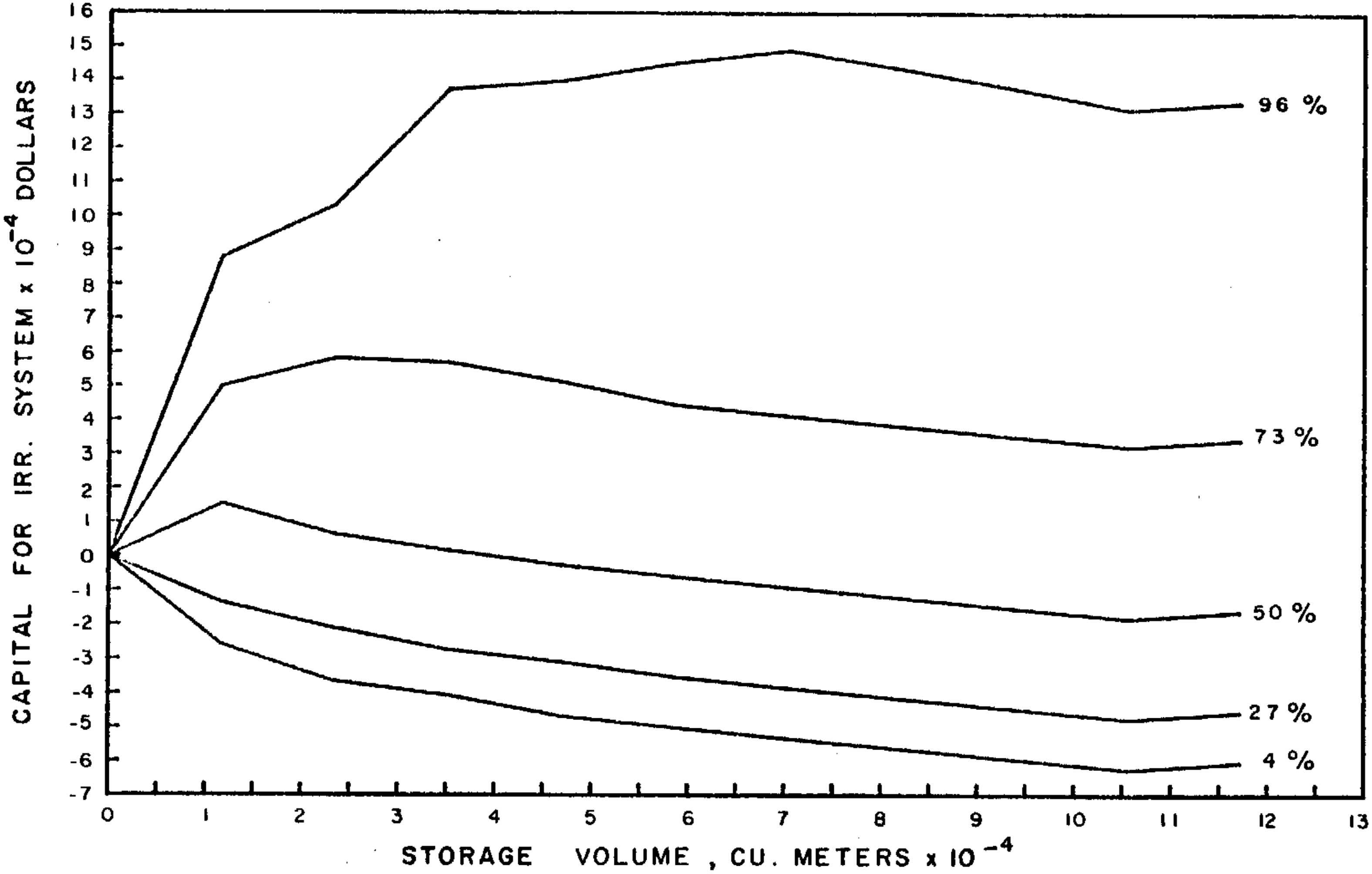

Figure 5-1, Capital available for investment as a function of reservoir size for various probability levels for 1.1 in. plant available water depletion, based on annual values.

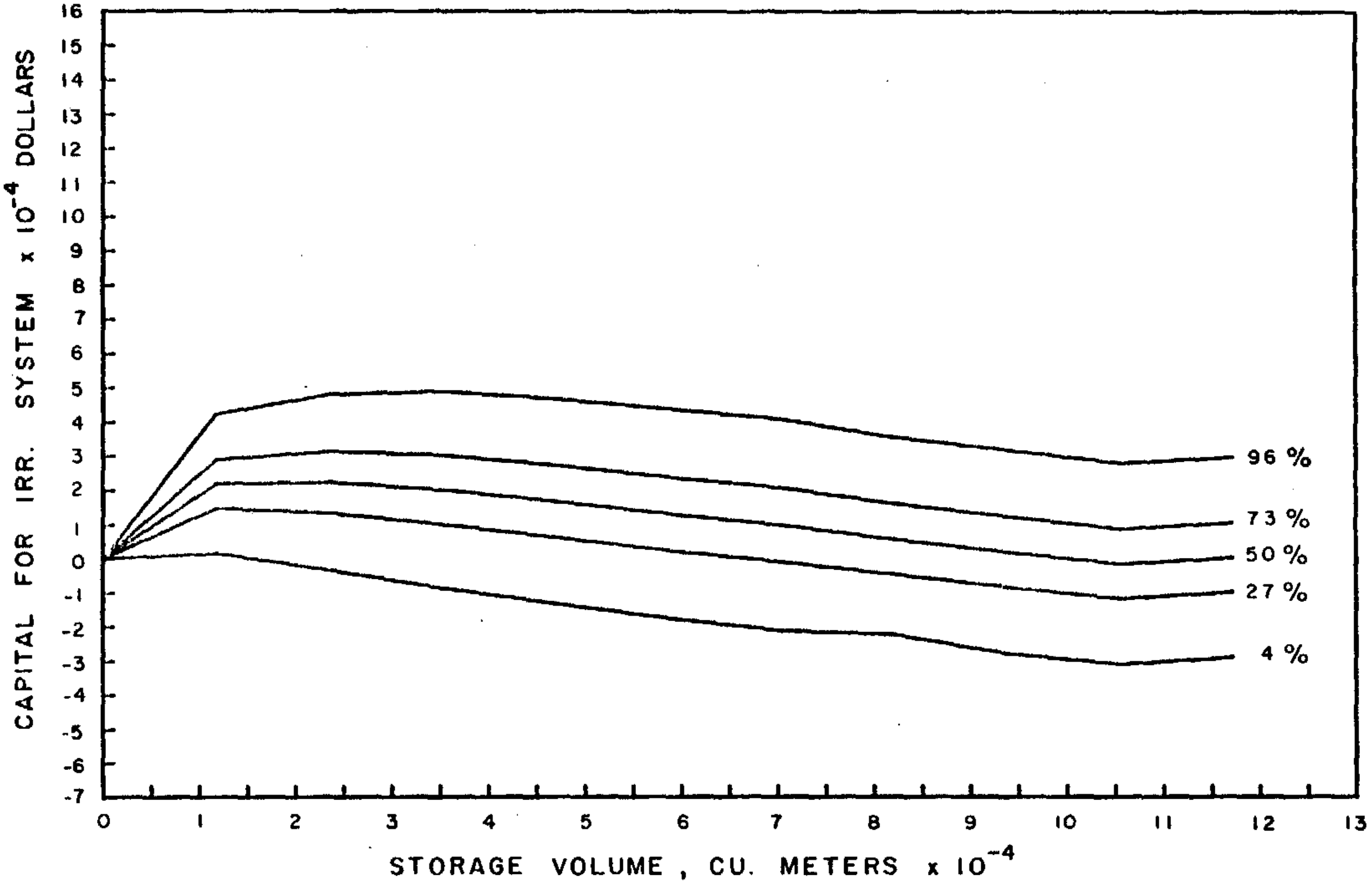

Figure 5-2. Capital available for investment as a function of reservoir size for various probability levels for 1.1 in. plant available water depletion, based on averages over life of system (10 years in this case).

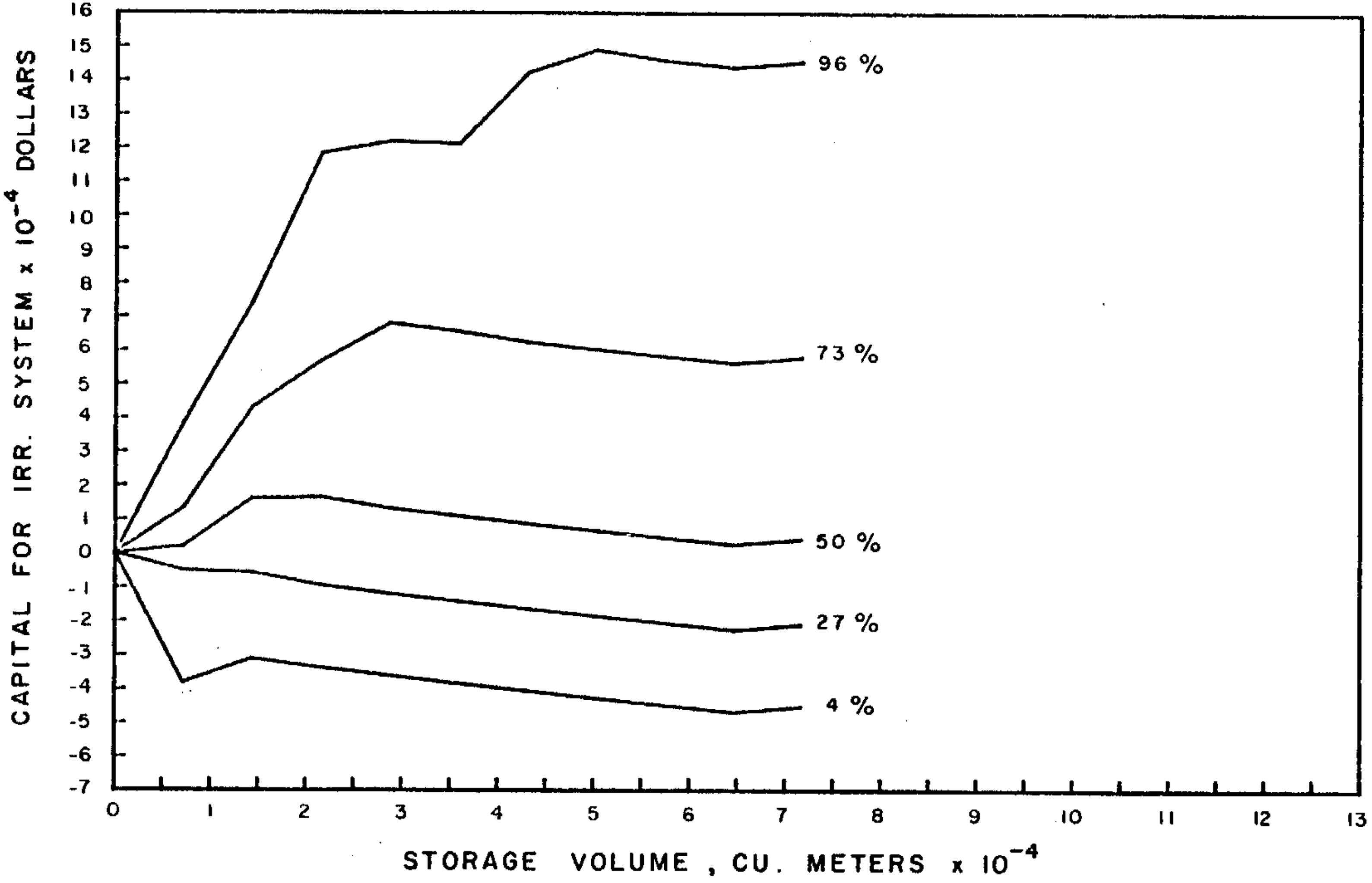

Figure 5-3. Capital available for investment as a function of reservoir size for various probability levels for 3.85 in. plant available water depletion, based on annual values.

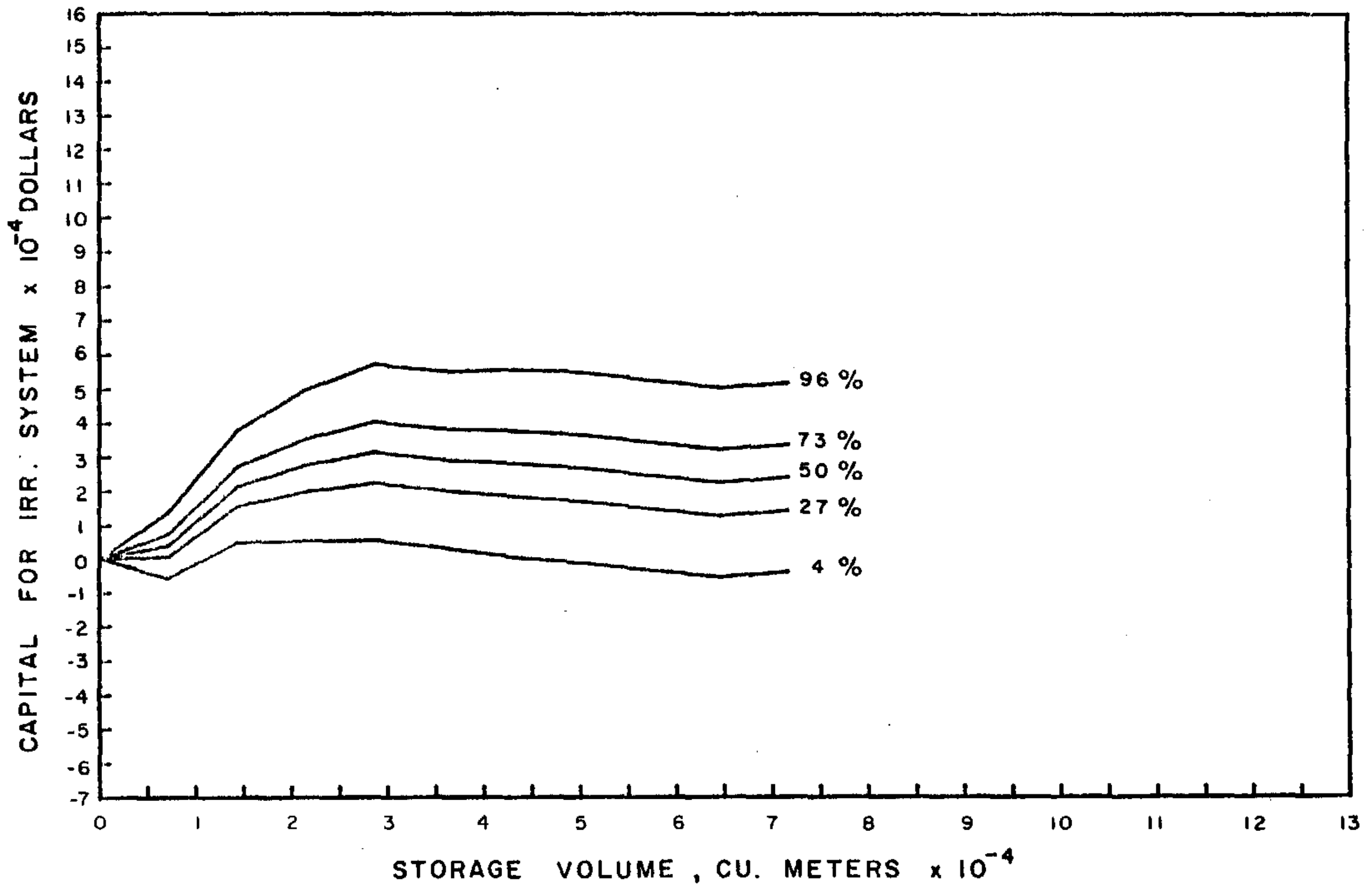

Figure 5-4. Capital available for investment as a function of reservoir size for various probability levels for 3.85 in. plant available water depletion, based on averages over life of system (10 years in this case).

SUMMARY AND CONCLUSIONS

A simulation model, IRECONS, has been presented which uses the Duncan SIMAIZ Model to simulate evapotranspiration and corn yields, and the Haan Water Yield Model to simulate water flow into a storage reservoir. These models are linked with a reservoir water balance routine and a present worth analysis to simulate the economics of irrigating corn for a variety of reservoir sizes. All procedures are described. A sensitivity analysis is presented on select inputs and a recommended procedure for model usage is defined.

The sensitivity analysis indicated that some inputs were more sensitive than others. The more sensitive inputs for both the well and reservoir economics were: the area irrigated (acres), the price of grain ($/bushel), the amount of water applied during one irrigation (in.), the inflation rate for grain price, the economic life of the system, the interest rate on capital, the amount of water which must be depleted before irrigation begins, and the amount of water which must evaporate from the soil surface before the soil ceases to act as a free water surface. Great care should be observed when defining these inputs.

The remaining inputs analyzed in the sensitivity analysis only mildly or partially affect the economic output. These inputs are summarized in Table 4-3. The definitions are found in Table 4-2. Because the economic output was only mildly or partially sensitive to variation in the later parameter values, a good approximation of the value is sufficient.

IRECONS can serve as a valuable tool for the farmer trying to make a decision of whether or not to invest in an irrigation system, or for the farmer wanting to examine different management strategies for an existing irrigation system. With appropriate field reconnaissance and calculations, input data forIRRECONS can be characterized. This capability is important, particularly when the economics of irrigation is questionable. IRECONS allows its user to examine the effects of different economic and management options on the economics of irrigating corn.

The major calculations in IRECONS are carried out in subroutine form. This allows for easier updating when more reliable methods of calculation are developed through further research. Research regarding evapotranspiration and soil moisture effects on plant growth is one area where the development of more reliable methods of calculation would improve IRECONS' reliability.

At the present time, IRECONS simulates only corn growth. An improvement would be to incorporate growth models for other crops. Another improvement would be to consider the length of time required to complete one irrigation, and instead of depleting the water needed for irrigation from the reservoir in one day, distribute the rate of water usage over the time period needed for irrigation.

APPENDIX A

DEFINITIONS AND TYPICAL VALUES

KPCORN - the number of daily plant descriptions in the three tables that will follow. (Three per card) (255)

XPCORN - contains daily descriptions of the weights of different parts of a corn plant for three maturity classes. Values found at end of Appendix B.

PTABLE - a photosynthesis table relating radiation, LAI, and daily photosynthesis per plant. Values found at end of Appendix B.

EVAPK - a curve relating soil moisture deficit and evapotranspiration. Value found at end of Appendix B.

XSTRES - a curve relating soil moisture deficit and plant stress. Values found at end of Appendix B.

VAR1 - maximum infiltration (.53)

VAR2 - maximum possible seepage rate (.0496)

VAR3 - maximum capacity which is less readily available for evapotranspiration (5.858)

VAR4 - constant defining the fraction of seepage that becomes runoff (.44)

RMU - volume of water in soil which is readily available for evapotranspiration (1.5)

RML - volume of water in soil which is less readily available for evapotranspiration (.5)

EVAPFC - factor relating pan evaporation to evapotranspiration. Example (.75)

DRYFAC - arbitrary daily fraction of grain moisture lost per day. Example (.50)

RESUSF - maximum part of reserves which can be mobilized in a day. Example (.10)

RESPFC - growth-related respiration rate. (RB, active respiration) Example (.30)

BMETFC - mass related respiration. (RO, basal metabolism) Example (.001)

SLKINF - physiological days required for ear-shoot development under favorable conditions. Example (9)

KERFIX - days after pollination kernels are considered latent. Example (7)

PRESAD - rate reserves are built up in competition with other growth. Example (.1)

DAYDEG - average number of degree days per day. (22)

SETMIN - base or minimum temperature for degree day calculations. Example (50)

TMPOPT - maximum temperature for degree day calculations. Example (86)

HARVST - moisture percentage at which corn is to be harvested. Example (20)

GRNSLO - days from slow-down in rate of grain growth to black-layer. Example (5)

XLEFGI - factor for arbitrarily changing leaf-stalk ratio. Example (1.3)

FMULCH - factor modifying surface evaporation. (Used to simulate no-till) Example (.1 to 1.0)

VTRTEX - exponent for modifying calculated effect of stress during vegetative growth. (Affects kernel numbers) Example (1)

H2OPRO - inches of water in profile at first climatic information. Example (5.5)

STLAEX - exponent for modifying calculated effect of stresses on rate of leaf area development. Example (1)

TLEFFC - exponent for modifying calculated effect of temperature on the rate of leaf photosynthesis. Example (.10)

RUNAVG - days in moving average for various calculations. Example (12)

PRSMXF - factor relating maximum reserves permitted to plant weight. Example (1.5)

H2OCAP - available water held in soil in rooting depth, in inches. Example (5.5)

PNWLFX - fraction of leaf area assumed to be actively growing and hence unable to export all of its photosynthate. Example (.1)

XERH2O - kernel moisture present at black layer maturity. Example (30)

STYLEF - leaf area difference in dM^2 between maturity groups. Example (20)

OILFAC - factor for reducing grain weight to account for oil content. Example (.95)

XSKREX - exponent for adjusting calculated factor for kernel number reduction by silk-period stresses. Example (1)

BARREN - average daily rate of photosynthesis per plant below which barrenness begins. Example (2.8)

U - amount of water that must evaporate from bare soil before it ceases to act as a free water surface. Example (12)

ALPHA - soil water conductivity. Example (5)

Varietal characteristics
with STYLE = 1 (early maturity) CLASSM can be + or -2
with STYLE = 2 (standard maturity) CLASSM can be + or -5
with STYLE = 3 (late maturity) CLASSM can be + or -8

STYLE - the maturity classification of the variety. (early = 1, intermediate = 2, late or full season = 3) (2)

CLASSM - fine adjustment of maturity classification in days later (-), or days earlier (+) than standard. (0)

WTKERN - the weight of an average kernel for the variety being simulated. (.33)

CORNMX - approximate weight of a whole plant grown under ideal conditions at a low plant population. Example (500)

EARMAX - maximum weight of the grain on a full ear. Example (200)

EARNMX - maximum expected ears per stalk at low plant population. Example (2)

USTEMF - the normal ratio between grain weight and stalk weight (less reserves) under favorable conditions. Example (4.0)

PCORRF - a factor for adjusting the photosynthetic rate of the variety to account for differences in this. Example (.8 to 1.5)

KERNLF - a factor for adjustment of the potential kernel number. Example (1)

YNGLAR - the initial leaf area of the seedling at emergence. Example (.07)

XSTDLA - the expected final leaf area per plant at low population. Example (110)

PLAIFC - the slope of the regression relating the log of leaf area per plant to the log of the plant population. Example (.7)

STDECL - the days after silking when decline of leaf area starts. (10)

DCRATE - the linear rate of leaf decline (fraction of maximum area per day). (.005)

GRNSTU - the lag in the start of grain growth after pollination. Example (6.00)

TTLC - provision for the name or other identification of the variety being simulated.

H2OLIM - lower limit for irrigation application amount. (0.5)

POPPLT - plant population in plants per acre. (30000)

H2ODEF - water deficit below field capacity at which irrigation is started if no rain occurs that day, in inches. (2.75)

H2OIRR - amount of water in inches to be added at each irrigation. (1.93)

NYEAR - number of years of weather information to be used. (25)

ISR - the number of divisions the reservoir volume is to be divided into. (10)

PANCHG - a one punch in column 70 signals that pan evaporation is to be used instead of calculating evaporation by the Penman equation. (0)

IRPLAN - a value of 1 indicates normal irrigation, a value of 2 indicates that water is to be saved for irrigation during pollination. (1)

AREAIR - area of corn to be irrigated, units acres. (100)

AREARO - area of watershed, units acres. (300)

ZZ - vertical distance from riser to top of dam, units feet.

ANG - angle formed by downstream and upstream faces and the ground surface.

CK - hydraulic conductivity of the material comprising the least permeable section of the dam, ft/min.

W - top width of the dam, units feet.

H - initial height of dam, units feet. (17)

HV - number of width readings. (42)

HH - increment for reading on pond area, units inches. (12)

HA - number of readings for pond area. (27)

HFIX - maximum height for dam, units feet. (22)

NEWSIZ - number of days dam may be dry before incrementing size. (1)

SAVIRR - amount of water to be saved for irrigation during pollination period, units are inches/irrigated area . (0.0)

This is where PR, the rainfall distribution curve for an hour, is read. Values are found at end of Appendix B.

PERMC - a factor used to determine maintenance cost for the reservoir based on the cost of the reservoir. (.02)

FLAB - an inflation rate for labor. (.06)

FPUM - an inflation rate for pumping cost. (.06)

FMAN - an inflation rate for maintenance cost. (.06)

FGRAN - an inflation rate for the price of corn. (0)

POPNOI - the population density for nonirrigated corn. (24000)

WELHED - the depth water must be pumped from if using a well. (100)

WELCST - the cost of constructing a well. (950)

QDSEP - accounts for deep seepage through the reservoir. (.0)

This is where WIDTH, which is the cross-sectional length of the dam, and PACRE, which is the pond area, are read in for each elevation for the proposed dam site. Values found at end of Appendix B.

This section reads in HD, the rainfall distribution curve, for 24 hours. Values found at end of Appendix B.

This section reads in the potential daily evapotranspiration/month. Values found at end of Appendix B.

This section reads in the percent sunshine associated with the integer values from the weather data tape, SUN(I). Values found at end of Appendix B.

XINT - interest rate on capital. (.11)

TDH - total dynamic head. (200)

EFFP - efficiency of pump. (.53)

EFFM - efficiency of motor. (.90)

CKWH - cost per kilowatt hour. (.045)

FILLPR - fill price used to determine the cost of constructing the reservoir based on the volume of soil moved in cubic yards $1.50/cu yd.

GRPR - average price of grain. (3.0)

EXTDPR - used when additional expenses are encountered for dam construction. (2000)

ALABOR - labor costs assumed for setting up the irrigation system for use. (267)

LIFE - expected life of the system used for economic calculations. (10)

ISTA - weather station number.

IYR - year

JM - month

IIDAY - day

JULL - Julian day number.

TTMAX - maximum daily temperature (degree F).

TTMIN - minimum daily temperature (degree F).

RR - precipitation (inches).

CA - average cloud cover (tenths).

Data changes for Lexington, Kentucky - 1978

DRYFAC - 1

HARVST - 25

H2OPRO - 5

TLEFFC - .5

H2OCAP - 5

YSTEMF - 3.9
PCORRF - 1.2
POPPLT - 20700 to 25000

Data changes for Davis, California - 1974 and 1975

DRYFAC - 1
DAYDEG - 20
XLEFGI - .99
H2OPRO - 16.5
H2OCAP - 16.5
U - 7
CORNMX - 390
EARNMX - 1.3
YSTEMF - 3.9
PCORRF - .9
POPPLT - 25300

Data changes for Utah 1974

DRYFAC - 1
DAYDEG - 20
H2OPRO - 7.5
H2OCAP - 7.5
XSKREX - .9
U - 9
STYLE - 1
CLASSM - -2
CORNMX - 400
EARMAX - 210
EARNMX - 1
YSTEMF - 3.5
PCORRF - .95
POPPLT - 34800

Data changes for Utah 1975 (variety changed from 1974)

DRYFAC - 1
DAYDEG - 20
H2OPRO - 7.5
H2OCAP - 7.5

Data changes for Utah 1975 - continued

XSKREX - .9
BARREN - 3.2
U - 9
STYLE - 1
CLASSM - -5
CORNMX - 410
EARMAX - 210
EARNMX - 1.3
YSTEMF - 3.5
PCORRF - .95
POPPLT - 34800

APPENDIX B

COMPUTER LISTING AND INPUT DATA

```
      DIMENSION PTABLE(17,20),XSTRES(11),EVAPK(11),WIDTH(60),PACRE(65),
     1STORV(65),HD(24),PET(12),PCORN(260,5),CLIMAT(366,6),R(366),PTSPLX
     1(317),JMO(366),IDAY(366),SOILWX(317,10),SOIL(10),SUN(11),CCA(366),
     1HR(24),RO(366),DAYINX(366),IYRR(25),JM(25,366),IIDAY(25,366),
     1JULL(25,366),TTMAX(25,366),TTMIN(25,366),PR(25,366),CA(25,366),
     1XSTOR(25),XPACRE(25),XWIDTH(35),DB(35),XDIFF(25,25),
     1A(25,25),BEINV(25,25),VOLDAM(35),YIELDS(25,25),H2OAD(25,25),
     1NSETUP(25,25),IPR(25)
      DIMENSION PR(10),ROFF(25,366)
      INTEGER*2 IYRR,JM,IIDAY,JULL,IDAY,JMO
      REAL KERFIX,LAI,LATUDE,MINUTS,MINFAC,KLYMAT,NEWDAY,LEFWT,KERMAX,
     1KERH2O,KERPOT,NYTFAC,NYTTYM,NYTAVG,KERDAY,KERNUM,KERMOD,KLXMAT,
     1LEFDEC,KERNLF,MU,ML
      INTEGER DAYNO,MO,DAZE,HA,HV,HAI,H,HFIX,HH,EVAP,PROBLM
C*********************************************************************
C KPCORN IS THE NUMBER OF DAILY PLANT DESCRIPTIONS IN THE THREE TABLES THAT
C WILL FOLLOW. (THREE PER CARD)
C*********************************************************************
      READ(5,1031) KPCORN
C*********************************************************************
C* KPCORN CONTAINS DAILY DESCRIPTIONS OF THE WEIGHTS OF DIFFERENT PARTS
C* OF A CORN PLANT FOR THREE MATURITY CLASSES.
C*********************************************************************
      READ(5,1000) ((PCORN(J,K),K=1,5),J=1,KPCORN)
 1000 FORMAT(15F5.0)
C*********************************************************************
C PTABLE IS A PHOTOSYNTHESIS TABLE RELATING RADIATION, LAI, AND DAILY
C PHOTOSYNTHESIS PER PLANT.
C*********************************************************************
      READ(5,1004) ((PTABLE(J,K),K=1,20),J=1,17)
 1004 FORMAT (20F4.1)
C*********************************************************************
C* XSTRES IS A CURVE RELATING SOIL MOISTURE DEFICIT AND PLANT STRESS.
C*********************************************************************
      READ(5,1005) (XSTRES(J),J=1,11)
      WRITE(6,1005) (XSTRES(J),J=1,11)
C*********************************************************************
C* EVAPK IS A CURVE RELATING SOIL MOISTURE DEFICIT AND EVAPOTRANSPIRATION.
C*********************************************************************
      READ(5,1005) (EVAPK(J),J=1,11)
      WRITE(6,1005) (EVAPK(J),J=1,11)
 1005 FORMAT(15F5.2)
      PANCHX=0.
      PLTNUM=0.
      UPDATE=0.
      LCARDS=10
C************************************************************************
C* VARB1  MAXIMUM INFILTRATION
C* VARB2  MAXIMUM POSSIBLE SEEPAGE RATE
C* VARB3  THE MAXIMUM CAPACITY WHICH IS LESS READILY AVAILABLE FOR EVAPOTRANSPER
C* VARB4  A CONSTANT DEFINING THE FRACTION OF SEEPAGE THAT BECOMES RUNOFF.
C* RMU VOLUME OF WATER IN SOIL WHICH IS READILY AVAILABLE FOR EVAPOTRANSPERATION
C* RML VOLUME OF WATER IN SOIL WHICH IS LESS READILY AVAILABLE FOR EVAPOTRANSPER
C****************************************************************************
      READ(5,1033) VARB1,VARB2,VARB3,VARB4,RML,RMU
      WRITE(6,1033) VARB1,VARB2,VARB3,VARB4,RML,RMU
 1033 FORMAT(6F10.4)
   12 PROBLM=1
C*********************************************************************
C EVAPFC FACTOR RELATING PAN EVAPORATION TO EVAPOTRANSPIRATION. EXAMPLE(.75)
C DRYFAC ARBITRARY DAILY FRACTION OF GRAIN MOISTURE LOST PER DAY. EXAMPLE (.50)
```

```
C RESUSF MAXIMUM PART OF RESERVES WHICH CAN BE MOBILIZED IN A DAY. EXAMPLE (.10)
C RESPFC GROWTH-RELATED RESPIRARION RATE. (RE,ACTIVE RESPIRATION) EXAMPLE (.30)
C BMETFC MASS RELATED RESPIRATION. (RC,BASAL METABOLISM) EXAMPLE(.001)
C SLKINF PHYSIOLOGICAL DAYS REQUIRED FOR EAR-SHOOT DEVELOPMENT UNDER FAVORABLE
C CONDITIONS. EXAMPLE (9)
C KERFIX DAYS AFTER POLLINATION KERNELS ARE CONSIDERED LATENT. EXAMPLE (7)
C PRESAD RATE RESERVES ARE BUILT UP IN COMPETETION WITH OTHER GROWTH.EXAMPLE(.1)
C SETMIN BASE OR MINIMUN TEMPERATURE FOR DEGRE DAY CALCULATIONS. EXAMPLE (50)
C TMPOPT MAXIMUN TEMPERATURE FOR DEGREE DAY CALCULATIONS. EXAMPLE (86)
C HARVST MOISTURE PERCENTAGE AT WHICH CORN IS TO BE HARVESTED. EXAMPLE (20)
C GRNSLC DAYS FROM SLOW-DOWN IN RATE OF GRAIN GROWTH TO BLACK-LAYER. EXAMPLE(5)
C XLEFGI FACTOR FOR ARBITRARILY CHANGING LEAF-STALK RATIO. EXAMPLE (1.3)
C FMULCH FACTOR MODIFYING SURFACE EVAPORATION. (USED TO SIMULATE NO-TILL)
C EXAMPLE (.1 TO 1.0)
C*******************************************************************
    5 READ(5,1021)EVAPFC,DRYFAC,RESUSF,RESPFC,BMETFC,SLKINF,KERFIX,
     1PRESAD,DAYDEG,SETMIN,TMPOPT,HARVST,GRNSLC,XLEFGI,FMULCH
      WRITE(6,1021)EVAPFC,DRYFAC,RESUSF,RESPFC,BMETFC,SLKINF,KERFIX,
     1PRESAD,DAYDEG,SETMIN,TMPOPT,HARVST,GRNSLC,XLEFGI,FMULCH
C*******************************************************************
C* VTRTEX EXPONENT FOR MODIFYING CALCULATED EFFECT OF STRESSE DURING VEGETATIVE
C* GROWTH.(AFFECTS KERNEL NUMBERS) EXAMPLE (1)
C* H2OPRO INCHES OF WATER IN PROFILE AT FIRST CLIMATIC INFORMATION. EXAMPLE(5.5)
C* STLAEX EXPONENT FOR MODIFYING CALCULATED EFFECT OF STRESSES ON RATE OF LEAF
C* AREA DEVELOPMENT. EXAMPLE (1)
C* TLEFFC EXPONENT FOR MODIFYING CALCULATED EFFECT OF TEMPERATURE ON THE RATE OF
C* LEAF PHOTOSYNTHESIS. EXAMPLE (.10)
C* RUNAVG DAYS IN MOVING AVERAGE FOR VARIOUS CALCULATIONS. EXAMPLE (12)
C* PRSMXF FACTOR RELATING MAXIMUM RESERVES PERMITTED TO PLANT WEIGHT. EXAMP(1.5)
C* H2OCAP AVAILABLE WATER HELD IN SOIL TO ROOTING DEPTH, IN INCHES. EXAMPLE(5.5)
C* PNWLFX FRACTION OF LEAF AREA ASSUMED TO BE ACTIVELY GROWING AND HENCE UNABLE
C* TO EXPORT ALL OF ITS PHOTOSYNTHATE. EXAMPLE (.1)
C* KERH2O KERNEL MOISTURE PRESENT AT BLACK LAYER MATURITY. EXAMPLE (30)
C* STYLEF LEAF AREA DIFFERENCE IN DM2 BETWEEN MATURITY GROUPS. EXAMPLE (20)
C* OILFAC FACTOR FOR REDUCING GRAIN WEIGHT TO ACCOUNT FOR OIL CONTENT. EXAM(.95)
C* XSKREX EXPONENT FOR ADJUSTING CALCULATED FACTOR FOR KERNES NUMBER REDUCTION
C* BY SILK-PERIOD STRESSES. EXAMPLE (1)
C* BARREN AVERAGE DAILY RATE OF PHOTOSYNTHESIS PER PLANT BELOW WHICH BARRENNESS
C* BEGINS. EXAMPLE (2.8)
C* U AMOUNT OF WATER THAT MUST EVAPORATE FROM BARE SOIL BEFORE IT CEASES TO ACT
C* AS A FREE WATER SURFACE. EXAMPLE (12)
C* ALPHA  SOIL WATER CONDUCTIVITY. EXAMPLE (5)
C*************************************************************************
      READ(5,1021)VTRTEX,H2OPRO,STLAEX,TLEFFC,RUNAVG,PRSMXF,H2OCAP,
     1PNWLFX,KERH2O,STYLEF,OILFAC,XSKREX,BARREN,U,ALPHA
      WRITE(6,1021)VTRTEX,H2OPRO,STLAEX,TLEFFC,RUNAVG,PRSMXF,H2OCAP,
     1PNWLFX,KERH2O,STYLEF,OILFAC,XSKREX,BARREN,U,ALPHA
 1031 FORMAT(I10)
      H2OZZZ=H2OPRO
      PLRTFC=.35
      DETAIL=0.
      IF(VTRTEX.EQ.0.)STOP
      H2OPXX=(H2OPRO/H2OCAP)*100.
      H2OSXX=H2OCAP
      IRATE=0
      IS=0
C************************************************************************
C     VARIETAL CHARACTERISTICS
C     WITH STYLE=1 (EARLY MATURITY)CLASSM CAN BE + OR -2
C     WITH STYLE=2 (STANDARD MATURITY)CLASSM CAN BE + OR -5
C     WITH STYLE =3 (LATE MATURITY)CLASSM CAN BE + OR -8
```

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C STYLE THE MATURITY CLASSIFICATION OF THE VARIETY.(EARLY =1, INTERMEDIATE= 2,
C LATE OR FULL SEASON = 3)
C CLASSM FINE ADJUSTMENT OF MATURITY CLASSIFICATION IN DAYS LATER (-), OR DAYS
C EARLIER (+) THAN STANDARD.
C WTKERN IS THE WEIGHT OF AN AVERAGE KERNEL FOR THE VARITY BEING SIMULATED.
C CORNMX THE APPROXIMATE WEIGHT OF A WHOLE PLANT GROWN UNDER IDEAL CONDITIONS AT
C A LOW PLANT POPULATION. EXAMPLE (500)
C EARMAX THE MAXIMUM WEIGHT OF THE GRAIN ON A FULL EAR. EXAMPLE (200)
C EARNMX THE MAXIMUM EXPECTED EARS PER STALK AT LOW PLANT POPULATION. EXAMPLE(2)
C YSTEMF IS THE NORMAL RATIO BETWEEN GRAIN WEIGHT AND STALK WEIGHT (LESS
C RESERVES) UNDER FAVORABLE CONDITIONS. EXAMPLE (4.0)
C PCORRF A FACTOR FOR ADJUSTING THE PHOTOSYNTHETIC RATE OF THE VARIETY TO
C ACCOUNT FOR DIFFERENCES IN THIS. EXAMPLE (.9 TO 1.1)
C KERNLF A FACTOR FOR ADJUSTMENT OF THE POTENTIAL KERNEL NUMBER. EXAMPLE (1)
C YNGLAR THE INITIAL LEAF AREA OF THE SEEDLING AT EMERGENCE. EXAMPLE (.3)
C XSTDLA THE EXPECTED FINAL LEAF AREA PER PLANT AT LOW POPULATION. EXAMPLE (110)
C PLAIFC THE SLOPE OF THE REGRESSION RELATING THE LOG OF LEAF AREA PER PLANT TO
C THE LOG OF THE PLANT POPULATION. EXAMPLE (.7)
C STDECL IS THE DAYS AFTER SILKING WHEN DECLINE OF LEAF AREA STARTS.
C DCRATE IS THE LINEAR RATE OF LEAF DECLINE (FRACTION OF MAX AREA PER DAY)
C GRNSTD THE LAG IN THE START OF GRAIN GROWTH AFTER POLLINATION. EXAMPLE (6.00)
C TTLC PROVISION FOR THE NAME OR OTHER IDENTIFICATION OF THE VARIETY
C BEING SIMULATED.
C*****************************************************************************
    3 READ(5,1022)STYLE,CLASSM,WTKERN,CORNMX,EARMAX,EARNMX,YSTEMF,
     1PCORRF,KERNLF,YNGLAR,XSTDLA,PLAIFC,STDECL,DCRATE,GRNSTD,TTLC
      WRITE(6,1022)STYLE,CLASSM,WTKERN,CORNMX,EARMAX,EARNMX,YSTEMF,
     1PCORRF,KERNLF,YNGLAR,XSTDLA,PLAIFC,STDECL,DCRATE,GRNSTD,TTLC
 1022 FORMAT(3F4.2,2F4.0,5F4.2,F4.0,4F4.2,4A4)
 1021 FORMAT(16F5.2)
      IF(STYLE.EQ.0.)STOP
C******************************************************************************
C* H2OLIM LOWER LIMIT FOR IRRIGATION APPLICATION AMOUNT.
C POPPLT PLANT POPULATION IN PLANTS PER ACRE.
C H2ODEF WATER DEFICIT BELOW FIELD CAPACITY AT WHICH IRRIGATION IS STARTED IF NO
C RAIN OCCURS THAT DAY. IN INCHES
C H2OIRR AMOUNT OF WATER IN INCHES TO BE ADDED AT EACH IRRIGATION.
C* NYEAR NUMBER OF YEARS OF WEATHER INFORMATION TO BE USED.
C* ISR THE NUMBER OF DIVISIONS THE RESERVOIR VOLUME IS TO BE DIVIDED INTO
C* PANCHG A ONE PUNCH IN COLUMN 70 SIGNALS THAT PAN EVAPORATION IS TO BE USED
C* INSTEAD OF CALCULATING EVAPORATION BY THE PENMAN EQUATION
C* IRPLAN A VALUE OF 1 INDICATES NORMAL IRRIGATION A VALUE OF 2 INDICATED THAT
C* WATER IS TO BE SAVED FOR IRRIGATION DURING POLLINATION
C******************************************************************************
      READ(5,1030)H2OLIM,POPPLT,H2ODEF,H2OIRR,NYEAR,ISR,PANCHG,IRPLAN
      WRITE(6,1030)H2OLIM,POPPLT,H2ODEF,H2OIRR,NYEAR,ISR,PANCHG,IRPLAN
      IIX=0
      NOIRR=0
 1030 FORMAT(4F10.3,2I10,F10.3,I10)
      IF(H2ODEF.EQ.0.)H2ODEF=99.
      IF(H2OIRR.EQ.0.)H2OIRR=.001
      H2=H2OIRR
C*************************************************************************
C* AREAIR AREA OF CORN TO BE IRRIGATED, UNITS ACRES
C* AREARO AREA OF WATERSHED, UNITS ACRES
C* ZZ VERTICAL DISTANCE FROM RISER TO TOP OF DAM, UNITS FEET
C* ANG ANGLE FORMED BY DOWNSTREAM AND UPSTREAM FACES AND THE GROUND SURFACE
C* CK HYDRAULIC CONDUCTIVITY OF THE MATERIAL COMPRISING THE LEAST PERMEABLE
C* SECTION OF THE DAM
C* W TOP WIDTH OF THE DAM, UNITS FEET
C* H INITIAL HEIGHT OF DAM, UNITS FEET
```

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C* HV NUMBER OF WIDTH READINGS
C* HH INCREMENT FOR READING ON POND AREA, UNITS INCHES
C* HA NUMBER OF READINGS FOR POND AREA
C* HFIX MAXIMUM HEIGHT FOR DAM., UNITS FEET
C* NEWSIZ NUMBER OF DAYS DAM MAY BE DRY BEFORE INCREMENTING SIZE
C* SAVIRR AMOUNT OF WATER TO BE SAVED FOR IRRIGATION DURING POLLINATION PERIOD
C*        UNITS ARE INCHES/IRRIGATED AREA
C***********************************************************************
      READ(5,2200)AREAIR,AREARO,ZZ,ANG,CK,W,H,HV,HH,HA,HFIX,NEWSIZ,
     1SAVIRR,EFFS
      WRITE(6,2200)AREAIR,AREARO,ZZ,ANG,CK,W,H,HV,HH,HA,HFIX,NEWSIZ,
     1SAVIRR,EFFS
C******************************************************************
C* THIS IS WHERE PR THE RAINFALL DISTRIBUTION CURVE FOR AN HOUR IS READ
C******************************************************************
      READ (5,9000) (PR(J) ,J=1,10)
      WRITE(6,9000) (PR(J) ,J=1,10)
 9000 FORMAT(10F8.3)
C******************************************************************
C* PERMC IS A FACTOR USED TO DETERMINE MAINTAINENCE COST FOR THE RESERVOIR
C*       BASED ON THE COST OF THE RESERVOIR
C* FLAB IS AN INFLATION RATE FOR LABOR
C* FPUM IS AN INFLATION RATE FOR PUMPING COST
C* FMAN IS AN INFLATION RATE FOR MAINTAINENCE COST
C* FGRAN IS AN INFLATION RATE FOR THE PRICE OF CORN
C* PCPNOI IS THE POPULATION DENSITY FOR NONIRRIGATED CORN
C* WELHED IS THE THE DEPTH WATER MUST BE PUMPED FROM IF USING A WELL
C* WELCST IS THE COST OF CONSTRUCTING A WELL
C* QDSEP ACCOUNTS FOR DEEP SEEPAGE THROUGH THE RESERVOIR
C******************************************************************
      READ(5,9000) PERMC,FLAB,FPUM,FMAN,FGRAN,PCPNOI,WELHED,WELCST,QDSEP
      WRITE(6,9000)PERMC,FLAB,FPUM,FMAN,FGRAN,PCPNOI,WELHED,WELCST,QDSEP
 2200 FORMAT(6F6.2,6I5,2F5.2)
      HLIM=H2OLIM
C******************************************************************
C* THIS IS WHERE WIDTH WHICH IS THE CROSSECTIONAL LENGTH OF THE DAM AND
C* PACRE WHICH IS THE POND AREA ARE READ IN FOR EACH ELEVATION FOR THE
C* PROPOSED DAM SITE.
C******************************************************************
      IF(HV.LE.20)GO TO 2000
      IF(HV.LE.40)GO TO 2001
      IF(HV.LE.60)GO TO 2002
      WRITE(5,2011)
 2011 FORMAT(5X,15H ERROR IN INPUT)
      STOP
 2010 FORMAT(20F4.0)
 2000 READ(5,2010) (WIDTH(I) ,I=1,HV)
      WRITE(6,2010) (WIDTH(I) ,I=1,HV)
      GO TO 2003
 2001 READ(5,2010) (WIDTH(I) ,I=1,20)
      WRITE(6,2010) (WIDTH(I) ,I=1,20)
      READ(5,2010) (WIDTH(I) ,I=21,HV)
      WRITE(6,2010) (WIDTH(I) ,I=21,HV)
      GO TO 2003
 2002 READ(5,2010) (WIDTH(I) ,I=1,20)
      WRITE(6,2010) (WIDTH(I) ,I=1,20)
      READ(5,2010) (WIDTH(I) ,I=21,40)
      WRITE(6,2010) (WIDTH(I) ,I=21,40)
      READ(5,2010) (WIDTH(I) ,I=41,HV)
      WRITE(6,2010) (WIDTH(I) ,I=41,HV)
 2003 CONTINUE
```

```
      IF(HA.LE.13) GO TO 2004
      IF(HA.LE.26) GO TO 2005
      IF(HA.LE.39) GO TO 2006
      IF(HA.LE.52) GO TO 2007
      IF(HA.LE.65) GO TO 2008
      WRITE(5,2011)
      STOP
 2004 READ(5,2012) (PACRE(J),J=1,HA)
      WRITE(6,2012) (PACRE(J),J=1,HA)
      GO TO 2009
 2005 READ(5,2012) (PACRE(J),J=1,13)
      WRITE(6,2012) (PACRE(J),J=1,13)
      READ(5,2012) (PACRE(J),J=14,HA)
      WRITE(6,2012) (PACRE(J),J=14,HA)
      GO TO 2009
 2006 READ(5,2012) (PACRE(J),J=1,13)
      WRITE(6,2012) (PACRE(J),J=1,13)
      READ(5,2012) (PACRE(J),J=14,26)
      WRITE(6,2012) (PACRE(J),J=14,26)
      READ(5,2012) (PACRE(J),J=27,HA)
      WRITE(6,2012) (PACRE(J),J=27,HA)
      GO TO 2009
 2007 READ(5,2012) (PACRE(J),J=1,13)
      WRITE(6,2012) (PACRE(J),J=1,13)
      READ(5,2012) (PACRE(J),J=14,26)
      WRITE(6,2012) (PACRE(J),J=14,26)
      READ(5,2012) (PACRE(J),J=27,39)
      WRITE(6,2012) (PACRE(J),J=27,39)
      READ(5,2012) (PACRE(J),J=40,HA)
      WRITE(6,2012) (PACRE(J),J=40,HA)
      GO TO 2009
 2008 READ(5,2012) (PACRE(J),J=1,13)
      WRITE(6,2012) (PACRE(J),J=1,13)
      READ(5,2012) (PACRE(J),J=14,26)
      WRITE(6,2012) (PACRE(J),J=14,26)
      READ(5,2012) (PACRE(J),J=27,39)
      WRITE(6,2012) (PACRE(J),J=27,39)
      READ(5,2012) (PACRE(J),J=40,52)
      WRITE(6,2012) (PACRE(J),J=40,52)
      READ(5,2012) (PACRE(J),J=53,HA)
      WRITE(6,2012) (PACRE(J),J=53,HA)
 2012 FORMAT(13F6.2)
 2009 CONTINUE
C***********************************************************************
C* CALCULATION OF STORAGE VOLUME FOR EACH HEIGHT
C***********************************************************************
      STORV(1)=PACRE(1)*HH
      ST=STORV(1)
      DO 2020 I=2,HA
      STORV(I)=ST+PACRE(I-1)*HH+HH*(PACRE(I)-PACRE(I-1))/2.
 2020 ST=STORV(I)
C***********************************************************************
C* THIS SECTION DETERMINES AT WHAT LEVEL OR ELEVATION THE DAM WILL BEGIN
C***********************************************************************
      I=0
  155 I=I+1
      IF(WIDTH(I).EQ.0)GO TO 155
      I=I-1
C***********************************************************************
C* THIS SECTION RESEQUENCES THE WIDTH ARRAY
C***********************************************************************
```

```
      JV=HV-I
      DO 255 J=1,JV
  255 WIDTH(J)=WIDTH(J+I)
C************************************************************************
C* THIS SECTION RESEQUENCES THE STORV ARRAY AND PACRE ARRAY
C************************************************************************
      JA=HA-I
      DO 355 J=1,JA
      STORV(J)=STORV(J+I)
  355 PACRE(J)=PACRE(J+I)
C************************************************************************
C* THIS SECTION READS IN HD THE RAINFALL DISTRIBUTION CURVE  FOR 24 HR
C************************************************************************
      K=0
      GO TO 2201
 2202 K=12
 2201 READ(5,2203) (HD(I+K),I=1,12)
      WRITE(6,2203) (HD(I+K),I=1,12)
      IF(K.EQ.0) GO TO 2202
C************************************************************************
C* THIS SECTION READS IN THE POTENTIAL DAILY EVAPOTRANSPIRATION / MONTH
C************************************************************************
      READ(5,2203) (PET(I),I=1,12)
      WRITE(6,2203) (PET(I),I=1,12)
 2203 FORMAT(12F5.3)
C************************************************************************
C* THE SECTION DETERMINS WHICH SET OF PCORN VALUES ARE TO BE USED
C************************************************************************
      IF(STYLE.EQ.1.)LL= 1
      IF(STYLE.EQ.2.)LL=73
      IF(STYLE.EQ.3.)LL=154
      N=1
      DO 105 J=1,KPCORN
      IF(LL.GT.J) GO TO 105
      DO 107 M=1,5
      PCORN(N,M)=PCORN(J,M)
  107 CONTINUE
      N=N+1
  105 CONTINUE
      ISA=90
      ISO=305
C************************************************************************
C* THIS SECTION READS IN THE PERCENT SUNSHINE ASSOCIATED WITH THE
C* INTEGER VALUES FROM THE WEATHER DATA TAPE
C************************************************************************
      READ(5,1111) (SUN(I),I=1,11)
      WRITE(6,1111) (SUN(I),I=1,11)
 1111 FORMAT(11F5.3)
C********************************************************************************
C* XINT INTEREST RATE ON CAPITAL
C* TDH TOTAL DYNAMIC HEAD
C* EFFP EFFICIENCY OF PUMP
C* EFFM EFFICIENCY OF MOTOR
C8 GPM PUMPING FLOW RATE IN GALLONS PER MINUITE
C* CKWH COST PER KILOWATT HOUR
C* FILLPR FILL PRICE USED TO DETERMINE THE COST OF CONSTRUCTING THE RESERVOIR
C* BASED ON THE VOLUME OF SOIL MOVED IN CUBIC YARDS $1.50/CU YD
C* GRPR AVERAGE PRICE OF GRAIN
C* EXTDPR USED WHEN ADDITIONAL EXPENSES ARE ENCOUNTERED FOR DAM CONSTRUCTION
C* ALABOR LABOR COSTS ASSUMED FOR SETTING UP THE IRRIGATION SYSTEM FOR USE
C* LIFE EXPECTED LIFE OF THE SYSTEM USED FOR ECONOMIC CALCULATIONS
```

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C**************************************************************************
      READ(5,800) XINT,TDH,EFFP,EFFM,GPM,CKWH,FILLER,GRPR,EXTDFR,ALABOR,
     1LIFE
      WRITE(6,800) XINT,TDH,EFFP,EFFM,GPM,CKWH,FILLER,GRPR,EXTDFR,ALABOR,
     1LIFE
  800 FORMAT(10F7.2,I7)
C**********************************************************************
C* THIS LOOP READS IN THE CLIMATIC DATA AND CALCULATES THE DAILY RUNOFF
C* TO BE STORED IN ARRAYS FOR LATTER CALCULATIONS
C**********************************************************************
      DO 332 IYEAR=1,NYEAR
      JEND=365
      DO 331 IJ=1,365
C**********************************************************************
C* ISTA  WEATHER STATION NUMBER
C* IYR   YEAR
C* JM    MONTH
C* IIDAY DAY
C* JULL  JULIAN DAY NUMBER
C* TTMAX MAXIMUM DAILY TEMPERATURE (DEG. F)
C* TTMIN MINIMUM DAILY TEMPERATURE (DEG. F)
C* PR    PRECIPITATION (INCHES)
C* CA    AVERAGE CLOUD COVER (TENTHS)
C* WSPX  MAXIMUM WIND SPEED (KNOTS)
C* WSPA  AVERAGE WIND SPEED (KNOTS)
C* TWBX  MAXIMUM WET BULB TEMPERATURE (DEG. F)
C* TWBN  MINIMUM WET BULB TEMPERATURE (DEG. F)
C* RHX   MAXIMUN RELATIVE HUMIDITY (%)
C* RHN   MINIMUN RELATIVE HUMIDITY (%)
C**********************************************************************
      READ(20,3333)ISTA,IYRR(IYEAR),JM(IYEAR,IJ),IIDAY(IYEAR,IJ),
     1JULL(IYEAR,IJ),TTMAX(IYEAR,IJ),TTMIN(IYEAR,IJ),RR(IYEAR,IJ)
     1,CA(IYEAR,IJ),WSPX,WSPA,TWBX,TWBN,RHX,RHN
 3333 FORMAT(1X,I5,1X,3I2,1X,I3,1X,F3.0,1X,F3.0,1X,F5.2,1X,F3.1,1X,F6.1,
     11X,F6.1,1X,F6.2,1X,F6.2,1X,F5.2,1X,F5.2)
      R(IJ)=RR(IYEAR,IJ)
      M=JM(IYEAR,IJ)
      CALL SRUNOF(PET,RMU,RML,VARB1,VARB2,VARB3,VARB4,HD,IJ,R,RO,M,PE,
     1PR)
  331 ROFF(IYEAR,IJ)=RO(IJ)
      IYR=IYRR(IYEAR)
      IF(IYR.EQ.48.OR.IYR.EQ.52.OR.IYR.EQ.56.OR.IYR.EQ.60.OR.IYR.EQ.64.
     1OR.IYR.EQ.68.OR.IYR.EQ.72)JEND=366
      IF(JEND.EQ.365)GO TO 332
      READ(20,3333)ISTA,IYR,JM(IYEAR,366),IIDAY(IYEAR,366),JULL(IYEAR,
     1366),TTMAX(IYEAR,366),TTMIN(IYEAR,366),RR(IYEAR,366)
      M=JM(IYEAR,366)
      R(366)=RR(IYEAR,366)
      CALL SRUNOF(PET,RMU,RML,VARB1,VARB2,VARB3,VARB4,HD,366,R,RO,M,PE,
     1PR)
      ROFF(IYEAR,366)=RO(366)
  332 CONTINUE
      IYEAR=0
 6666 IYEAR=IYEAR+1
      JEND=365
      IF(NCIRR.EQ.10)ROFELT=RCFNOI
      H2OIRR=H2
C**********************************************************************
C* THIS LOOP DETERMINES THE YEARLY CLIMATIC AND RUNOFF ARRAY FOR A GIVEN YEAR
C**********************************************************************
      DO 333 IJ=1,365
```

```
      IYR=IYRR(IYEAR)
      RO(IJ)=ROFF(IYEAR,IJ)
      CCA(IJ)=CA(IYEAR,IJ)
      JMO(IJ)=JM(IYEAR,IJ)
      IDAY(IJ)=IIDAY(IYEAR,IJ)
      JUL=JULL(IYEAR,IJ)
      ITMAX=TTMAX(IYEAR,IJ)
      ITMIN=TTMIN(IYEAR,IJ)
      R(IJ)=RR(IYEAR,IJ)
      CLIMAT(JUL,1)=0.0
      CLIMAT(JUL,2)=ITMAX
      CLIMAT(JUL,3)=ITMIN
      CLIMAT(JUL,5)=0.0
      CLIMAT(JUL,6)=JUL
  333 CONTINUE
C***********************************************************************
C* THIS SECTION ADJUSTS FOR LEAP YEAR
C***********************************************************************
      IF(IYR.EQ.48.OR.IYR.EQ.52.OR.IYR.EQ.56.OR.IYR.EQ.60.OR.IYR.EQ.64.
     1OR.IYR.EQ.68.OR.IYR.EQ.72)JEND=366
      IF(JEND.EQ.365) GO TO 1551
      RO(366)=ROFF(IYEAR,366)
      CLIMAT(366,6)=JULL(IYEAR,366)
      CLIMAT(366,2)=TTMAX(IYEAR,366)
      CLIMAT(366,3)=TTMIN(IYEAR,366)
      CLIMAT(366,4)=RR(IYEAR,366)
      R(366)=RR(IYEAR,366)
      JMO(366)=JM(IYEAR,366)
 1551 CONTINUE
C***********************************************************************
C* THIS SECTION CALCULATES SOLAR RADIATION BASED ON CLOUD COVER,
C* CALCULATED EXTRATERESTRIAL RADIATION AND MONTH. EQUATION ARE
C* GENERATED BY REGRESSION USING LEXINGTON DATA FOR APRIL THROUGH OCTOBER.
C***********************************************************************
      DO 510 I=ISA,ISO
      ISUN=CCA(I)*10.+1.
      IMO=JMO(I)-3
      IF(IMO.LT.1) GO TO 510
      IF(IMO.GT.7) GO TO 510
      J=I
      ATC=((CLIMAT(J,2)+CLIMAT(J,3))/2.-32.)*5./9.
      RA=11.87+5.45*COS(.986*(J+193)*3.14159/180.)
      RSM=RA*0.1*(597.3-.56*ATC)
      GO TO (503,504,505,506,507,508,508),IMO
  503 CLIMAT(I,1)=RSM*(.279+.564*SUN(ISUN))
      GO TO 510
  504 CLIMAT(I,1)=RSM*(.304+.472*SUN(ISUN))
       GO TO 510
  505 CLIMAT(I,1)=RSM*(.312+.457*SUN(ISUN))
       GO TO 510
  506 CLIMAT(I,1)=RSM*(.311+.417*SUN(ISUN))
      GO TO 510
  507 CLIMAT(I,1)=RSM*(.311+.418*SUN(ISUN))
      GO TO 510
  508 CLIMAT(I,1)=RSM*(.348+.488*SUN(ISUN))
  510 CONTINUE
  165 CONTINUE
      NRESET=-1
  555 RESET=0.0
C***********************************************************************
C* REDEFINES RAINFALL TERMS FOR A  GIVEN YEAR
```

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C***********************************************************************
      DO 696 I=1,365
  696 CLIMAT(I,4)=R(I)
C***********************************************************************
C* STARTING HERE VALUES ARE INITIALLIZED FOR EACH YEAR
C***********************************************************************
      STOR=STORV(N)
      H2OPRC=H2OZZZ
      NRESET=NRESET+1
      JCOUNT=1
      RADFAC=.0174533
      MINFAC=.0002909
      BUACRE=.159324
      DMACRE=404700.
      KCUNT1=0
      GRFACT=POPPLT*2.471/(1000.*100.)
      FACPOP=POPPLT/DMACRE
      POPFAC=DMACRE/POPPLT
  342 CONTINUE
      SHIFT=0.
      KERH2O=XERH2O
      LBBU=56.
      GRAMBU=25401.
      KGBU=GRAMBU/1000.
      ACREHA=1./.4047
      FUNCFF=0.
      ZMES1=0.
      XXX=0.
      ZMES2=0.
      TDRY=0.
      ESUBS=0.
      WIND=20
      KERPOT=0.
      IRRST=0
      RATIOS=0.
      PLINCX=0.
      PRSINX=0.
      DAYX=0.
      LAG=7
      TMP=0.
      PRESZZ=0.
      DAYZZ=0.
      YXX=0.
      STAGES=0.
      SUMRAD=0.
      SLKING=2.0
      QRESP=0.
      H2OADD=0.
      DRY=0.
      PLNTZZ=0.
      KERDAY=0.
      AVGDAY=0.
      QUALTY=0.
      SETMIX=SETMIN
      PRESIN=0.
      IOLD=0
      AVGPTS=0.
      HUSK=0.
      GRAIN=.001
      NEWDAY=1.
      KERKON=0
```

```
      H2OLCS=0.
      SPLCST=0.
      BLKLYR=0.
      SILKED=0.
      PTSMAX=0.0
      PCLYNA=0.
      IRRTOT=0
      IRR=0
      DO 15 J=1,317
   15 PTSPLX(J)=0.
      PL NTWT=0.
      DEGDAZ=0.
      I=1
      YNGLEF=0.
      TASSXX=0.
      ENTRY=0.0
      KERNUM=0.
      SHOOT=1.
      EARZ=1.
      DAY=0.
      LAI=0.
      PLANTW=1.
      PRES=0.
      TIME=1.
      XSKER=0.
      AGE=0.0
      STMWT=0.001
      LEFWT=0.001
      HSKWT=0.001
      COBWT=0.001
      ROOTWT=0.001
      K=1
      IX=0
C**********************************************************************
C* THIS LOOP IS ENTERED UNTIL PLANTING DATE IS DETERMINED
C**********************************************************************
      DO 25 J=1,200
      JJ=J
C**********************************************************************
C* IF THIS IS A NON IRRIGATED SIMULATION SUBROUTINE DAM IS NOT ENTERED
C**********************************************************************
      IF(NOIRR.EQ.10)GO TO 511
      DEMIRR=0.0
      CALL        DAM(DEMIRR,RO,AREAIR,AREAPC,H,STORV,NEWSIZ,RESET,JJ,HV,
     1RAI,HA,ZZ,ANG,CK,W,STOR,HFIX,PACRE,PE,WIDTH,R,H2OIRR,JCOUNT,IS,IIX
     1,XWIDTH,DH,XPACRE,XSTOR,ISR,QDSEP)
      IF(RESET.EQ.10)GO TO 555
C**********************************************************************
C* THIS SECTION CALCULATES AN AVERAGE TEMPERATURE FOR ONE WEEK
C**********************************************************************
  511 IF(JJ.GT.LAG)GO TO 53
      TMP=CLIMAT(JJ,2)+TMP
      GO TO 51
   53 TMP=CLIMAT(JJ,2)+TMP-CLIMAT(JJ-LAG,2)
   51 CONTINUE
C**********************************************************************
C* THIS SECTION PREVENTES PLANTING DATE TO OCCURE BEFORE APRIL 2
C**********************************************************************
      IF(CLIMAT(JJ,6).LT.92) GO TO 25
      IX=IX+1
      CALL        WATERX(JJ,CLIMAT,LAI,U,ALPHA,H2OCAP,H2OPRC,WIND,RUNOFF,
```

```
     1 ZMES1,ZMES2,TDRY,ESUBS,STRESF,XSTRES,STRESS,XXX,PMULCH,PLTH2O,
     1TRANSUF,TOTES,PLHTPC,SOILWX,DETAIL,ALBESC,PANCEG,EVAPPC,EVAPK,IX)
      TMPA=TMP/LAG
C***********************************************************************
C* IF THE 1ST OF 10 LAYERS OF SOIL ISNOT 50% DRY THEN PLANTING DATE DOES
C* NOT OCCURE
C***********************************************************************
      IF(SOILWX(JJ,1).GT.H2OCAP/20.)GO TO 25
C***********************************************************************
C* IF THE AVERAGE MAXIMUM TEMPERATURE FOR THE LAST WEEK IS LESS THAN 60
C* DEGREES F THEN PLANTING DATE DOESNOT OCCURE
C***********************************************************************
      IF(TMPA.LT.60) GO TO 25
C***********************************************************************
C* ONCE REACHING THIS POINT PLANTING WILL OCCUR
C***********************************************************************
      GO TO 59
   25 CONTINUE
   59 CONTINUE
      JPLDAY=JJ+1
      PLTDAY=JPLDAY
      SEASON=ISO-PLTDAY
      H2OPCC=(H2OPRO/H2OCAP)*100.
      WRITE(6,4000) PROBLM,IYR
 4000 FORMAT(1H1,'      PROBLEM NUMBER  ',I4,'    YEAR=  ',I3)
      PROBLM=PROBLM+1
      DETAIL=0.
C***********************************************************************
C* THIS IS THE BEGINING OF THE DAILY LOOP
C***********************************************************************
      DO 99 JJ=JPLDAY,ISO
      H2OTRN=H2OCAP-H2OPRO
      DAYNO=CLIMAT(JJ,6)
      IF(DRY.GT.0.)GO TO 999
      SUMRAD=SUMRAD+CLIMAT(JJ,1)
      IF(H2OPRO.LE.0.)CLIMAT(JJ,1)=0.
C    IF SOIL IS DRY PHOTOSYNTHESIS IS STOPPED BY SETTING RADIATION TO ZERO
      IF(KOUNT1.GT.10)GO TO 97
C***********************************************************************
C* THIS STATEMENT CALCULATES MAXIMUM WEIGHT FOR PLANT RESERVES
C***********************************************************************
      PRESMX=PRSMXF*(STMWT+HSKWT)
      GO TO 37
C***********************************************************************
C* WHEN WATER STRESS IS SEVERE ENOUGH AFTER TASSELING HAS ACCURED TO
C* INHIBIT SILKING< THEN THE PLANTS ARE BARREN AND THE MODEL EXITS
C* FROM THE DAILY LOOP
C***********************************************************************
   97 WRITE(6,3070)
 3070 FORMAT(1H0,' PLANT IS BARREN DUE TO STRESS')
      DRY=1.
      GO TO 999
   98 WRITE(6,2069)JJ
C***********************************************************************
C* WHEN NO MORE MOISTURE EXISTS IN THE SOIL THE PLANTS DIE AND THE
C* MODEL EXITS FROM THE DAILY LOOP.
C***********************************************************************
 2069 FORMAT(1H0,'PLANTS KILLED BY DROUGHT ON DAY',I5)
      DRY=1.
      GO TO 999
   37 CONTINUE
```

```
      H2OLOS=0.
      PLOST=0.
      PTSPLT=0.
      PTSLEF=0.
      H2OREM=0.
      AGE=AGE+TIME
      IF(AGE.GT.SEASON) GO TO 999
      LAST=JJ
C*********************************************************************
C* THIS IS USED TO SIGNAL WHETHER AN IRRIGATED OR NONIRRIGATED YEAR IS
C* SIMULATED
C*********************************************************************
      IF(NCIRR.EQ.10) GO TO 611
      H2OLIM=HLIM
      CALL        IRIGAT(JJ,H2OTRN,H2ODEF,CLIMAT,B,H2OADD,H2OIRR,HFIX
     1,DEMIRR,STOR,AREAIR,STORV,IRRTOT,H2,IS,XSTOR,IIX,H2OLIM,IRPLAN,
     1TASSXX,SILKED,BLKLYR,SAVIRR,EFFS)
      CALL        DAM(DEMIRR,RO,AREAIR,AREARC,H,STORV,NEWSIZ,RESET,JJ,HV,
     1HAI,HA,ZZ,ANG,CK,W,STOR,HFIX,PACRE,RR,WIDTH,R,H2OIRR,JCOUNT,IS,IIX
     1,XWIDTH,DH,XPACRE,XSTOR,ISR,QDSEP)
C*********************************************************************
C* THIS IS USED WHEN FINDING THE MAXIMUM RESERVOIR SIZE
C*********************************************************************
      IF(RESET.EQ.10)GO TO 555
  611 IX=IX+1
      CALL        WATERX(JJ,CLIMAT,LAI,U,ALPHA,H2OCAP,H2OEFC,WIND,RUNOFF,
     1 ZMES1,ZMES2,TDRY,ESUBS,STRESF,XSTRES,STRESS,XXX,FHUICH,PLTH2O,
     1RANSUM,TOTES,PERTFC,SOILWX,DETAIL,ALBESC,RANCHG,EVAPFC,EVAPK,IX)
      CALL        PHZDAZ(JJ,CLIMAT,DAY,NEWDAY,ICID,I,DEGDAZ,GRODAY,DAYINC
     1,DAYDEG,RUNAVG,AVGDAY,AVGDAX,SETMIN,SILKED,
     1DAGRIN,BLKLYR,TMPOPT,DEGREZ,JPLDAY)
      CALL        LAILEF(LEFWT,YNGLEF,DAYX,YXX,DAYINC,XSTDLA,CLASSM,
     1DMACRE,PCPPLT,PCPFAC,PLAIFC,DAYZZ,LAI,STRESF,STLAEX,PCORN,I,
     1FACPOP,STYLE,STYLEF,JJ,SUMRAD,XDMPLT,YDMPLT,YNGLAR,
     1ZLAI,STDECL,DCRATE,PCLYNA)
      IF(BLKLYR.GT..5)GO TO 50
      CALL        PTOTAL(LAI,CLIMAT,PCPFAC,PLANTW,RESPFC,EMETFC,PTS,JJ,ST
     1RESS,PTSLEF,PTSPLT,PTABLE,I,AVGPTS,PTSPLX,DAYINC,RUNAVG,PRES,
     1 STMWT,QRESP,PRESMX,PLOST,PCORRF,LCARDS,TLEFFC,STRESF,PRESIN,
     1ZLAI,PTSMAX)
      IF((TASSXX.GT..5).AND.(SILKED.GT..5))GO TO 40
      CALL        QPVEG(PTS,I,PCORN,GRODAY,CORNMX,RCOTWT,STMWT,LEFWT,
     1HSKWT,PRES,SILKED,TASSXX,COBWT,STRESS,HUSK,SHOOT,CLASSM,PLOST,
     1PRESMX,RESUSE,JJ,DEGDAZ,SLKINF,QRESP,STRESF,SLKING,PITLAI,
     1PLANTW,PRESAD,STYLE,RNWLFX,PRESIN,XLEFGI,RATIOS,STAGES)
   40 CONTINUE
      IF(PCLYNA.GT..5)GO TO 60
      IF(TASSXX.LT..5)GO TO 45
      CALL        TASSEL(I,JJ,DEGDAZ,TASSXX,SILKED,SLKING,SHOOT,
     1CLASSM,PCORN,PCLYNA,QRESP,STRESF,KCUNT1,VTRTEX,VEGPOT,
     1RATIOS,STAGES,GRODAY)
   60 CONTINUE
      IF(KERKCN.EQ.2)GO TO 70
      IF(SILKED.LT..5)GO TO 70
      CALL        KERNOZ(I,JJ,KERDAY,KERFIX,              PTSPLT,AVGPTS,KE
     1RNUM,KERPOT,EARZ,EARMAX,XSKER,BLKIYF,EGFS,KERKCN,CORNMX,RUNAVG,
     1AVGDAY,DAYINC,ADJFAC,RRES,EMETFC,PLANTW,KERNLF,EARNMX,VEGPOT,
     1YSTEMF,STMWT,GRODAY,              VTRTEX,EARPOT,AGEFCT,XSKERX,
     1XSKREX,STRESF,PTSMAX)
   70 CONTINUE
      IF(BLKLYR.GT..5)GO TO 50
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      XQ=JJ
      IF(POLYNA.EQ.XQ)GO TO 45
      IF(POLYNA.EQ.0)GO TO 45
      CALL       GRAINZ(I,JJ,DEGREZ,KERNUM,MO,DAZE,ENTRY,ECCSN,WTKERN,
     1DAYINC,GENSTU,AVGPTS,BARREN,HSKWT,COBWT,PTS,OILFAC,PRESMX,BLKLYR,
     1QUALTY,PLOST,PRES,EARZ,EARMX,EARNMX,KERECT,GRAIN,RUNAVG,EARFAC)
   50 CONTINUE
      IF(BLKLYR.LT..5)GO TO 45
      CALL       DRYING(KERH2O,CLIMAT,DRYFAC,I,JJ,DEGDAZ,H2ODAY,SEASON,
     1H2OLOS,HARVST,MO,DAZE,AVGPTS,PRES,PRESMX,PLOST,JPLDAY)
   45 CONTINUE
      PLANTW=STMWT+LEFWT+HSKWT+COBWT+ROOTWT+PRES+GRAIN
   71 CONTINUE
      IF(JJ.EQ.JPLDAY)GO TO 61
   62 CONTINUE
      GO TO 24
   61 NP=JMO(JJ)
      NDZZ=IDAY(JJ)
   24 CONTINUE
      SPLOST=SPLOST+PLOST
      IF(H2OREM.LT.0.)GO TO 98
      H2OREM=H2OPRC
   99 CONTINUE
  999 CONTINUE
      MATURE=LAST
      LAST=LAST+1
      IF(BLKLYR.EQ.0.)WRITE(6,1025)
 1025 FORMAT(1H0,'VARIETY USED DID NOT MATURE IN PERIOD SUPPLIED ')
      YIELD=(GRAIN/.845)*(POPPLT/GRAMBU)*EARFAC
      GRAIN=(GRAIN/.845)*EARFAC
      IF(IIX.EQ.0) RESVOL=STORV(H)
      IF(IIX.NE.0) RESVOL=XSTOR(IS)
      IF(NOIRR.EQ.10) GO TO 711
      DO 666 JJ=LAST,JEND
  666 CALL       DAM(DEMIRR,RO,AREAIR,AREARC,H,STORV,NEWSIZ,RESET,JJ,HV,
     1HAI,HA,ZZ,ANG,CK,W,STOR,HFIX,PACRE,PE,WIDTH,F,H2OIRR,JCOUNT,IS,IIX
     1,XWIDTH,DH,XPACRE,XSTOR,ISR,CDSEP)
  711 CONTINUE
C   AT THE END OF EACH YEAR THE YIELD, TOTAL AMOUNT OF IRRIGATION WATER APPLIED
C   AND THE NUMBER OF TIMES IRRIGATION WAS PERFORMED ARE STORED IN ARRAYS
C   CORRISPONDING TO THE YEAR AND RESERVOIR SIZE.
      IF(IIX.NE.0)GO TO 5003
      YIELDG(IYEAR,ISR+1)=YIELD
      H2OAD(IYEAR,ISR+1)=H2OADD
      NSETUP(IYEAR,ISR+1)=IRRTCT
      GO TO 5001
 5003 CONTINUE
      YIELDG(IYEAR,IS)=YIELD
      H2OAD(IYEAR,IS)=H2OADD
      NSETUP(IYEAR,IS)=IRRTCT
 5001 CONTINUE
C   WHEN A COMPLETE YEAR OF DATA IS USED AND IT IS NOT THE LAST YEAR OF RECORD
C   THE NEXT YEAR GOES THROUGH THE SIMULATION PROCESS. WHEN THE DATA RECORD IS
C   COMPLETED THE FIRST TIME THE CALCULATIONS DISCRIBED BELOW ARE CONDUCTED AND
C   THE RESERVOIR SIZE IS REDUCED EACH ADDITIONAL TIME THE RESERVOIR SIZE IS
C   REDUCED AND THE COMPLETE DATA RECORD IS REPEATED UNTIL A ZERO RESERVOIR SIZE
C   EXISTS AT THIS POINT THE DAILY CALCULATIONS ARE COMPLETE.
      IF(IYEAR.EQ.NYEAR) GO TO 6
      GO TO 6666
    6 IYEAR=0
      IF(IIX.NE.0)GO TO 6555
```

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C THIS SECTION DETERMINS THE INCREMENTAL REDUCTIONS IN RESERVOIR SIZE, ISR IS
C  THE NUMBER OF DIVISIONS THE MAXIMUM SIZE RESERVOIR IS TO BE DIVIDED INTO
      IS=ISR+1
      I=0
      STRMAX=STORV(H)
      STORI=STORV(H)/ISR
  700 XSTOR(IS)=STRMAX-I*STORI
      I=I+1
      IS=IS-1
      IF(IS.NE.0)GO TO 700
C  THIS SECTION DETERMINES THE CORRISPONDING DAM HEIGHTS FOR THE REDUCED
      IS=ISR+1
      DH(1)=0.
      XWIDTH(1)=0.
      XPACRE(1)=0.
      IF(0.LT.XSTOR(2).AND.XSTOR(2).LT.STORV(1))DH(2)=XSTOR(2)/STORV(1)
      DO 701 I1=2,IS
      DO 702  I2=1,HA
      IF(STORV(I2).LT.XSTOR(I1).AND.XSTOR(I1).LT.STORV(I2+1))GO TO 703
      IF(XSTOR(I1).NE.STORV(I2+1))GO TO 702
      DH(I1)=I2+1
      XWIDTH(I1)=WIDTH(I2+1)
      XPACRE(I1)=PACRE(I2+1)
      GO TO 701
  702 CONTINUE
      GO TO 701
  703 XRATIO=(XSTOR(I1)-STORV(I2))/(STORV(I2+1)-STORV(I2))
      DH(I1)=XRATIO+I2
      XWIDTH(I1)=XRATIO*(WIDTH(I2+1)-WIDTH(I2))+WIDTH(I2)
      XPACRE(I1)=XRATIO*(PACRE(I2+1)-PACRE(I2))+PACRE(I2)
  701 CONTINUE
      DO 919 I=1,10
      IS=IS+1
      H=H+1
      DH(IS)=H
      XWIDTH(IS)=WIDTH(H)
  919 CONTINUE
      IS=IS-10
      H=H-10
      HFIX=H
C      THIS SECTION CALCULATES THE VOLUME OF THE DAM IN CUBIC YARDS
       VOLDAM(1)=0
      BASE=WIDTH(1)
      DO 818 II=2,IS
      HDAM=DH(II)+ZZ
      ID1=HDAM
      ID2=ID1+1
      XFAC=HDAM-ID1
      HWIDTH=(WIDTH(ID2)-WIDTH(ID1))*XFAC+WIDTH(ID1)
      VOLDAM(II)=.007*HDAM*(2.*BASE+HWIDTH)*(2.*(HDAM+35.)/5.+5.*HDAM)
  818 CONTINUE
      IIX=IIX+1
 6555 CONTINUE
      IS=IS-1
      IF(IS.EQ.1)  NOIRR=10
      IF(IS.EQ.0)  GO TO 6655
      GO TO 6666
 6655 CONTINUE
      IS=ISR+1
C  THIS PART DETERMINS THE YIELD DIFFERENCE DUE TO IRRIGATION
      DO 3055 I=1,NYEAR
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      DO 3055 J=1,IS
 3055 XDIFF(I,J)=YIELDG(I,J)-YIELDG(I,1)
      WRITE(6,3001)
 3001 FORMAT(1H1,51X,'RESERVOIR SIZE IN ACRE-INCH')
      WRITE(6,3002)(XSTOR(I),I=1,IS)
 3002 FORMAT(1H0,9X,11F10.2)
      WRITE(6,3003)
 3003 FORMAT(10H0   YEAR   ,48X,'YIELD IN BU/AC')
C    THIS SECTION PRINTS OUT THE YIELDS FOR EACH YEAR CORRESPONDING TO A GIVEN
C    RESERVOIR SIZE
      DO 3005 I=1,NYEAR
      WRITE(6,3004)IYER(I),(YIELDG(I,K),K=1,IS)
 3004 FORMAT(1H0,I7,2X,11F10.2)
 3005 CONTINUE
      CALL  ECONOM(NYEAR,XDIFF,NSETUP,H2OAD,IS,VOLDAM,
     1FILLPR,EXTDPR,XINT,LIFE,ALABCR,TDH,EFFP,EFFM,CKWH,GRPR,AREAIR
     1,BEINV,PERMC,FLAB,FPUM,FGRAN,FMAN,WELHED,WELCST)
      CALL   RANK(A,BEINV,NYEAR,IS)
      WRITE(6,3006)
      WRITE(6,3007)(XSTOR(I),I=1,IS)
      WRITE(6,3012)
      DO 3101 I=1,NYEAR
      IPR(I)=100.*I/(NYEAR+1)+.5
      WRITE(6,3004)IPR(I),(A(I,K),K=1,IS)
 3101 CONTINUE
      BEINV(13,1)=0.
      DO 89 I=2,IS
      AX=0.
      NSETUX=0.
      H2OADX=0.
      DO 87 J=1,NYEAR
      AX=AX+XDIFF(J,I)
      NSETUX=NSETUP(J,I)+NSETUX
      H2OADX=H2OAD(J,I)+H2OADX
   87 CONTINUE
      CL=0.0
      CP=0.0
      CM=0.0
      CG=0.0
      H2OADX= H2OADX/NYEAR
      AX=AX/NYEAR
      NSETUX=NSETUX/NYEAR
      PMPCST=CKWH*TDH*H2OADX*AREAIR*0.085308/(EFFP*EFFM)
      DAMCST=VOLDAM(I)*FILLPR+EXTDPR
      CSTLAB=NSETUX*ALABCR
      MANTCS=DAMCST*PERMC
      GRANPR=AX*GRPR*AREAIR
      DO 187 K=1,LIFE
      CL=CL+CSTLAB*((1.+FLAB)**(K-1))*((1.+XINT)**(-1.*K))
      CP=CP+PMPCST*((1.+FPUM)**(K-1))*((1.+XINT)**(-1.*K))
      CM=CM+MANTCS*((1.+FMAN)**(K-1))*((1.+XINT)**(-1.*K))
  187 CG=CG+GRANPR*((1.+FGRAN)**(K-1))*((1.+XINT)**(-1.*K))
      BEINV(13,I)=CG-CL-CP-DAMCST-CM
   89 CONTINUE
      WRITE(6,3006)
 3006 FORMAT(12H1PROBABILITY,40X,'RESERVOIR SIZE IN ACRE-INCH')
      WRITE(6,3007)(XSTOR(I),I=1,IS)
 3007 FORMAT(10H0RANKING  ,11F10.2)
      WRITE(6,3008)
 3008 FORMAT(10H0OF YIELDS,48X,'YIELD IN BU/AC')
      CALL RANK(A,YIELDG,NYEAR,IS)
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      DO 3009 I=1,NYEAR
      DO 600 J=1,IS
  600 A(I,J)=A(I,J)*KGBU*ACREHA
      IPR(I)=100.*I/(NYEAR+1)+.5
      WRITE(6,3004)IPR(I),(A(I,K),K=1,IS)
 3009 CONTINUE
 3012 FORMAT(10H0OF YIELDS,23X,'AMOUNT OF CAPITAL AVAILABLE FOR INVESTME
     1NT IN IRRIGATION SYSTEM')
      REDX=1.
      WRITE(6,3004)IPR(13),(REINV(13,K),K=1,IS)
      WRITE(6,399)H2OCAP,H2OIPR,IRPLAN,REDX
  399 FORMAT(1H1,5X,'PAW=',F5.2,'IRRIGATION APPLICATION=',F5.2,
     1'IRRIGATION PLAN=',I2,'REDUCTION IN SUMMER RAINFALL=',F3.2)
      STOP
      END
      SUBROUTINE WATERX(JJ,CLIMAT,LAI,U,ALPHA,H2OCAP,H2OPRC,WIND,RUNOFF,
     1 ZMES1,ZMES2,TDRY,ESUBS,STRESF,XSTRES,STRESS,XXX,RMULCH,PLTH2O,
     1RANSUM,TOTES,PLRTFC,SOILWX,DETAIL,ALBESO,RANCHG,EVAPFC,EVAPK,IX)
      REAL LAI
      DIMENSION CLIMAT(366,6),XSTRES(11)
      DIMENSION SOILWX(317,10), SOILW(10)
      DIMENSION EVAPK(11)
      IF(IX.NE.1) GO TO 6
      RUNOFF=0.
      ZMES1=0.
      XXX=0.
      ZMES2=0.
      TDRY=0.
      ESUBS=0.
      H2OPRZ=H2OPRC*25.4
      H2OCAZ=H2OCAP*25.4
      PLTH2O=0.
      TOTES=0.
      RANSUM=0.
      ZESUBP=0.
      STRESS=1.
      STRESF=1.
      ALBESO=.07
      ESUBZ=0.
      DO 5 J=1,10
    5 SOILW(J)=(H2OPRZ/H2OCAZ)*H2OCAZ/10.
      YX=SOILW(1)*.6
    6 CONTINUE
      RAINW=CLIMAT(JJ,4)*25.4
      RAINQX=RAINW
      ZLAIZ=LAI
      IF(LAI.GT.4.)ZLAIZ=4.
      ALBEDO=ALBESO+(.23-ALBESO)*.25*ZLAIZ
      RADNO=.75*(1.-ALBEDO)*CLIMAT(JJ,1)/59.
      IF(RAINW.GT..05) STRESF=1.
      TMPMAX=(CLIMAT(JJ,2)-32.)*.5555
      TMPMIN=(CLIMAT(JJ,3)-32.)*.5555
      TMPAVG=(TMPMAX+TMPMIN)/2.
      DELT1=.78675+(TMPAVG+.5)*.02747
      DELT1=10.**DELT1
      DELT2=.78675+(TMPAVG-.5)*.02747
      DELT2=10.**DELT2
      DELTA=DELT1-DELT2
      ESUBO=1.3*RADNO*DELTA/(DELTA+.66)
      IF(RANCHG.EQ.1.)ESUBO=EVAPFC*CLIMAT(J,5) *25.4
      ESUBSO=(DELTA/(DELTA+.66))*RADNO*(EXP(-.398*LAI))
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      ESUBSO=ESUBSO*STRESS
      ESUBSZ=ESUBSO
      IF(ZMES1.LT.U) GO TO 1
      IF(RAINW.GT.0.)GO TO 2
   24 ESUBSO=ESUBSO-RAINW
      TDRY=TDRY+1.00001
      ESUBS=ALPHA*(TDRY**.5-(TDRY-1.)**.5)
      IF(ESUBS.GT.ESUBSO) ESUBS=ESUBSO
      ZMES2=ZMES2+ESUBS
      TDRY=(ZMES2/ALPHA)**2
      GO TO 9
    2 IF(RAINW.GT.ESUBSO) GO TO 30
      ZMES1=ZMES1-RAINW
      IF(ZMES1.LT.0.)GO TO 3
      GO TO 24
    3 ZMES2=ZMES2+ZMES1
      ZMES1=0.
      GO TO 24
   20 IF(XXX.EQ.1.) GO TO 30
      WRITE(6,2020)
 2020 FORMAT(1H0,'WATER EXHAUSTED FROM PROFILE')
      GO TO 55
   30 IF(RAINW.LE.ZMES1) GO TO 35
      RAINW=RAINW-ZMES1
      ZMES2=ZMES2-RAINW
      ZMES1=0.
      IF(ZMES2.LT.0.) ZMES2=0.
      GO TO 45
    1 IF(RAINW.LE.0.)GO TO 45
      ZMES1=ZMES1-RAINW
      IF(ZMES1.GT.0.) GO TO 45
      ZMES1=0.
      IF(ZMES2.GT.0.)GO TO 50
      GO TO 45
   50 ZMES2=ZMES2-(RAINW-ZMES1)
      IF(ZMES2.GT.0.)GO TO 45
      ZMES2=0.
      GO TO 45
   35 ZMES1=ZMES1-RAINW
   45 ZMES1=ZMES1+ESUBSO*FMULCH
      IF(ZMES1.GT.U) GO TO 8
      ESUBS=ESUBSO*FMULCH
      GO TO 9
    8 ESUBS=ESUBSO*FMULCH-.4*(ZMES1-U)
      IF(ZMES2.GT.0.) GO TO 60
      ZMES2=ZMES2+.6*(ZMES1-U)
      ZMES1=U
      TDRY=(ZMES2/ALPHA)**2
    9 IF(LAI.GE..1)GO TO 10
      ESUBP=0.
      GO TO 100
   60 TDRY=TDRY+1.
      ZMES2=ZMES2+.6*ALPHA*(TDRY**.5-(TDRY-1.)**.5)
      ZMES1=U
      GO TO 9
   10 IF(LAI.GT.2.7) GO TO 18
      ESUBP=ESUBO*(-.21+.7*LAI**.5)
      ESUBZ=ESUBP
      Q=ESUBO-ESUBS
      IF(ESUBP.GT.Q) GO TO 18
      GO TO 100
```

```
   18 ESUBP=ESUBO-ESUBS
      ESUBZ=ESUBP
  100 ESUBP=ESUBP*STRESS
      EDAILY=ESUBP+ESUBS
      XESUBS=ESUBS
      XESUBP=ESUBP+ZESUBP
      YESUBP=ESUBP+ZESUBP
      PLTH2O=PLTH2O+ESUBP
      RUNPOT=RAINQX-(H2OCAZ-H2OPRZ)
      TOTES=TOTES+ESUBS
      RANSUM=RANSUM+RAINQX
      IF(RUNPOT.GT.0.)RUNOFF=RUNOFF+RUNPOT
      IF(RUNPOT.LT.0.)RUNPOT=0.
      H2OPRZ=H2OPRZ-EDAILY+RAINQX-RUNPOT
      IF(H2OPRZ.LT.0.)H2OPRZ=0.
      IF(H2OPRZ.LE.0.)GO TO 20
      RADNOX=RADNO*59.
      H2OPCT=(H2OPRZ/H2OCAZ)*100.
      PLANTE=ESUBP
      IF(DETAIL.EQ.0.)GO TO 55
      WRITE(6,1010)JJ,RADNOX,TMPMAX,TMPMIN,PLTH2O,ESUBO,ESUBSZ,ESUBS,ESU
     1BZ,PLANTE,EDAILY,STRESS,ZMES2,ZMES1,TDRY,H2OPCT,H2OPRZ,RAINQX
 1010 FORMAT(1H0,I3,F5.0,F5.1,F5.1,F8.1,6F8.3,F8.2,3F8.3,2F6.1,F6.3)
   55 CONTINUE
      IF(RAINQX.GT.0.)GO TO 102
  101 DO 125 J=1,10
      IF(SOILW(J).LE.0.)GO TO 125
      IF(XESUBS.LE.0.)GO TO 105
      SOILZ=SOILW(J)-XESUBS
      IF(SOILZ.LE.0.)GO TO 110
      SOILW(J)=SOILW(J)-XESUBS
      XESUBS=0.
  106 XESUBP=YESUBP*PLRTPC
      SOILZ=SOILW(J)-XESUBP
      IF(SOILZ.LE.0.)GO TO 115
      YESUBP=YESUBP-XESUBP
      SOILW(J)=SOILW(J)-XESUBP
      GO TO 125
  105 IF(YESUBP.LE..0001)GO TO 125
      GO TO 106
  110 XESUBS=XESUBS-SOILW(J)
      SOILW(J)=0.
      GO TO 106
  115 YESUBP=YESUBP-SOILW(J)
      SOILW(J)=0.
  125 CONTINUE
      ZESUBP=YESUBP
      GO TO 130
  102 RAINX=RAINQX
      HORCAZ=H2OCAZ/10.
      DO 225 J=1,10
      DRYCAP=HORCAZ-SOILW(J)
      IF(DRYCAP.LT.RAINX)GO TO 205
      SOILW(J)=SOILW(J)+RAINX
      RAINX=0.
      GO TO 225
  205 SOILW(J)=HORCAZ
      RAINX=RAINX-DRYCAP
  225 CONTINUE
      GO TO 101
  130 DO 31 N=1,10
```

```
 31 SOILWX(JJ,N)=SOILW(N)
    KSOILW=0.
    SOLMAX=0.
    DO 111 J=1,10
    IF(SOLMAX.EQ.1.)GO TO 111
    IF(SOILW(J).GT.YX)GO TO 112
    KSOILW=KSOILW+1
    GO TO 111
112 SOLMAX=1.
111 CONTINUE
    IF(KSOILW.EQ.0) KSOILW=1
    STRESF=XSTRES(KSOILW)
    STRESS=EVAPK(KSOILW)
    H2OPRC=H2OPRZ/25.4
    RETURN
    END
    SUBROUTINE PHZDAZ(JJ,CLIMAT,DAY,NEWDAY,IOLD,I,DEGDAZ,GRODAY,DAYINC
   1,DAYDEG,RUNAVG,AVGDAY,AVGDAX,SETMIN,SILKED,
   1DAGRIN,BLKLYR,TMPOPT,DEGREZ,JPLDAY)
    DIMENSION DAYINX(366), CLIMAT(366,6)
    REAL NEWDAY,MAX,MIN
    MAX=CLIMAT(JJ,2)
    MIN=CLIMAT(JJ,3)
    IF(MIN.LE.32.) WRITE(6,1000) JJ
1000 FORMAT(1H0,'POSSIBLE FROST DAMAGE ON',I4,' DAY AFTER PLANTING')
    IF(MAX.GT.TMPOPT) MAX=TMPOPT
    MINXX=MIN
    MAXXX=MAX
    IF(MAX.LT.SETMIN) MAXXX=SETMIN
    IF(MIN.LT.SETMIN) MINXX=SETMIN
    DEGREZ=(MAXXX+MINXX) /2.-SETMIN
    DEGDAZ=DEGDAZ+DEGREZ
    DAYINC=DEGREZ/DAYDEG
    IF(DAYINC.LE.0.)DAYINC=.001
    GRODAY=DAYINC
    DAGRIN=1.
    DAY=DAY+DAYINC
    I=(DAY*10.+5.)/10.
    IF(I.LT.1)I=1
    NEWDAY=I-IOLD
    IOLD=I
    DAYINX(JJ)=DAYINC
    AJJ=JJ
    AVG=AJJ-RUNAVG-JPLDAY
    IF(AVG.LE.0.)GO TO 10
    AVGDAY=AVGDAY+DAYINX(JJ)-DAYINX(AJJ-RUNAVG)
    GO TO 20
 10 AVGDAY=AVGDAY+DAYINX(JJ)
 20 CONTINUE
    AVGDAX=AVGDAY/RUNAVG
    RETURN
    END
    SUBROUTINE LAILEF(LEFWT,YNGLEF,DAYX,YXX,DAYINC,XSTDLA,CLASSM,
   1DMACRE,PCPPLT,PCPFAC,PLAIFC,DAYZZ,LAI,STRESF,STLAEX,PCCRN,I,
   1FACPOP,STYLE,STYLEF,JJ,SUMRAD,XDMPLT,YDMPLT,YNGLAR,
   1ZLAI,STDECL,DCRATE,PCLYNA)
    REAL LEFWT,LAI
    DIMENSION PCCRN(260,5)
    STRLAI=STRESF**STLAEX
    IF(PCLYNA.GT.0.)GO TO 20
    IF(PCCRN(I,3).EQ.0.)GO TO 99
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```
      IF(LAI.EQ.0.)GO TO 10
      DAYZZ=DAYZZ+DAYINC
      REMLAI=DMPLNT-YDMPLT
      IF(YNGLEF.GT.5.)GO TO 50
      DAYX=DAYX+DAYINC
      A=-.69897+DAYX*YNGLAR
      YNGLEF=10.**A
      PLTLEF=(YNGLEF-YXX)
      YXX=YNGLEF
      GO TO 80
   10 PLTLEF=.2
      DMPLNT=100.
      QXONE=0.
      GO TO 80
   50 IF(LYY.EQ.1)GO TO 15
      GO TO 16
   15 LYY=2
      IF(STYLE.EQ.1.)STDLA=XSTDLA-STYLEF-STYLEF*.095*CLASSM
      IF(STYLE.EQ.2.)STDLA=XSTDLA-STYLEF*.095*CLASSM
      IF(STYLE.EQ.3.)STDLA=XSTDLA+STYLEF-STYLEF*.095*CLASSM
      XQLAI=STDLA*12000./DMACRE
      IF(POPPLT.LE.12000.)GO TO 51
      XQPCP=POPPLT/12000.
      XLOG=ALOG10(XQLAI)+PLAIFC*ALOG10(XQPCP)
      DMPLNT=10.**XLOG*POPFAC
   52 CONTINUE
      IF(STYLE.EQ.1.)ALRATE=(DMPLNT-27.)/(54.-22.5-14.-CLASSM)
      IF(STYLE.EQ.2.)ALRATE=(DMPLNT-27.)/(63.-22.5-14.-CLASSM)
      IF(STYLE.EQ.3.)ALRATE=(DMPLNT-27.)/(75.-22.5-14.-CLASSM)
      XDMPLT=DMPLNT
      TAPER=6.5
   16 IF(TAPER.GE.REMLAI)GO TO 60
      PLTLEF=ALRATE*DAYINC
   80 LAI=LAI+PLTLEF*FACPOP*STRLAI
      ZLAI=LAI
      YDMPLT=LAI/FACPOP
      GO TO 100
   60 PLTLEF=.43*DAYINC*DMPLNT/STDLA
      GO TO 80
   51 DMPLNT=STDLA
      GO TO 52
   99 LYY=1
      GO TO 100
   20 IF(QXONE.GT.0.)GO TO 21
      QX=LAI*DCRATE
      DXX=JJ-PCLYNA
      IF(DXX.GT.STDECL)QXONE=1.0
      GO TO 100
   21 LAI=LAI-QX
      IF(LAI.LE.0.0)LAI=0.0
      ZLAI=LAI
  100 CONTINUE
      RETURN
      END
      SUBROUTINE PTOTAL(LAI,CLIMAT,PCPFAC,PLANTW,RESPFC,EMETFC,PTS,JJ,ST
     1RESS,PTSLEF,PTSPLT,PTABLE,I,AVGPTS,PTSPLX,DAYINC,RUNAVG,PRES,
     1 STMWT,ORESP,PRESMX,PLCST,PCCRRF,LCARDS,TLEFFC,STRESF,PRESIN,
     1ZLAI,PTSMAX)
C     THIS SUBROUTINE CALCULATES PHOTOSYNTHESIS PER DAY (PTS) PER PLANT
C     IN GRAMS OF DRY MATTER
C     CLIMAT IS RADIATION PER DAY
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C      DAYTYM AND NYTTYM ARE LENGTHS OF DAY AND NIGHT IN PHYSIOLOGICAL
C      TIME
C      RESPFC IS RESPIRATION AS A FRACTION OF PHOTOSYNTHESIS (R SUB B)
C      RMETFC IS RESPIRATION AS A FRACTION OF TOTAL DRY WEIGHT (R SUB 0)
C      PTSRED IS THE FACTOR BY WHICH LEAF WILTING REDUCES THE RATE OF
C      PHOTOSYNTHESIS
       REAL LAI
       DIMENSION PTSPLX(317), CLIMAT(366,6),PTABLE(17,20)
       IF(LAI.EQ.0.)GO TO 20
       XLAI=0.
       PTSRED=STRESF
       IF(ZLAI.LE.1.)XLAI=ZLAI
       IF(ZLAI.LE.1.)ZLAI=1.
       JLAIA=(ZLAI*20.+10.)/10.
       IF(JLAIA.GT.16)JLAIA=16
       JLAIZ=(ZLAI*10.+4.9999)/10.
       JLAIY=ZLAI
       ZY=JLAIZ-JLAIY
       IF(ZY.GT.0.)GO TO 25
       XJLAI=JLAIY
       GO TO 26
    25 XJLAI=JLAIY
       XJLAI=XJLAI+.5
    26 CONTINUE
       JLAIB=JLAIA+1
       JRADA=(CLIMAT(JJ,1)*.2+10.)/10.
       IF(JRADA.GT.19)JRADA=19
       JRADAZ=(CLIMAT(JJ,1)*.1+4.9999)/10.
       JRADY= CLIMAT(JJ,1)/100.
       ZY=JRADAZ-JRADY
       IF(ZY.GT.0.)GO TO 250
       XJRAD=JRADY*100
       GO TO 260
   250 XJRAD=JRADY
       XJRAD=XJRAD*100.+50.
   260 CONTINUE
       JRADB=JRADA+1
       SMRSML=PTABLE(JLAIA,JRADA)
       SMRBGL=PTABLE(JLAIB,JRADA)
       BGRSML=PTABLE(JLAIA,JRADB)
       BGRBGL=PTABLE(JLAIB,JRADB)
       ZSMR=(SMRBGL-SMRSML)*((ZLAI-XJLAI)/.5)+SMRSML
       ZBGR=(BGRBGL-BGRSML)*((ZLAI-XJLAI)/.5)+BGRSML
       PTS=(ZBGR-ZSMR)*((CLIMAT(JJ,1)-XJRAD)/50.)+ZSMR
       IF(ZLAI.EQ.1.)PTS=PTS*XLAI
       IF(ZLAI.EQ.1.)ZLAI=XLAI
       PTS=PTS*PCORRF
       IF(LCARDS.EQ.1)GO TO 51
       TX=CLIMAT(JJ,2)
       TDIFF=CLIMAT(JJ,2)-CLIMAT(JJ,3)
       IF(CLIMAT(JJ,3).LT.50.)TDIFF=CLIMAT(JJ,2)-50.
       TPTSFS=(TX-TDIFF)*.006
       TPTSFS=TPTSFS+((TX-TDIFF*.86)*.040)
       TPTSFS=TPTSFS+((TX-TDIFF*.70)*.066)
       TPTSFS=TPTSFS+((TX-TDIFF*.52)*.073)
       TPTSFS=TPTSFS+((TX-TDIFF*.35)*.112)
       TPTSFS=TPTSFS+((TX-TDIFF*.20)*.132)
       TPTSFS=TPTSFS+((TX-TDIFF*.08)*.138)
       TPTSFS=TPTSFS+((TX-TDIFF*.03)*.132)
       TPTSFS=TPTSFS+((TX-TDIFF*.00)*.112)
       TPTSFS=TPTSFS+((TX-TDIFF*.00)*.073)
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      TPTSFS=TPTSFS+((TX-TDIFF*.03)*.068)
      TPTSFS=TPTSFS+((TX-TDIFF*.07)*.040)
      TPTSFS=TPTSFS+((TX-TDIFF*.16)*.006)
      IF(TPTSFS.GT.115.)GO TO 50
      IF(TPTSFS.LT.50.)GO TO 50
      IF(TPTSFS.GT.95.)GO TO 55
   51 IF(LCARDS.EQ.1)TPTSFS=CLIMAT(I,2)
      TPTSFS=-.46+.01717*TPTSFS
      GO TO 60
   50 TPTSFS=0.001
      GO TO 60
   55 TPTSFS=1.0-.01717*(TPTSFS-95.)
   60 PTS=PTS*POPFAC*PTSRED*.01*(TPTSFS**TLEFFC)
   15 PTSLEF=PTS
      ACTPLT=PLANTW-PRES
      BMET=ACTPLT*BMETFC*DAYINC
      PTS=PTS-(PTS-BMET)*RESPFC-BMET
      IF(PTS.LE..01)PTS=0.
      PTSPLT=PTS
      QRESP=QRESP+PTSLEF-PTSPLT
      PTSPLX(JJ)=PTSPLT
      AJJ=JJ
      AVG=AJJ-RUNAVG
      IF(AVG.LE.0.)GO TO 10
      AVGPTS=AVGPTS+PTSPLX(JJ)-PTSPLX(AJJ-RUNAVG)
      GO TO 20
   10 AVGPTS=AVGPTS+PTSPLX(JJ)
   20 CONTINUE
      IF(AVGPTS.LT.PTSMAX)GO TO 5
      PTSMAX=AVGPTS
    5 CONTINUE
      RETURN
      END
      SUBROUTINE QPVEG(PTS,I,PCORN,GRODAY,CORNMX,ROOTWT,STMWT,LEFWT,
     1HSKWT,PRES,SILKED,TASSXX,COBWT,STRESS,HUSK,SHOOT,CLASSM,PLOST,
     1PRESMX,RESUSF,JJ,DEGDAY,SLKINF,QRESP,STRESF,SLKING,PLTLAI,
     1PLANTW,PRESAD,STYLE,PNWLFX,PRESIN,XLEFGI,RATIOS,STAGES)
      REAL LEFWT
      DIMENSION PCORN(260,5)
      PRSCLD=PRES
      IF((PCORN(I,3).EQ.0.).AND.(I.LT.10))GO TO 70
      IF(LEFWT.EQ.0.)LEFWT=.02
      RATIO=1.
      MC=I
      IF(STYLE.EQ.1.)GO TO 62
      IF(STYLE.EQ.2.)GO TO 62
      IF(STYLE.EQ.3.)GO TO 64
   62 IF(I.GT.40)MC=MC+CLASSM
      GO TO 65
   64 IF(I.GT.50)MC=MC+CLASSM
   65 CONTINUE
      F=GRODAY*CORNMX/100.
      SHOOTX=PLANTW-ROOTWT
      RUTLOG=-.52288+.96221*ALOG10(SHOOTX)
      RTSTOT=10**RUTLOG
      PQRTS=RTSTOT-ROOTWT
      IF(PQRTS.LT.0.)PQRTS=0.
      PQSTM=PCORN(MC,2)*F
      PQLEF=PCORN(MC,3)*F*XLEFGI
      PQCOB=PCORN(MC,5)*F
      PQHSK=PCORN(MC,4)*F
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```
      IF(TASSXX.GT..5)GO TO 6
      IF(PCORN(MC,2).GT.9.) GO TO 5
      PREQ=PQRTS+PQSTM+PQLEF+PQHSK+PQCOB
      PRESAZ=PRESAD
      PRESZZ=PRES/(STMWT+LEFWT+.0001 )
      IF(PRESZZ.GT..03) PRESAZ=0.
      PRES=PRES+PTS*PRESAZ
      PTS=PTS-PRESAZ*PTS
      IF(PTS.GT.PREQ) GO TO 25
      RESAVL=PRES*RESUSF
      PAVAIL=PTS+RESAVL
      IF(PAVAIL.GE.PREQ) GO TO 29
      RATIO=PAVAIL/PREQ
      PRES=PRES-RESAVL
      IF(STMWT.LT.1.)GO TO 27
      PNWLEF=PTS*PNWLEX
       IF(PNWLEF.GT.PQLEF)GO TO 27
      LEFWT=LEFWT+PNWLEF
      PQLEF=PQLEF-PNWLEF
      PAVAIL=PAVAIL-PNWLEF
      PREQ=PREQ-PNWLEF
      RATIO=PAVAIL/PREQ
      GO TO 27
   29 PRES=PRES-PREQ+PTS
   27 LEFWT=LEFWT+PQLEF*RATIO
      ROOTWT=ROOTWT+PQRTS*RATIO
      STMWT=STMWT+PQSTM*RATIO
      HSKWT=HSKWT+PQHSK*RATIO
      COBWT=COBWT+PQCOB*RATIO
   81 IF(HUSK.GT.0.) GO TO 50
      IF(PQHSK.GT.0.)GO TO 310
      GO TO 50
  310 HUSK=1.
      SHOCT=MC
      SLKING=SLKINF+SHOCT
      GO TO 50
    6 PREQ=PQHSK+PQCOB
      IF(PTS.GT.PREQ) GO TO 30
      RESAVL=PRES*RESUSF
      PAVAIL=PTS+RESAVL
      IF(PAVAIL.GE.PREQ)GO TO 31
      RATIO=PAVAIL/PREQ
      PRES=PRES-RESAVL
      GO TO 32
   31 PRES=PRES-PREQ+PTS
      GO TO 32
   30 RATIO=PTS/PREQ
      IF(RATIO.GT.1.15) RATIO=1.15
      PRES=PRES+PTS-PREQ*RATIO
   32 HSKWT=HSKWT+PQHSK*RATIO
      COBWT=COBWT+PQCOB*RATIO
      GO TO 50
   25 RATIO=PTS/PREQ
      IF(RATIO.GT.1.15) RATIO=1.15
      PRES=PRES+PTS-PREQ*RATIO
      GO TO 27
    5 CONTINUE
      TASSXX=JJ
      GO TO 6
   50 IF(RATIO.GT.1) RATIO=1.
      IF(RATIO.LT.0.) RATIO=0.
```

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      RATIOX=RATIO**.25
      IF(RATIOX.LE..5) RATIOX=.5
      IF(HSKWT.GT..001) SHOOT=SHOOT+RATIOX*GRODAY
      IF(PRES.GT.PRESMX) GO TO 53
   54 IF(SHOOT.GE.SLKING) GO TO 60
      GO TO 70
   53 PLOST=PRES-PRESMX
      PRES=PRESMX
      GO TO 54
   60 IF(SILKED.GT.0.)GO TO 70
      SILKED=JJ
   70 PTS=0.
      PRESIN=PRES-PRSOLD
      RETURN
      END
      SUBROUTINE TASSEL(I,JJ,DEGDAZ,TASSXX,SILKED,SLKING,SHOOT,
     1CLASSM,PCORN,POLYNA,CFESP,STRESF,KOUNT1,VTRTEX,VEGFCT,
     1RATIOS,STAGES,GRODAY)
      DIMENSION PCORN(260,5)
      LL=CLASSM
      MC=I+LL
      IF(POLYNA.GT.0.) GO TO 50
      IF((TASSXX.GT..5) .AND. (SILKED.GT..5)) GO TO 49
      IF(TASSXX.GT..5)GO TO 10
      IF(SILKED.GT..5) GO TO 22
      IF(SHOOT.GT.SLKING) GO TO 21
      SHOOT=SHOOT+STRESF*GRODAY
   22 IF(PCORN(MC,2) .GT.9.) GO TO 25
      GO TO 50
   10 IF(SHOOT.GT.SLKING) GO TO 15
      SHOOT=SHOOT+STRESF*GRODAY
      KOUNT1=KOUNT1+1
      GO TO 50
   15 CONTINUE
      SILKED=JJ
      GO TO 50
   25 CONTINUE
      TASSXX=JJ
      GO TO 50
   21 CONTINUE
      SILKED=JJ
      GO TO 22
   49 POLYNA=JJ
   50 CONTINUE
      RETURN
      END
      SUBROUTINE KERNOZ(I,JJ,KERDAY,KERFIX,              PTSFLT,AVGPTS,KE
     1RNUM,KERPOT,EARZ,EARMAX,XSKER,ELKIYS,EGFP,KERKON,CORNMX,RUNAVG,
     1AVGDAY,DAYINC,ADJFAC,PRES,BMETFC,PLANTW,KERNLF,EARNMX,VEGPOT,
     1YSTEMF,STMWT,GRODAY,                VTRTEX,EARPOT,AGEFCT,XSKERX,
     1XSKREX,STRESF,PTSMAX)
      REAL KERDAY,KERFIX,KERNUM,         KERPOT,KERADJ,KERNLF,KERNMX
      IF(KERKON.GT.0) GO TO 10
      KERNMX=EARNMX*EARMAX
      KERPOT=STMWT*YSTEMF
      KERPOT=KERPOT*KERNLF
      IF(KERPOT.GT.KERNMX) KERPOT=KERNMX
      IF(KERPOT.LT.0.) KERPOT=0.
      KERKON=1
   10 CONTINUE
      KERADJ=(AVGPTS/PTSMAX) *100.0
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   IF(KERADJ.GT.70.)GO TO 50
   KERADJ=KERADJ*.0174533
   XSKER=XSKER+SIN(KERADJ)
   GO TO 51
50 XSKER=.93+(KERADJ-70.)*.002+XSKER
51 KERDAY=KERDAY+1.0
   IF(KERDAY.LT.KERFIX) GO TO 40
   XSKERX=(XSKER/KERDAY)**XSKREX
   IF(XSKERX.GT.1.)XSKERX=1.
   KERNUM=KERPOT*XSKERX
   IF(KERNUM.GT.KERNMX) KERNUM=KERNMX
   KERDAY=KERDAY+1.
   KEARZ=KERNUM/(EARMAX*.33)
   EARZ=KEARZ+1
   KERKON=2
40 CONTINUE
   RETURN
   END
   SUBROUTINE GRAINZ(I,JJ,DEGREZ,KERNUM,MO,DAZE,ENTRY,PCCRN,WTKERN,
  1DAYINC,GRNSTU,AVGPTS,BARREN,HSKWT,COBWT,PTS,OILFAC,PRESMX,BLKLYR,
  1QUALTY,PLCST,PEES,EARZ,EARMX,EARNMX,KERPCT,GRAIN,RUNAVG,EARFAC)
   INTEGER MO,DAZE
   REAL KERNUM,KERPOT
   DIMENSION PCCRN(260,5)
   IF(ENTRY.GT.0.0) GO TO 1
   PKERN=1.0
   GRAIN=0.0
   ENTRY=1.00
   STDKEN=0.33
   PHDAY=0.0
   ACTKER=0.0
   GNRIPE=0.0001
   PQCOB =(KERPOT*.16-COBWT)/GRNSTU
   PQHUSK=(KERPCT*.08-HSKWT)/GRNSTU
   PQREQ=(PQHUSK+PQCOB)*DAYINC
   IF(PQHUSK.LE.0.0) PQHUSK=.001
   IF(PQCOB.LE.0.0) PQCOB=.001
   PXHUSK=PQHUSK
   PXCOB=PQCOB
   AVGPTY=AVGPTS/RUNAVG
   EARFAC=AVGPTY/BARREN
   IF(EARFAC.GT.1.0) EARFAC=1.0
 1 CONTINUE
   AVGPTY=AVGPTS/RUNAVG
   PHDAY=PHDAY+DAYINC
   IF(KERNUM.LE.0.0) GO TO 70
   IF(ACTKER.GT.0.0) GO TO 2
   PQHUSK=PXHUSK*KERNUM/KERPOT
   PQCOB=PXCOB*KERNUM/KERPCT
   PQREQ=(PQHUSK+PQCOB)*DAYINC
   PKERN=KERNUM/WTKERN
 2 CONTINUE
   PLRATE=0.427*DEGREZ*WTKERN/(STDKEN*1000.0)
   IF(ACTKER.GT.0.0) GO TO 50
   IF(PHDAY.GT.GRNSTU) GO TO 49
70 CONTINUE
   IF(AVGPTY.LT.PQREQ) GO TO 77
   GO TO 79
49 ACTKER=PKERN
50 PQREQ=PKERN*PLRATE
   IF(AVGPTY.GT.PQREQ) GO TO 51
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      DEFCIT=PQREQ-AVGPTY
      RESERV=DEFCIT*0.75
      IF(PRES.GT.RESERV) GO TO 76
      AVAIL=AVGPTY+PRES
      PRES=0.0
      AVGPTY=0.0
      GRAIN=GRAIN+AVAIL*CILFAC
      GO TO 60
   51 GRAIN=GRAIN+PQREQ*CILFAC
      PRES=PRES+AVGPTY-PQREQ
      AVGPTY=0.0
      IF(PRES.LT.PRESMX) GO TO 60
      PLOST=PRES-PRESMX
      PRES=PRESMX
      GO TO 60
   76 GRAIN=GRAIN+(AVGPTY+RESERV)*CILFAC
      PRES=PRES-RESERV
      AVGPTY=0.0
      GO TO 60
   77 DEFCIT=PQREQ-AVGPTY
      RESERV=DEFCIT*0.75
      IF(PRES.GT.RESERV) GO TO 78
      COBWT=COBWT+PQCOB* DAYINC*(AVGPTY+PRES)/PQREQ
      HSKWT=HSKWT+PQHUSK*DAYINC*(AVGPTY+PRES)/PQREQ
      PRES=0.0
      AVGPTY=0.0
      GO TO 60
   78 HSKWT=HSKWT+PQHUSK*DAYINC*(AVGPTY+RESERV)/PQREQ
      COBWT=COBWT+PQCOB* DAYINC*(AVGPTY+RESERV)/PQREQ
      PRES=PRES-RESERV
      AVGPTY=0.0
      GO TO 60
   79 HSKWT=HSKWT+PQHUSK*DAYINC
      COBWT=COBWT+PQCOB* DAYINC
      PRES=PRES+AVGPTY-PQREQ
      AVGPTY=0.0
      IF(PRES.LT.PRESMX) GO TO 60
      PLOST=PRES-PRESMX
      PRES=PRESMX
   60 IF(ACTKER.LE.0.0) GO TO 100
      GNRIPE=GNRIPE+FLRATE
C   FILLING PERIOD IS ASSUMED TO END WHEN AVERAGE KERNEL IS FILLED ASSUMING
C   THAT THE MOST FAVORED KERNELS ARE NOT RESTRICTED BY DEFICIENCY
C   OF PHOTOSYNTHATE AND THAT THE WHOLE COB MATURES WHEN THE MOST FAVORED
C   KERNELS MATURE
      IF(GNRIPE.LT.WTKERN) GO TO 100
      BLKLYR=JJ
  100 CONTINUE
      EARHSC=GRAIN+HSKWT+COBWT
      QUALTY=GRAIN/(WTKERN*EKERN)
      RETURN
      END
      SUBROUTINE DRYING(KERH2O,CLIMAT,DRYFAC,I,JJ,DEGDAY,H2ODAY,SEASON,
     1H2OLOS,HARVST,MO,DAZE,AVGPTS,PRES,PRESMX,PLOST,JPLDAY)
      INTEGER MO,DAZE
      REAL KERH2O
      DIMENSION CLIMAT(366,6)
      PRES=PRES+AVGPTS
       IF(PRES.LT.PRESMX) GO TO 10
      PLOST=PRES-PRESMX
   10 CONTINUE
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      IF(CLIMAT(JJ,4).GT..01)GO TO 100
      H2OLOS=DRYFAC
      KERH2O=KERH2O-H2OLOS
      IF(KERH2O.LE.HARVST)GO TO 95
      GO TO 100
   95 CONTINUE
      SEASON=JJ-JPLDAY
  100 CONTINUE
      RETURN
      END
      SUBROUTINE DAYDAT(DAYNO,MO,DAZE)
C  CONVERTS DAY OF YEAR TO MONTH AND DAY
C  ALL PARAMETERS PASSED ARE INTEGERS
C
      INTEGER*4 DAYNO,MO,DAZE
      INTEGER*4 DACNT (12) /31,28,31,30,31,30,31,31,30,31,30,31/
      MO = 1
      DAZE=DAYNO
      DO 10 I=1,12
      IF(DAZE.LE.DACNT(I))GO TO 20
      MO = MO+1
      DAZE=DAZE-DACNT(I)
   10 CONTINUE
   20 RETURN
      END
      SUBROUTINE DAM(DEMIRR,RO,AREAIR,AREARO,H,STORV,NEWSIZ,RESET,JJ,HV,
     1HAI,HA,ZZ,ANG,CK,W,STOR,HFIX,PACRE,EE,WIDTH,R,H2OIRR,JCOUNT,IS,IIX
     1,XWIDTH,DH,XPACRE,XSTOR,ISR,QDSEP)
      DIMENSION RO(366),STORV(65),XSTOR(25),PACRE(65),XPACRE(25),
     1WIDTH(60),XWIDTH(35),DH(35),R(366)
      INTEGER HA,HV,HAI,H,HFIX
      IF(JCOUNT.NE.1) GO TO 15
      H2OI=H2OIRR
      DAYSOR=0.0
      TODRY=0.0
   15 JCOUNT=2
      QIN=RO(JJ)*AREARO
      QIROUT=DEMIRR*AREAIR
      IF(ZZ.EQ.0.)ZZ=5.
      II=IS
      ISS=IS
      IF(IIX.NE.0) GO TO 100
      II=H
      DO 14 I=1,H
      IF(STOR.LE.STORV(II)) HE=II
   14 II=H-1
      IF(HE.EQ.0) HE=1
      PONDA=PACRE(HE)
      DHIGHT=H+ZZ
      IDAM=DHIGHT
      PONDF=PACRE(IDAM)
      DWIDTH=WIDTH(HE)
      HI=H
      GO TO 101
  100 DO 114 I=1,IS
      IF(STOR.GT.XSTOR(II))GO TO 114
      HE=DH(II)
      ISS=II
  114 II=IS-I
      IF(HE.EQ.0) HE=1
      PONDA=XPACRE(ISS)
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      DWIDTH=XWIDTH(ISS)
      HI=DH(IS)
      DHIGHT=HI+ZZ
      I=0
  105 I=I+1
      IF(DH(I).LE.DHIGHT.AND.DHIGHT.LT.DH(I+1)) GO TO 106
      GO TO 105
  106 IF(I.GT.ISR+1) GO TO 17
      PCNDB=XPACRE(I)
       GO TO 18
   17 PCNDB=XPACRE(ISR+1)
   18 CONTINUE
  101 CONTINUE
      EVLOS=PCNDA*PE
      IF(ANG.EQ.0.) ANG=3.
      IF(W.NE.0.) GO TO 16
      W=12.
      IF(DHIGHT.GT.15) W=.2*HI+10.
   16 Z=DHIGHT-HE
      IF(CK.EQ.0.) CK=0.00004
      L=(1.3*HE+2.*Z-HE/6.) *ANG+W
      QSEEP=(4.*CK*HE**2)/(9.*L)
      QSEEP=QSEEP*DWIDTH*12.*1440./43560.
      QRAIN=PCNDB*R(JJ)
      DIFFQ=QIN-QIRODT-QSEEP-EVLOS+QRAIN-QDSEP*PONDA
      STOR=STOR+DIFFQ
      IF(IIX.NE.0) GO TO 102
      IF(STOR.GT.STORV(H)) STOR=STORV(H)
      GO TO 103
  102 IF(STOR.GT.XSTOR(IS)) STOR=XSTOR(IS)
  103 IF(STOR.LE.0.) STOR=0.
      IF(STOR.GT.0.) GO TO 13
      IF(IIX.NE.0.AND.IS.EQ.1) GO TO 104
      WRITE(6,11) JJ
   11 FORMAT(5X,17H RESERVOIR IS DRY,5X,I6)
  104 CONTINUE
      H2OIRR=0.
      DAYSDR=DAYSDR+1
      IF(DAYSDR.LT.NEWSIZ) GO TO 12
      TDDRY=DAYSDR+TDDRY
      DAYSDR=0.
      IF(IIX.NE.0) GO TO 12
      RESET=10
      IF(H.LT.HFIX) GO TO 10
      RESET=0
      GO TO 12
   10 H=H+1
   13 H2OIRR=H2OI
   12 RETURN
       END
      SUBROUTINE SRUNCF(PET,MU,ML,VAR1,VAR2,VAR3,VAR4,HD,I,R,RO,M,PE,PR)
      DIMENSION PR(10)
      DIMENSION PET(12),RC(366),HD(24),ER(24),R(366)
       REAL MU,ML
      IF(R(I).GE..01) GO TO11
      PE=PET(M)
      GO TO 12
   11 PE=PET(M)/2.
   12 CONTINUE
      IF(MU.GT.0.) GO TO 13
      ML=ML-PE*ML/VAR3
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    GO TO 23
 13     MU=MU-PE
    IF(MU.GE.0.) GO TO 23
    ML=ML+MU
    MU=0.
 23  CONST=VAR2*ML/VAR3
     ML=ML-CONST
    RO(I)=VAR4*CONST
     IF(ML.LT.0.)  ML=0.
    IF(H(I).EQ.0.) GO TO 31
     DO 30 II=1,24
    DO 30 J=1,10
     IF  (II.EQ.1)  GO TO 15
    HR(II)=H(I)*(HD(II)-HD(II-1))*PR(J)
     GO TO 25
 15 HR(II)=H(I)*HD(1)*PR(J)
 25  IF(HR(II).GT.VAR1) GO TO 40
     MU=MU+HR(II)
     GO TO 50
 40  RO(I)=RO(I)+HR(II)-VAR1
     MU=MU+VAR1
 50  IF(MU.LE.1.)  GO TO 30
     ML=ML+MU-1.
     MU=1.
     IF(ML.LE.VAR3)  GO TO 30
     RO(I)=RO(I)+ML-VAR3
     ML=VAR3
 30 CONTINUE
 31 CONTINUE
     RETURN
    END
    SUBROUTINE IRIGAT(JJ,H2OTRN,H2ODEF,CLIMAT,H,H2OAID,H2OIRR,HFIX
   1,DEMIRR,STOR,AREAIR,STORV,IRRTOT,H2,IS,XSTOR,IIX,H2OLIM,IRPLAN,
   1TASSXX,SILKED,BLKLYR,SAVIRR,EFFS)
    DIMENSION STORV(65),CLIMAT(366,6),XSTOR(25)
    INTEGER H,HFIX
    IRRST=0
    H2OIRR=H2
    IRR=0
    IF(IRPLAN.EQ.1)GO TO 25
    IF(IIX.EQ.0)GO TO 25
    IF(SILKED.GT.1.OR.TASSXX.GT.1)GO TO 25
    ADDH2O=STOR/AREAIR-SAVIRR
    IF(XSTOR(IS)/AREAIR.LT.H2OLIM)H2OLIM=XSTOR(IS)*.95/AREAIR
    IF(ADDH2O.LT..1)GO TO 35
    IF(ADDH2O.LT.H2OIRR)H2OIRR=ADDH2O
    GO TO 101
 25 IF(BLKLYR.GT.1)GO TO 35
    IF(H2OTRN.GE.H2ODEF) IRRST=10
    IF(IRRST.NE.10)GO TO 444
    IF(CLIMAT(JJ,4).LT..25)IRR=1
444 CONTINUE
    IF(IRR.NE.1)GO TO 35
     ADDH2O=STOR/AREAIR
    IF(ADDH2O.LT.H2OIRR.AND.H.LT.HFIX) ADDH2O=H2OIRR
    IF(ADDH2O.LT.H2OIRR)H2OIRR=ADDH2O
    IF(IIX.EQ.0)GO TO 101
    IF(IIX.NE.0.AND.IS.EQ.1)GO TO 101
    IF(XSTOR(IS)/AREAIR.LT.H2OLIM)H2OLIM=XSTOR(IS)*.95/AREAIR
101 CONTINUE
    IF(H2OIRR.LT.H2OLIM)GO TO 35
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      H2OACD=H2OACD+H2OIRR/EFFS
      IRRTOT=IRRTOT+1
      CLIMAT(JJ,4)=CLIMAT(JJ,4)+H2OIRR
      DEMIRR=H2OIRR/EFFS
      GO TO 36
   35 DEMIRR=0.
   36 CONTINUE
      RETURN
      END
      SUBROUTINE RANK(A,X,N,K)
C    THIS SUBROUTINE RANKS THE YIELD DIFFERENCES BETWEEN IRRIGATED AND
C    NONIRRIGATED CONDITIONS.
      DIMENSION A(25,25),X(25,25)
      J=K
   14 I=N
      A(I,J)=X(I,J)
      JX=1
      II=1
   10 IF(A(I,J).LT.X(II,J))GO TO 12
   11 II=II+1
      IF(II.LE.N) GO TO 10
      I=I-1
      X(JX,J)=X(JX,J)-1000000.0
      IF(I.EQ.0) GO TO 13
      II=1
   12 A(I,J)=X(II,J)
      JX=II
      GO TO 11
   13 DO 15 JJ=1,N
   15 X(JJ,J)=X(JJ,J)+1000000.0
      J=J-1
      IF(J.NE.0) GO TO 14
      RETURN
      END
      SUBROUTINE ECONOM(NYEAR,XDIFF,NSETUP,H2OAD,IS,VOLDAM,
     1FILLPR,EXTDPR,XINT,LIFE,ALABOR,TDH,EFFP,EFFM,CKWH,GRPR,AREAIR
     1,BEINV,PERMC,FLAB,FPUM,FGRAN,FMAN,WELHED,WELCST)
C    THIS SUBROUTINE LOOKS AT THE ECONOMICS AND DETERMINS WHAT AMOUNT OF CAPITAL
C    WOULD BE AVAILABLE FOR INVESTING IN AN IRRIGATION SYSTEM FOR EACH RESERVOIR
C    SIZE AND PROBABILITY OF SUCCESS.
      DIMENSION XDIFF(25,25),NSETUP(25,25),H2OAD(25,25),
     1VOLDAM(25),BEINV(25,25)
      WELHED=WELHED+TDH
      DO 15 I=1,IS
      DAMCST=VOLDAM(I)*FILLPR+EXTDPR
      MANTCS=DAMCST*PERMC
      DO 25 J=1,NYEAR
      CSTLAB=NSETUP(J,I)*ALABOR
      PUMCST=CKWH*TDH*H2OAD(J,I)*AREAIR*0.085308/(EFFP*EFFM)
      GRANPR=XDIFF(J,I)*GRPR*AREAIR
      CL=0.
      CP=0.
      CG=0.
      TX=0.
      CM=0.0
      DO 30 K=1,LIFE
      CL=CL+CSTLAB*((1.+FLAB)**(K-1))*((1.+XINT)**(-1.*K))
      CP=CP+PUMCST*((1.+FPUM)**(K-1))*((1.+XINT)**(-1.*K))
      CM=CM+MANTCS*((1.+FMAN)**(K-1))*((1.+XINT)**(-1.*K))
   30 CG=CG+GRANPR*((1.+FGRAN)**(K-1))*((1.+XINT)**(-1.*K))
      BEINV(J,I)=CG-CL-CP-DAMCST-CM+TX
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      IF(I.NE.IS.OR.WELCST.EQ.0.0) GO TO 25
      CM=0.0
      CP=0.0
      PUMCST=CKWH*WELHED*H2OAD(J,I)*AREAIR*0.085308/(EFFP*EFFM)
      MANTCS=WELCST*PERMC
      DO 45 KK=1,LIFE
      CP=CP+PUMCST*((1.+FPUM)**(K-1))*((1.+XINT)**(-1.*K))
   45 CM=CM+MANTCS*((1.+FMAN)**(K-1))*((1.+XINT)**(-1.*K))
      WELECC=CG-CL-CP-CM-WELCST
      WRITE(6,100) WELECO
  100 FORMAT(10X,F10.2)
   25 CONTINUE
   15 CONTINUE
      RETURN
      END
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     .     .12   .     .         .     .14   .     .         .     .16   .     .
     .     .19   .     .         .     .20   .     .         .     .25   .     .
     .10   .25   .     .         .20   .30   .     .         .20   .30   .     .
     .30   .35   .     .         .30   .40   .     .         .40   .45   .     .
     .40   .80   .     .         .50   .75   .     .         .70   .75   .     .
     .70   .60   .     .         .80   .50   .     .         .70   .40   .     .
     .70   .40   .     .         .60   .30   .     .         .50   .20   .05   .
     .40   .30   .05   .         .50   .10   .10   .         .30   .10   .10   .
     .30   .10   .10   .05       .30   .10   .10   .05       .40   .10   .15   .10
     .30   .     .20   .10       .20   .     .20   .10     10.00   .     .20   .10
   10.00   .     .20   .10     10.00   .     .20   .10     10.00   .     .20   .10
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     .30   .35   .     .         .30   .40   .     .         .40   .45   .     .
     .40   .80   .     .         .30   .75   .     .         .70   .75   .     .
     .60  1.00                   .90  1.00                  1.00  1.00
    1.00  1.00                  1.00  1.00                  1.00   .80
    1.00   .90                  1.00   .90                   .30   .70
     .70   .60   .     .         .80   .50   .     .         .70   .40   .     .
     .30   .10   .10   .05       .30   .10   .15   .10       .40   .10   .15   .10
     .40   .30   .05   .         .50   .10   .10   .         .30   .10   .10   .
     .70   .40   .     .         .60   .30   .     .         .50   .20   .05   .
     .30   .     .20   .10       .20   .     .20   .10     10.00   .     .20   .10
   10.00   .     .20   .10     10.00   .     .20   .10     10.00   .     .20   .10
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  .40   .80   .     .           .50   .75   .     .           .70   .75   .     .
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 1.00  1.00                    1.00  1.00                    1.00   .80
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  .70   .60   .     .           .80   .50   .     .           .70   .40   .     .
  .70   .40   .     .           .60   .30   .     .           .50   .20   .05   .
  .40   .30   .05   .           .50   .10   .10   .           .30   .10   .10   .
  .30   .10   .10   .05         .30   .10   .15   .10         .40   .10   .15   .10
  .30   .     .20   .10         .20   .     .20   .10       10.00   .     .20   .10
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  .10   .25   .     .           .20   .30   .     .           .20   .30   .     .
  .30   .35   .     .           .30   .40   .     .           .40   .45   .     .
  .40   .80   .     .           .50   .75   .     .           .70   .75   .     .
  .60  1.00                     .90  1.00                    1.00  1.00
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  .70   .60   .     .           .80   .50   .     .           .70   .40   .     .
  .70   .40   .     .           .60   .30   .     .           .50   .20   .05   .
  .40   .30   .05   .           .50   .10   .10   .           .30   .10   .10   .
  .20   .10   .10   .05         .30   .10   .15   .10         .40   .10   .15   .10
  .30   .     .20   .10         .20   .     .20   .10       10.00   .     .20   .10
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  .     .     .20   .10         .     .     .20   .10         .     .     .20   .10
  .     .     .30   .60         .     .     .20   .60         .     .     .10   .40
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        32   56   76   96 117 132 147 166 181 196 210 224 237 250 263 279 292 305 318
        40   71   99 124 148 169 190 211 230 250 270 290 307 325 342 359 376 393 410
        46   83 114 140 168 191 217 240 264 287 311 330 351 372 393 414 435 456 477
        50   90 125 155 182 208 236 260 287 310 336 366 380 405 430 455 480 505 530
        51   95 134 165 194 220 249 275 304 327 355 381 402 427 452 470 495 518 540
        52   98 140 173 202 230 260 287 316 340 369 393 412 442 466 490 515 540 565
        53 100 144 177 209 237 268 295 325 350 377 403 428 434 479 505 527 550 575
        54 101 146 192 214 244 274 302 331 358 386 410 435 462 487 510 535 560 585
        55 102 148 185 216 247 278 307 337 364 392 415 442 468 493 516 540 567 592
        56 103 149 186 219 249 280 310 340 368 396 421 446 473 499·525 550 575 600
        57 105 150 187 220 251 281 312 342 370 400 424 450 475 500 526 551 577 601
        58 106 151 188 221 252 282 313 343 371 401 425 452 476 501 527 552 578 602
        60 108 152 188 222 253 283 314 344 372 402 426 453 477 502 528 553 579 603
        61 109 153 189 224 254 284 315 345 373 403 427 454 478 503 529 554 580 604
        62 110 154 190 225 255 285 316 346 374 404 428 455 479 504 530 555 581 605
    1. .995   .99   .98   .97   .96   .80   .57   .10   .01 1.76
    1. .995   .99   .98   .97   .96   .30   .57   .10   .01 1.76
        .53        .0496        5.858          .44           1.5           .5
  .75    .5   .10   .30  .001    9.    7.   .10   22.   50.   86.   20.    5.  1.3    1.
    1. 5.50    1.   .10   12.   1.5 5.50    .1   30.   20.   .95    1.   2.8   12.    5.
  2.    0 .33500.200. 2.0 4.0 1.0 1.0.069110.0.7010.0.005 6.0AVERAGE VALUES
        .50     30000.        2.75         1.93            25            10           .0          1
 100.0  300.                .0000              17    42    12    30    25    1  0.0  .75
      .04       .06       .09       .33       .18       .09       .07       .06       .04       .04
     .020       .06       .06       .06       .00    24000.    100.0    950.0      .050
 0.0 0.0 0.0 0.0 0.0194.210.210.218.227.234.243.251.260.268.277.284.293.310.310.
318.326.334.343.352.360.369.376.385.394.402.411.420.429.437.445.454.462.471.480.
488.496.
  0.00  0.02  0.04  0.13  0.21  0.46  0.70  1.01  1.32  1.67  2.01  2.52  3.02
  3.36  3.69  4.26  4.83  5.32  5.80  6.53  7.25  7.89  8.53  9.19  9.84 10.78
 11.73 12.73 13.73 14.73
0.0110.0220.0350.0480.0640.0800.1000.1200.1470.1810.2350.663
0.7720.8200.8500.8800.8930.9160.9340.9520.9640.9750.9881.000
0.0010.0030.0250.0630.1210.1750.1900.1710.1280.0660.0240.004
  .95   .85   .80   .75   .65   .55   .50   .40   .30   .15   .00
   .110   200.     .53     .90    300.    .045     1.5     3.0  2000.   266.7      10
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