DEVELOPMENT AND TESTING OF A MULTIPURPOSE HYDROLOGIC YIELD MODEL

by

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CHAPTER I

INTRODUCTION

A dependable supply of water for domestic, agricultural and industrial use in the United States has increased in importance during the past few years. Although water is fundamentally a renewable resource in some regions, it is becoming increasingly scarce. For example, the water levels in many reservoirs are falling and groundwater tables are declining to dangerously low levels in many areas, thus resulting in periodic restrictions placed upon its use. In an effort to remedy these conditions extensive research is being conducted on the technological possibilities of providing sufficient water to meet man's increasing demands. These technological possibilities include providing new supplies of fresh water while increasing the efficiency of available supplies.

Statement of Problem

A possible method for increasing the water supply within a particular locality is by weather modification. Weather modification is an attempt to alter the atmospheric conditions, thereby providing a more favorable distribution of precipitation. During the past thirty years the main emphasis of weather modification has been to increase localized precipitation. Although considerable research has been conducted in the past two decades on cloud seeding technology, the effect on the hydrological environment remains uncertain.

In addition to methods of providing new supplies of water by weather modification, methods to increase the efficiency of available water supplies have also received considerable attention. The method of optimizing available water supplies considered in this study is the utilization of effluent from wastewater-treatment plants for irrigation purposes. This method involves the controlled discharge of wastewater to the land for the purpose of promoting plant growth. A major factor which must be considered in land application of wastewater effluent is the design of a storage facility for wastewater control. The design of such a facility requires the evaluation of the relative effect of various conditions on the minimum containment volume necessary to store and control the wastewater effluent.

This research study consisted of the development of a new methodological approach to the previously described problems. The new methodology was incorporated into a computer program initially developed by Bean (1). The final computer program considers selective land disposal and evaporative techniques to enhance agricultural production under various geographic and climatic conditions. The computer program can be used to predict the optimized design for a disposal control facility in addition to evaluating the hydrological effects resulting from the implementation of a rainfall alteration scheme.

CHAPTER II

REVIEW OF PREVIOUS PROGRAM PARAMETERS

The purpose of this Chapter is to review the basic theories and concepts utilized in the computer program developed previous to this study which established feedlot runoff control and disposal guidelines (1). Presented in the first section are the concepts and principles of evapotranspiration. The second section reviews the hydrological aspects of infiltration, interception and surface runoff. Presented in the final section are the concepts of moisture redistribution.

Evapotranspiration

The concept of evapotranspiration was incorporated into the program to evaluate the change in the soil-moisture regime as a result of a change in the climatic environment. Evapotranspiration as used in this study is defined as the rate of moisture loss to the atmosphere as a result of the evaporation of water from plants and/or a specified surface under ambient climatological conditions. It should be noted that a difference exists between potential and actual evapotranspiration for any given site. The potential evapotranspiration, more correctly termed the evapotranspiration potential, is the maximum rate of moisture lost under ideal conditions. Therefore, the evapotranspiration potential is the upper boundary limit on the rate of moisture loss. This fact necessitates that the actual value of the evapotranspiration can never be greater than the evapotranspiration potential and is usually appreciably lower. The evapotranspiration potential as well as the actual evapotranspiration for any crop and soil condition can only be estimated by indirect means.

A common method for computing evapotranspiration is the Penman combination equation. This equation is capable of considering the effects of various climatic conditions on the rate of evaporation likely to occur from lakes, bare soil, and vegetative surfaces. The Penman equation incorporates both energy balance and aerodynamic transport theories into a single mathematical expression. The mathematical model, based on the Penman equation as developed by Bean (1), for determining the daily evapotranspiration is shown in Equation (1).

$$\begin{aligned} ETP = {} & 0.039\ Ta^{0.673}\ [(1-r)\ Ra\ (0.22 + 0.54\ PSUNS) - \\ & 2.010 \times 10^{-9}\ T^{4}\ (0.98 - a-b\sqrt{ES \times RHD}) \times (0.1 + 0.9\ PSUNS)] \\ & + (1 - 0.039\ Ta^{0.673}) \times 0.26(e + 0.01\ WVD)\ (ES - ES \times RHD) \end{aligned} \tag{1}$$

where

ETP = evapotranspiration potential, in inches

Ta = mean daily air temperature, in $^{\circ}F$

T = mean daily air temperature, in $^{\circ}K$

Ra = solar radiation, in mm of water

PSUNS = percent sunshine, in %/100

ES = saturated vapor pressure at Ta, in millibars

RHD = relative humidity, in %/100

WVD = wind speed, in miles/day

a,b = geographic location constants

r = reflectance coefficient (albedo)

e = mass transfer coefficient

The variables Ra, PSUNS, RHD and WVD for a specific geographic location are extrapolated monthly averages from first-order weather station data while T and Ta are computed from daily climatological records. The value of the reflectance coefficient is dependent on the type of surface cover. The evaporation potential is equivalent to evaporation from a free water surface when r is equal to 0.05. For green crops r varies from 0.20 to 0.25. The geographic location constants can be obtained by the methods described by Zovne and Koelliker (2). The saturated vapor pressure, according to Linsley (3), can be computed by the use of Equation (2).

$$ES = 33.9 \, [(0.00738 + 0.8072)^{8} - 0.000019 \, | \, 1.8Ta + 48 \, | + 0.001316] \qquad (2)$$

where

ES and Ta have been previously defined.

The actual rate of evapotranspiration for either bare or vegetated soil conditions is affected by the type of soil and crop present. Evapotranspiration is believed to occur in two stages (4). The first stage, known as the constant rate stage, occurs when the available soil moisture is greater than thirty percent of the maximum amount of available soil moisture. Hillel (4) defines available soil moisture as the difference between the in situ soil moisture content and the permanent wilting point. The maximum available soil moisture is defined as the difference between the field capacity and the permanent wilting point. To calculate the first stage evaporation, Equation (1) is used for a bare soil condition with r equal to 0.20.

When the available soil moisture is less than thirty percent of the maximum available soil moisture, second stage evapotranspiration occurs. To calculate the evaporation from bare soil for this stage Equation (3) can be used.

$$E_s = c' \, t^{\frac{1}{2}} - c' \, (t - 1)^{\frac{1}{2}} \qquad (3)$$

where

E_s = soil evaporation, in inches

c' = hydraulic coefficient of the soil, in inches/day$^{\frac{1}{2}}$

t = time after the first stage evaporation, in days

If a vegetated surface exists, then Equation (4) should be used to calculate the evapotranspiration.

$$AET = ETP \times k \times \theta_a \; / \; .3 \; \theta_{max} \qquad (4)$$

where

AET = actual evapotranspiration, in inches

k = crop consumptive use coefficient

θ_a = available soil moisture, in inches

θ_{max} = maximum available soil moisture, in inches

ETP = same as defined previously

When the soil moisture content is at the permanent wilting point, evapotranspiration does not occur. Equation (4) therefore assumes a linearly decreasing AET from ETP to zero from $0.3 \; \theta_{max}$ to wilting point. The crop consumptive use coefficient (K) incorporates the Blaney-Criddle Method (5) for evaluating actual evapotranspiration. A daily k value is computed as described in (2).

Surface Runoff

A method for estimating surface runoff which has received wide acceptance has been developed by the Soil Conservation Service (SCS) (6). This method assumes that there is an initial abstraction (IA) of rainfall prior to the occurrence of any surface runoff. The initial abstraction consists of infiltration, interception and surface storage. Incorporated into the method is the assumption that IA is equal to 0.2 of the maximum potential difference(s) between precipitation and runoff. Equation (5) can be used to calculate this maximum difference.

$$S = \frac{1000}{N} - 10 \qquad (5)$$

where

N = runoff curve number

S = maximum potential difference, in inches

As can be seen in this Equation, S is dependent upon the antecedent moisture conditions, soil conditions, land use, and conservation practices through the use of a value (N) obtained from generalized runoff curves. Values for N are listed in Table VI located in Appendix B.

Upon evaluating the maximum potential difference, the magnitude of surface runoff can be estimated by the use of Equation (6).

$$Q = \frac{(P - 0.2\ S)^2}{P + 0.8\ S} \qquad (6)$$

where

Q = surface runoff, in inches

P = precipitation, in inches

S = as defined previously

This equation is applicable only when the amount of precipitation is greater than twenty percent of S. When precipitation is less than twenty percent of S, surface runoff is assumed not to occur.

To evaluate the magnitude of the initial abstraction believed lost as a result of interception Bean (1) suggested using an interception-storage capacity of 0.1 inch which is evaporated at the free potential rate. By this method the interception-storage requirement must be satisfied prior to the evaluation of any infiltration or runoff. The remainder of the potential difference which is not lost to evaporation or interception is considered as infiltration.

Moisture Redistribution

This section of the Chapter discusses the concepts used by Bean (1) for the redistribution of moisture within the soil profile. The soil profile was divided into two layers with the first layer being one foot in thickness and the second layer being three feet thick. These two layers were believed to adequately describe the potential root zone within the subsurface soil profile. This assumption is presented conceptually in Figure 1.

Based on this assumption infiltration which resulted from either rainfall or irrigation was assumed to fill each layer to ninety percent of the saturation value with any excess moisture passing below four feet to be used as groundwater recharge. When the time between any successive events which could result in infiltration exceeded two days, the soil moisture of the upper zone was decreased to field capacity with the excess moisture redistributed to the lower zone. The lower zone was then decreased

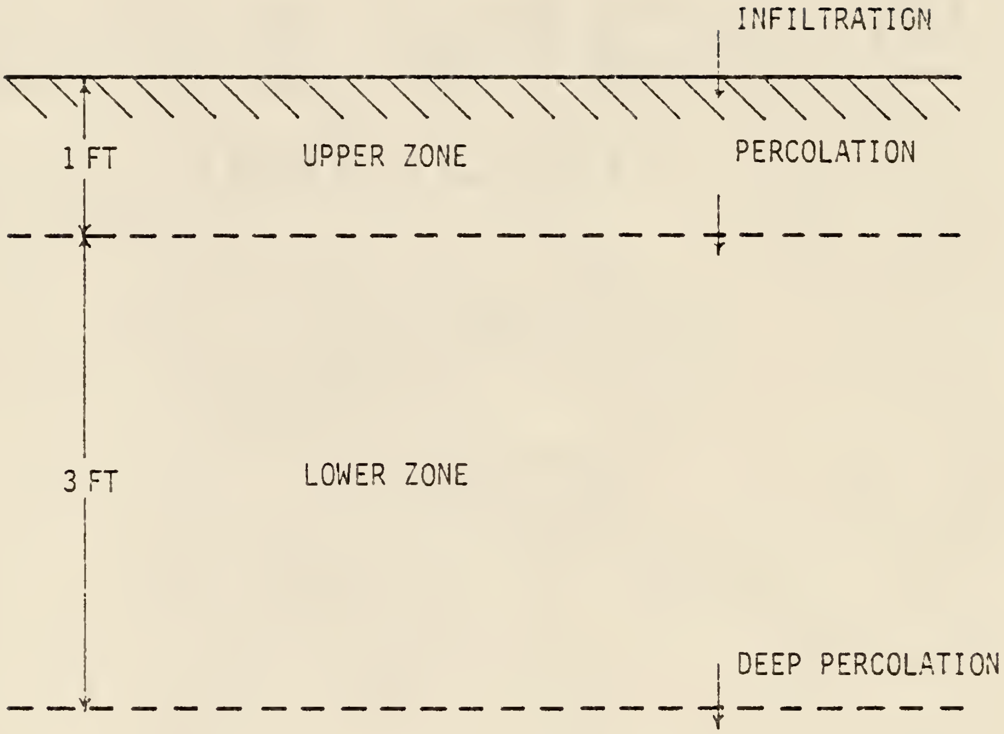


Figure 1. Schematic of the Subsurface Profile

to ninety percent field capacity. The remaining moisture was considered to percolate below the two layers as a source for groundwater recharge. This method for the redistribution of moisture has produced reasonable estimates of the vertical movement of infiltrating water, although it neglects upward movement of sub-soil water.

CHAPTER III

DEVELOPMENT OF NEW METHODOLOGICAL CONCEPTS

Presented in this Chapter are the basic theories utilized in the development of new methodological concepts incorporated in the computer program (1). The Chapter is divided into three sections. The first section reviews the predictive techniques to evaluate the effect of weather modification on precipitation. The concepts and principles of moisture redistribution within the upper subsurface stratum are presented next. Presented in the final section are the current theories and research which relate to the use of municipal waste as a controllable source of water for irrigation.

Weather Modification

Weather modification encompasses all aspects of weather and climate changes brought about by the activities of man. This section of the Chapter presents the current theories of weather modification which could be used to increase the amount of precipitation within a particular locality. The principal technique used is cloud seeding from airborne or ground-based generators.

Two methods whereby precipitation could be increased artificially by cloud seeding have been suggested by Hobbs (7). The first method is the introduction of large hygroscopic particles or liquid water droplets into a warm cloud formation which lies completely below the level of the 0°C isotherm. The artificial nuclei initiate the coalescence mechanism of rainfall production by falling through the cloud which results in the collision and coalescence of the smaller droplets lying in their paths. In this way the larger droplets tend to increase in size rapidly. Upon emerging from the base of the cloud the larger droplets should be large enough to survive evaporation in the dry air and reach the ground as raindrops.

The second method to increase precipitation is to introduce artificial ice nuclei in a cold cloud. Precipitation from a cold cloud is dependent upon the coexistence of supercooled water droplets and ice particles in the regions of a cloud above the 0°C isotherm. Since the concentration of natural ice nuclei in the atmosphere is small, cloud seeding with artificial ice nuclei could result in the rapid growth of the ice crystals by condensation of the ambient moisture. The ice crystals then combine to form snowflakes which fall to the 0°C isotherm, and subsequently melt to form raindrops as they reach the ground.

During the past thirty years experimental research has been conducted concerning the effects of cloud seeding on the amount of precipitation. The first extensive experiment conducted on the seeding of warm clouds was carried out in 1952. Warm clouds were seeded with small particles of sodium chloride in East Africa by exploding bombs impregnated with sodium chloride just above the base of the cloud (7). On some occasions the clouds in which the sodium chloride bombs were exploded were noted to disperse rapidly. However, during the seeding period of one month the total rainfall in an area 10 miles downwind had increased six inches over a similar period in this area of nonseeded days.

During this same period of time Bowen (7) experimented in Australia by seeding warm clouds directly with water droplets. In this experiment, the behavior of the seeded clouds were compared with that of similar nonseeded formations and an increase in precipitation was observed. More recently, the University of Chicago conducted research by seeding warm cumulus clouds in the Caribbean with water droplets. An increase in clouds developing precipitation was noted.

The first experimental research conducted on seeding cold clouds occurred in 1946 by Vincent Schaefer and Irving Langmuir (8). Schaefer and Langmuir observed that dry ice, when dropped into a cloud of supercooled droplets under laboratory conditions, produced numerous ice crystals. Consequent field testing verified dry ice to be an effective means to nucleate large areas of supercooled clouds.

Following this demonstration, Bernard Vonnegut (8), who was also working with Schaefer and Langmuir, began to search for other substances having the same crystal properties as ice. Vonnegut found that a silver iodide solution was an effective ice nucleator and could be applied from a ground-based generator, thereby reducing the cost of modifying cold clouds. Thus, a silver iodide solution became the source for consequent cloud seeding research.

In 1966 the National Academy of Sciences Panel on Weather and Climate Modification analyzed the results of research projects involving cloud seeding with ground-based silver iodide generators. The panel concluded that the artificial seeding of clouds apparently could modify cloud structure and increase precipitation by an average of approximately ten percent. However, it remained uncertain whether it is possible to increase precipitation over large areas for extended periods of time by this weather modification technique. Many more experiments need to be conducted before definitive conclusions can be drawn.

To estimate the potential effects of weather modification on the environment it was assumed in this study that cloud seeding can produce changes in precipitation and that this change will occur in a specified manner. Based on the research conducted by Changnon and Huff (9) the effects of a seeding program will produce a seventy-five percent increase in precipitation of normally small precipitational clouds. They further indicate that clouds producing normally large amounts of precipitation do not benefit from cloud seeding and, in some cases, seeding can reduce the natural efficiency of a cloud by ten percent. Factors hindering the effectiveness of a cloud seeding program are incorporated into the precipitation alteration scheme developed during this research study.

Model B-ZERO which is presented in Table I is based on the results of Changnon and Huff's research (10). The model alters the daily rainfalls in Kansas by the percentages indicated during the months March through September. In the model a discontinuity occurs at the 24-hour precipitation value of one inch. To correct this anomoly and also to provide a precipitation enhancement range, Model B-ZERO MODIFIED was developed (11). Model B-ZERO MODIFIED, also presented in Table I, assumes that there is no increase nor decrease to daily rainfalls of greater than one inch. The effects of these two precipitation alteration models on the hydrological aspects in Kansas are discussed in detail in Chapter V.

TABLE I

PRECIPITATION ENHANCEMENT MODELS

Precipitation Amount (inches)	Model B-Zero (% increase)	Model B-Zero Modified (% increase)
0.10 or less	75	75
0.11 - 0.50	30	30
0.51 - 1.00	10	10
over 1.00	-10	0

Moisture Redistribution

The process of moisture redistribution within a soil profile primarily occurs under unsaturated conditions. The unsaturated flow process is difficult to describe quantitatively because of the complex relationships between water content, hydraulic conductivity, and hydraulic gradient. Hillel (4) suggested that an accepted method for estimating the movement of water one-dimensionally is by use of the Darcy equation, represented mathematically by Equation (7).

$$q' = K \, \Delta t \, i \tag{7}$$

where

q' = volume of water movement per unit area, in inches

K = hydraulic conductivity, in inches/day

Δt = time increment, in days

i = hydraulic gradient, in feet/feet

The hydraulic conductivity in Equation (7) is a function of the water content of the soil. The value of the hydraulic conductivity is at its greatest when the soil is saturated, and decreases steeply with decreasing water content. Since the value of soil moisture is a continuous variable over time within the computer program, unsaturated hydraulic conductivity-soil moisture content relationships for the in situ soil are required to apply Equation (7). These relationships can be obtained from laboratory experimentation.

The hydraulic gradient in Equation (7) is the sum of the gravitational gradient, directly dependent on elevation, and the soil water potential. This is expressed mathematically by Equation (8).

$$i = \frac{\Delta z + \Delta h}{\Delta z} \tag{8}$$

where

Δz = change in elevation, in feet

Δh = change in soil water potential over distance Δz, in feet

i is the same as previously defined

The soil water potential is assumed to be a positive value when the water movement is in the downward direction indicating a decrease in soil water potential with a decrease in elevation. A negative soil water potential, also referred to in literature as a capillary potential or a soil water suction, occurs when the decrease in soil water potential is in the upward direction causing an upward movement of flow. To apply the value of the soil water potential within the computer program to Equation (7) laboratory experimentation relating soil moisture and the soil water potential is required.

To evaluate the redistribution of moisture using Darcy's equation for one-dimensional flow, the subsurface profile illustrated in Figure 2 was incorporated conceptually into the computer program. As illustrated, the subsurface profile was divided into three layers with the upper layer being one foot in thickness, the middle layer being three feet in thickness, and the lower layer being two feet thick. The three layers were believed to adequately describe the movement of moisture within the potential root zone of the subsurface profile.

An infiltrating event resulting from either rainfall or irrigation is distributed within the soil profile by filling each successive layer to field capacity. All excess moisture passing below six feet is assumed to

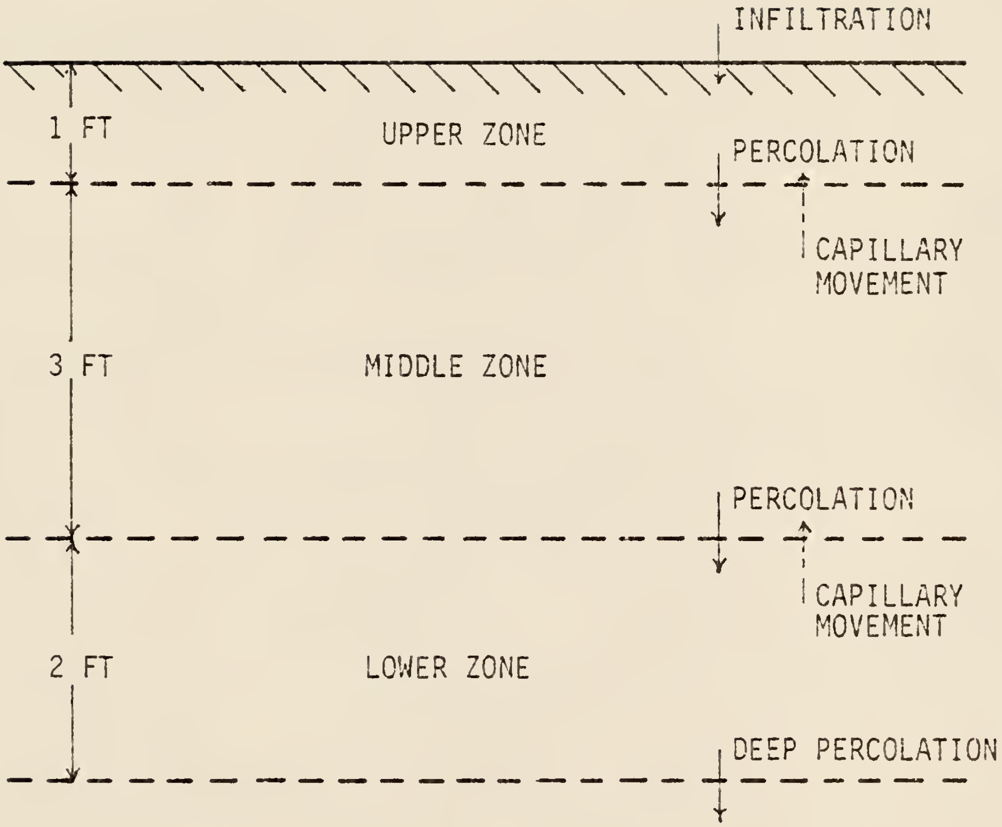


Figure 2. Schematic Representation of Moisture Redistribution

be eventually used as groundwater recharge. The moisture within each layer is then redistributed by applying the Darcy equation for one-dimensional flow. The time increment Δt, suggested by Neibling, et al. (12), is assumed to be equal to one day when no water infiltrates the soil surface on any given day and equal to 1/6 day when an infiltration event occurs.

The use of the Darcy equation for the one-dimensional unsaturated redistribution of moisture requires the use of soil water potential-soil moisture and unsaturated hydraulic conductivity-soil moisture relationships obtainable from laboratory testing on undisturbed soil samples, as described by Neibling, et al. (12).

Municipal Wastewater Effluents

The application of municipal wastewater effluents on agricultural land has received considerable attention during recent years. With the enactment of the Federal Water Pollution Control Amendments of 1972 requiring that the discharge of pollutants into waterways cease by 1985, the irrigation method of land application has been recognized as an alternate means to treat wastewater. The irrigation process is used primarily to maximize crop production while the disposing of municipal wastewater is a secondary benefit.

There are many factors affecting the use of wastewater effluent as a source of water for irrigation. The first factor to be considered is the minimum level of wastewater treatment required prior to land application. Wastewater effluent from primary and/or secondary treatment plants has been used for irrigation in many states. As an example, California allows the use of primary effluent for surface irrigation of orchards, vineyards, and fodder, fiber and seed crops (13). Generally, the public health agencies of each state place limitations on the quality of municipal wastewater that can be used for irrigation.

The next factor to be considered is site selection. Hall, Wilding and Erickson (14) suggest that the site selection criteria be based upon three interrelated parameters. These parameters include general topographic features, geologic characteristics, and in situ properties of the soil. An evaluation of the proposed site includes both a careful inspection of the site and preliminary tests conducted on the soils.

The ideal topography for utilization of wastewater by irrigation is directly dependent upon the type of distribution system to be used. For example, the irrigation of cultivated crop lands using the sprinkler technique restricts the slopes to fifteen percent or less. However, slopes of up to thirty percent are permissible if the sprinkler method of irrigation is to be applied where noncultivated crops are grown. Surface irrigation requires relatively flat land although slopes as steep as five percent could be used with contour furrows. Increasing slopes generally result in a reduction of the infiltration rates of most soils thus causing excessive runoff and soil erosion. The cost effectiveness of various irrigation practices is a major constraint in selecting the topography best suited for application of the wastewater effluent.

The suitability of a site is also a function of the physical, chemical and mineralogical properties of the soil. These properties influence the infiltration rate, moisture holding capacity and any absorption reactions with the waste components. In land application of municipal wastewater, the soil functions both as a natural filter and as a medium for any biological and/or chemical reactions, thus providing for the natural treatment of wastewater. An ideal situation would be to have a soil with the ability to assimilate large quantities of dissolved solids while remaining highly permeable, however such a soil does not exist. Therefore, the selection of the most advantageous soil is dependent upon other constraints.

The storage requirement for the wastewater effluent is the third factor to be considered. Conventional treatment plants collect, treat, disinfect and discharge effluent wastewater into available surface water on a continuous basis. The design of a land disposal treatment facility, like the conventional plant, must be operated continuously with the exception that the ability to discharge effluent is seasonal. The design of a land disposal facility must include a storage reservoir capable of containing the effluent wastewater for a period ranging from three months in moderate climates to seven months in cold northern states. This storage requirement is directly related to several climatic factors. The primary climatic factors are temperature, precipitation and snow cover. The application of effluent to the land is generally suspended when the temperature falls below 25 degrees Fahrenheit (13). The maximum daily precipitation allowed before the application of wastewater must be suspended is dependent on the infiltration rate of the soil. Snow cover should be minimal during the land application process.

The treatment process of wastewater by land application requires an extensive monitoring program. The program should be designed to consider influent, pretreatment, storage, disinfection, drainage, seepage, groundwater, surface water, soil and crop characteristics. Data obtained from these monitoring programs is essential to the management decisions concerning land application.

In recent years a number of experimental and operational land application systems have been designed to utilize wastewater. The Michigan State University Water Quality Management Project (WQMP) is an example of a research and development project which studies the applications of wastewater to agricultural land (15). This facility, which was completed in 1974, utilizes effluent from the East Lansing sewage treatment plant after it has undergone primary and secondary treatment processes. The site is carefully monitored and controlled to determine possible changes in groundwater, soil, or other variables.

The WQMP facility consists of four artificial lakes having a total surface area of forty acres with an average depth of eight feet. The municipal effluent undergoes chemical, biological and physical treatment while it passes sequentially through the four lakes over a period of 30 to 60 days. Up to two million gallons per day of effluent can be handled by this facility.

The facility at Michigan State University also includes three hundred and twenty acres for application of treated wastewater effluent to agricultural lands. One hundred and fifty of these acres have been provided with irrigation spray equipment capable of applying effluent at a rate of two inches per week between the months March and November. Both annual and perennial forage crops have been irrigated using this technique. Although the project is still in the experimental stage, present results indicate the economic feasibility of applying wastewater effluents on agricultural land for the purpose of enhancing food and fiber production for livestock.

The largest wastewater land treatment facility using sprinkler irrigation equipment in the United States at the present time is the Muskegon County Wastewater Management System (16). This facility was designed to transmit municipal and industrial effluents on a county-wide basis into a central treatment plant. At the central plant the wastewater is treated to comply with the local, state and federal discharge requirements prior to land application. All facets of the operation are continuously monitored to guard against possible pollution of the soil, groundwater and surface waters.

The Muskegon County facility was designed for an influent flow rate of forty-two million gallons per day. The current average flow is approximately twenty-eight million gallons per day with forty percent domestic wastewater and sixty percent industrial. The wastewater is initially treated biologically in three aerated lagoons. The wastewater is then discharged into two large storage lagoons which have a maximum design storage period of four months. The water quality of the storage facilities is monitored daily. When the water quality meets the state health department standards, the treated wastewater is released from the storage lagoons into an outlet lagoon where it is disinfected by chlorination prior to land application. The disinfected effluent is then sprayed on 6,000 acres of farmland at an application rate of approximately 3.5 inches per week.

The Muskegon County Wastewater Management System has proven to be an efficient means of treating and productively disposing of the municipal wastewater effluent while maintaining strict environmental protection. The elimination of direct effluent discharges into the waterways has also resulted in improvements in the water quality of the surface water while providing conservation of the groundwater.

CHAPTER IV

DESCRIPTION OF THE COMPUTER PROGRAM

Purpose

The purpose of the computer program is to provide a means of designing various disposal control facilities. The program also serves as a means of evaluating both selective land disposal and evaporative techniques to enhance agricultural production within Kansas. The general format of the model makes it applicable over a wide range of disposal conditions in addition to being readily adaptable to various geographic and climatic regions. The computer program also serves as an effective means to evaluate the variation in hydrological effects which could result from the implementation of methods to modify existing weather patterns.

The size of the disposal control facility required is directly dependent upon the magnitude of inflow. There are four major sources of inflow which can be considered by this model. These sources are: (1) precipitation directly into the pond, (2) runoff from the natural watershed, (3) feedlot runoff, and (4) municipal wastes. Any combination of these sources can be considered by the model as inflow to the system. However, outflow from the system can occur only as evaporation, overflow or induced removal. The induced removal of outflow generally consists of incorporating the wastes into a supplemental irrigation system. Although pond overflow is a source of outflow it should not be directly considered in the design. The model depicted by the computer program simulates field conditions by extrapolating the data obtained from previously recorded precipitation and temperature patterns. The model also considers variation in soil properties, meteorological conditions, tillage and farming practices which may exist in the area under consideration.

Organization

This section of the Chapter describes the organizational make-up of the computer program. Included with a description of the main program are brief descriptions of each subroutine and generalized flowcharts illustrating their operational procedures. The computer program, titled Kansas State University Hydrologic Yield Model (KSUHYDRO), was written in Fortran IV language and calibrated on the ITEL AS/5 computer located at Kansas State University.

KSUHYDRO consists of a main computer program which utilizes several subroutines as a means of incorporating various options. The use of several subroutines rather than a continuous program provides for a stable framework upon which to base future modifications. In addition, this framework allows for building, testing and modifying the program without necessitating long periods of down time.

The main program, illustrated in Figure 3, controls and regulates the various program components. As can be seen in Figure 3, the first function of the main program is to read-in the various information required. This information is read-in on both data cards and data statements. After the data has been entered, properly stored and categorized the main program initiates the sequence of computational operations specified by the model.

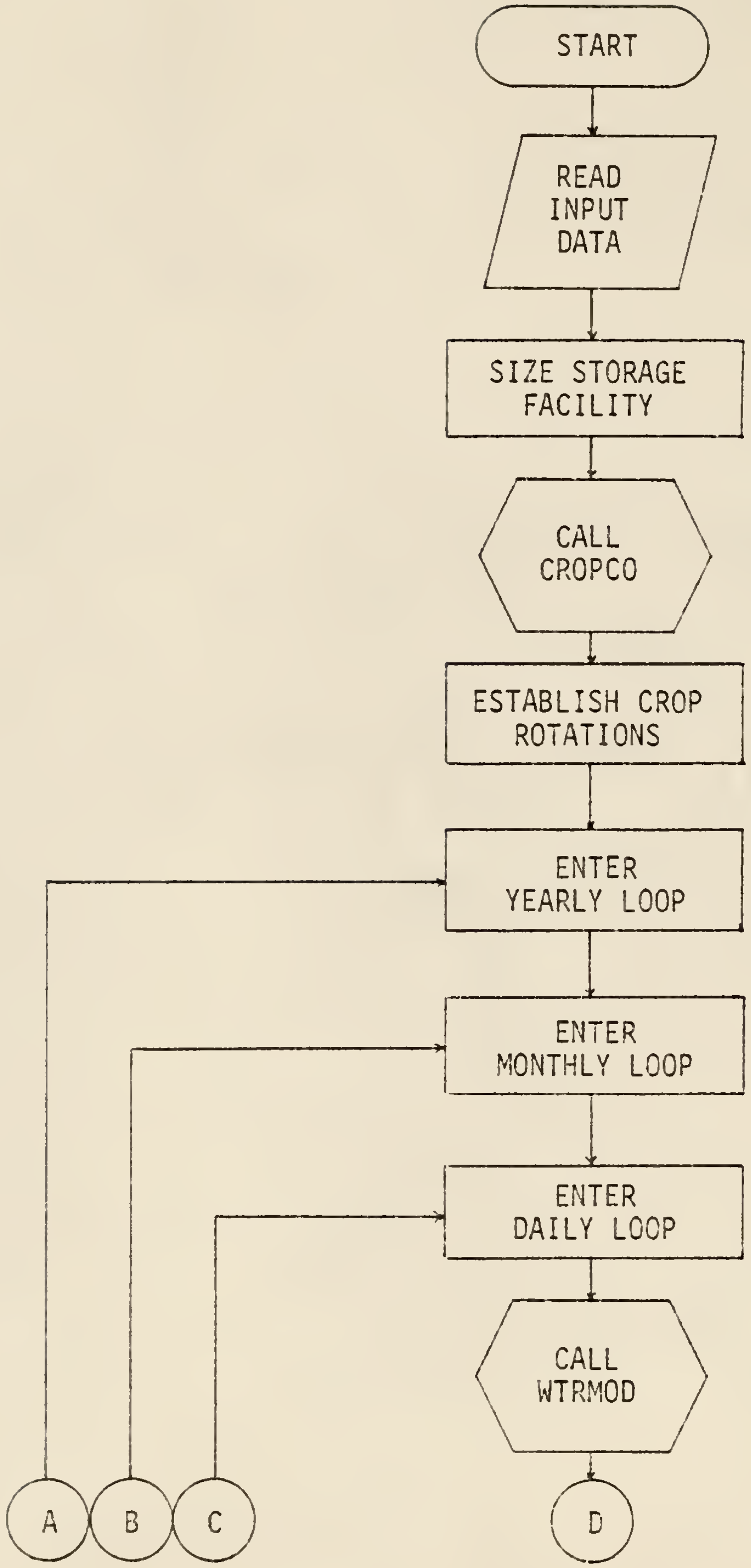


Figure 3. Generalized Flowchart for Main Program

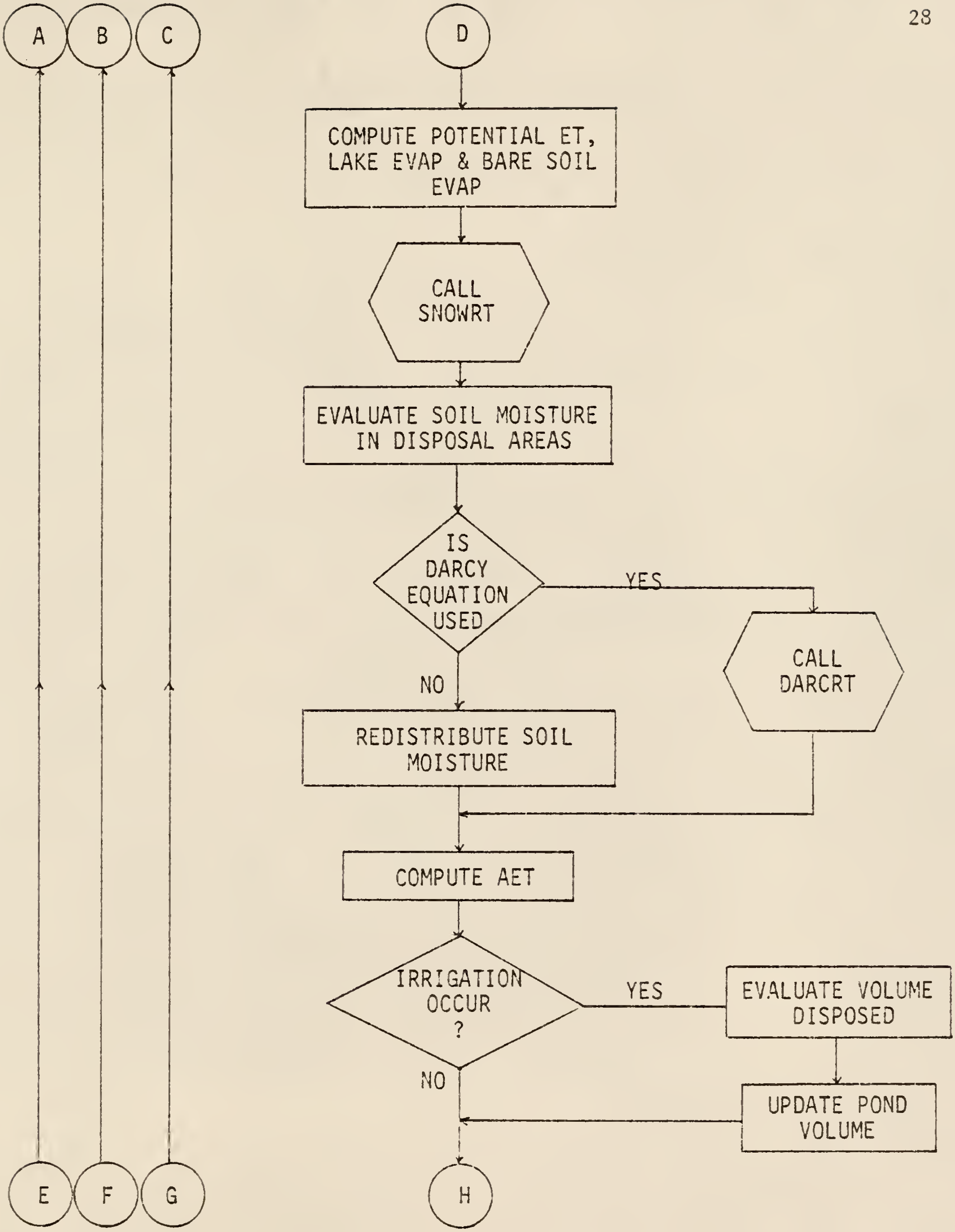


Figure 3. (Continued)

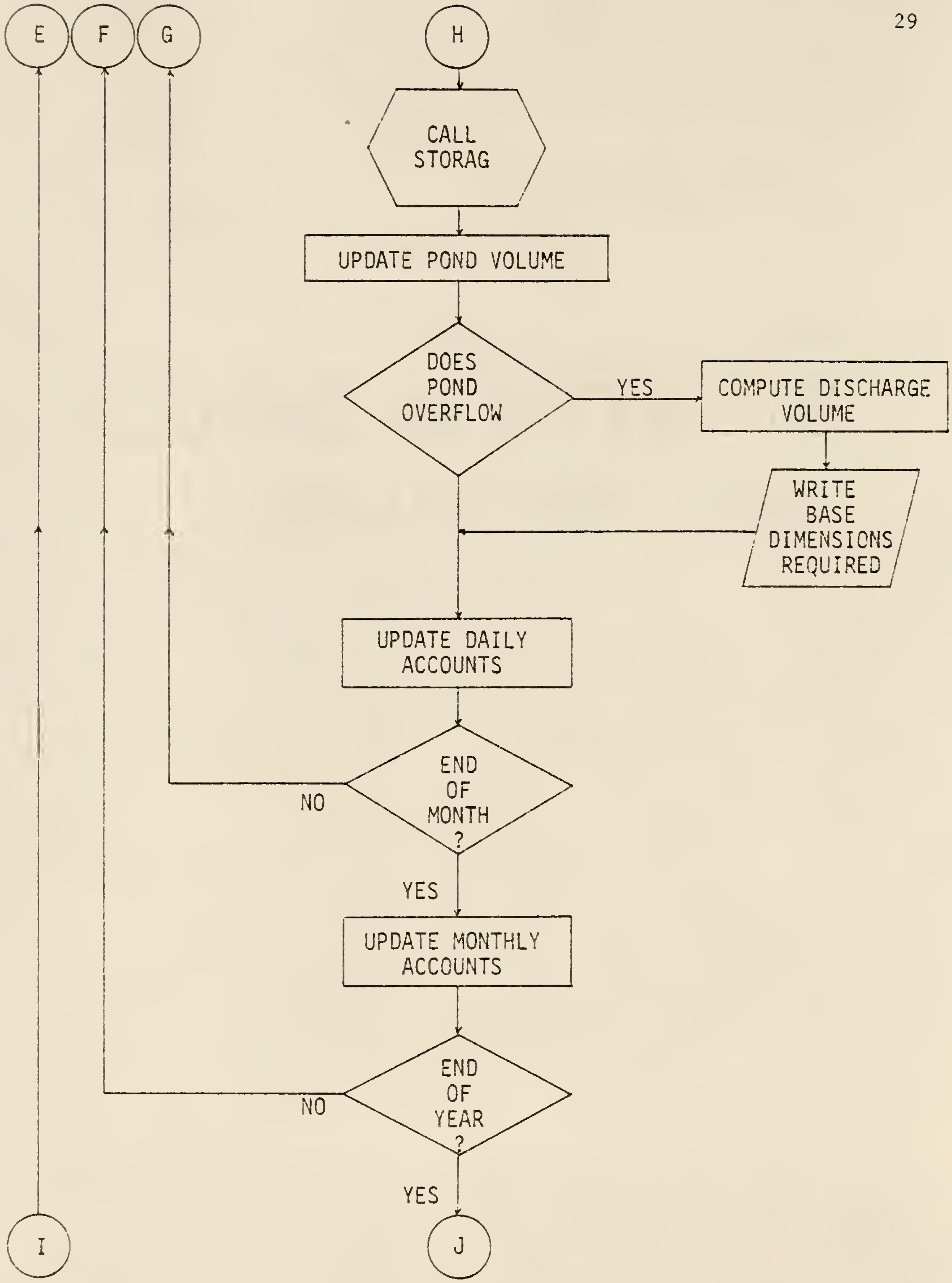


Figure 3. (Continued)

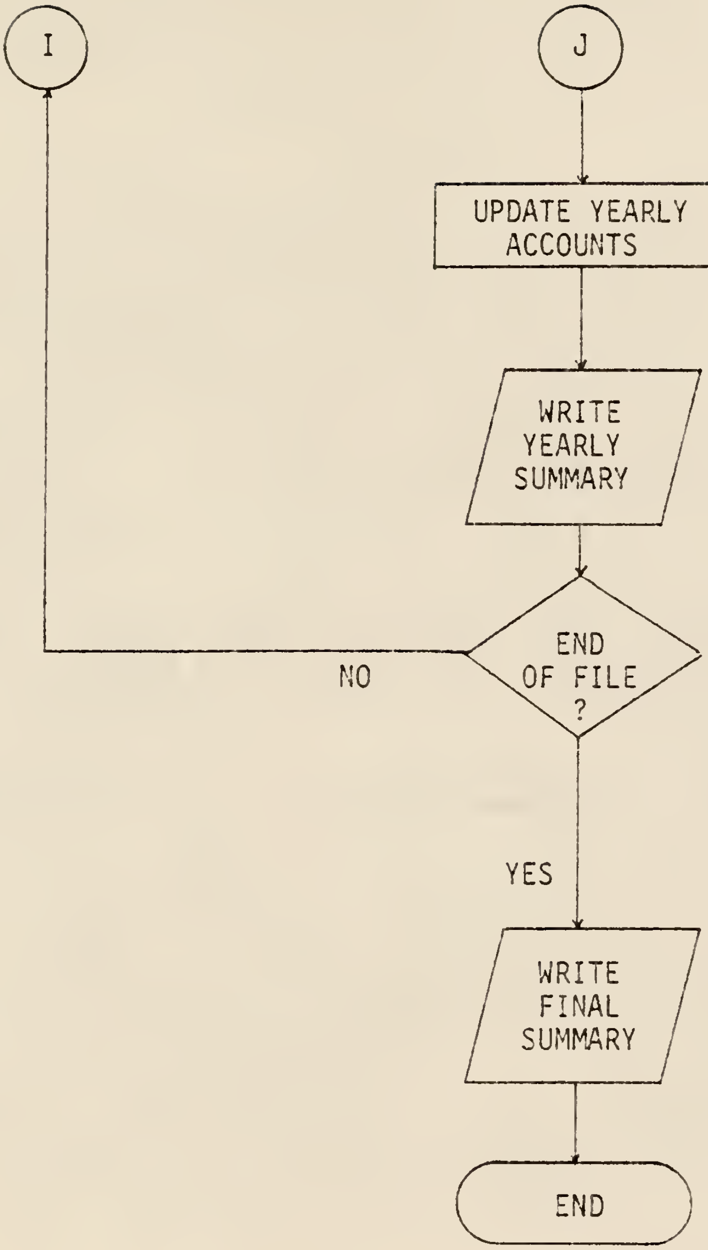


Figure 3. (Continued)

The computational operations begin by sizing the storage facility. The required storage facility or pond is developed by using the general configuration of a prismatoid. The maximum depth, base length, base width, and side slopes of the prismatoid are varied to maximize the volume and surface area. This maximization technique provides for the optimization of required resources.

The format of the main program directs the computer to call subroutine CROPCO next. Subroutine CROPCO, developed by Zovne, et al. (2), is used to calculate the various crop coefficients necessary in the analysis of the evapotranspiration of the disposal areas under consideration. Figure 4 shows the generalized flowchart for this subroutine. Upon returning to the main program, the annual crop rotation pattern for the disposal areas is established.

WTRMOD, the next subroutine called by the main program, incorporates the implementation of a weather modification technique. As presented in Chapter III, the only weather modification technique considered by KSUHYDRO is cloud seeding. The generalized flowchart for this subroutine is shown schematically in Figure 5. After all the adjustments are made to the values previously recorded for the daily precipitation, the operational coding directs the computer to return to the main program.

The calculation of the potential evapotranspiration is the next operation performed by the main program. Potential evapotranspiration is determined by means of the Penman Combination equation. Following completion of this operation, lake and bare soil evaporation potentials are determined for the geographic area under consideration. Subroutine SNOWRT is then called by the main program. SNOWRT evaluates the maximum and

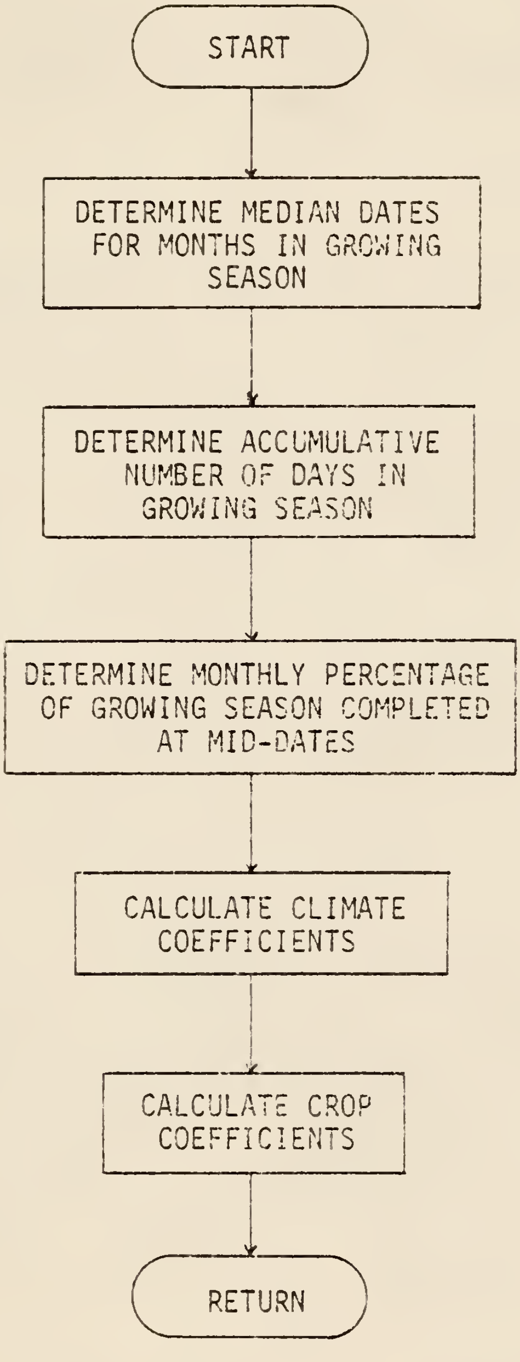


Figure 4. Generalized Flowchart for Subroutine CROPCO

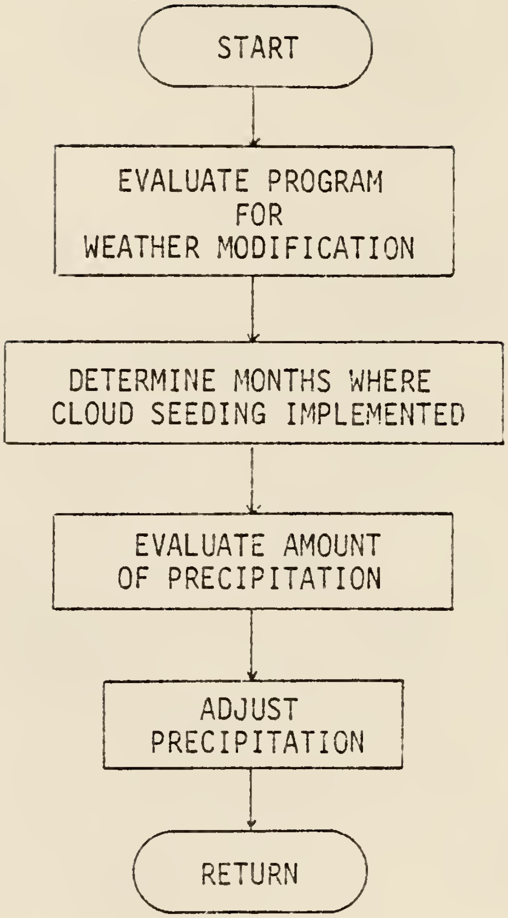


Figure 5. Generalized Flowchart for Subroutine WTRMOD

minimum daily temperatures, and determines if the precipitation is in the form of rain or snow. Also the potential accumulation of the snow pack or the possibility of the formation of a snow melt is evaluated. Following these computations subroutine SNOWRT, represented by the flowchart shown in Figure 6, directs the computer to return to the main program.

The main program evaluates the amount of soil moisture within the land disposal area next. If any precipitation has occurred, the magnitude of infiltration, interception storage, and runoff is calculated. The amount of moisture which infiltrated from the surface is distributed within the upper six feet of the soil profile. Any moisture infiltrating below six feet is considered as groundwater recharge. The volume for surface runoff is calculated by using the method developed by the Soil Conservation Service (SCS) for the antecedent moisture condition II. Modifications to antecedent moisture conditions I or III are then made and evaluated. The soil moisture which has been modified is then redistributed. The main program calls subroutine DARCRT where redistribution is accomplished by utilizing a modified form of Darcy's equation for unsaturated one-dimensional flow. The equation requires the use of hydraulic conductivity and soil-water potential parameters which should be determined from laboratory testing. Subroutine DARCRT, as shown conceptually in Figure 7, then directs the computer to return to the main program. If soil laboratory testing data is not available, moisture redistribution can be established through an evaluation of field capacity, as discussed in Chapter II.

The next operation conducted by the main program is the calculation of the magnitude of evapotranspiration likely to occur under field

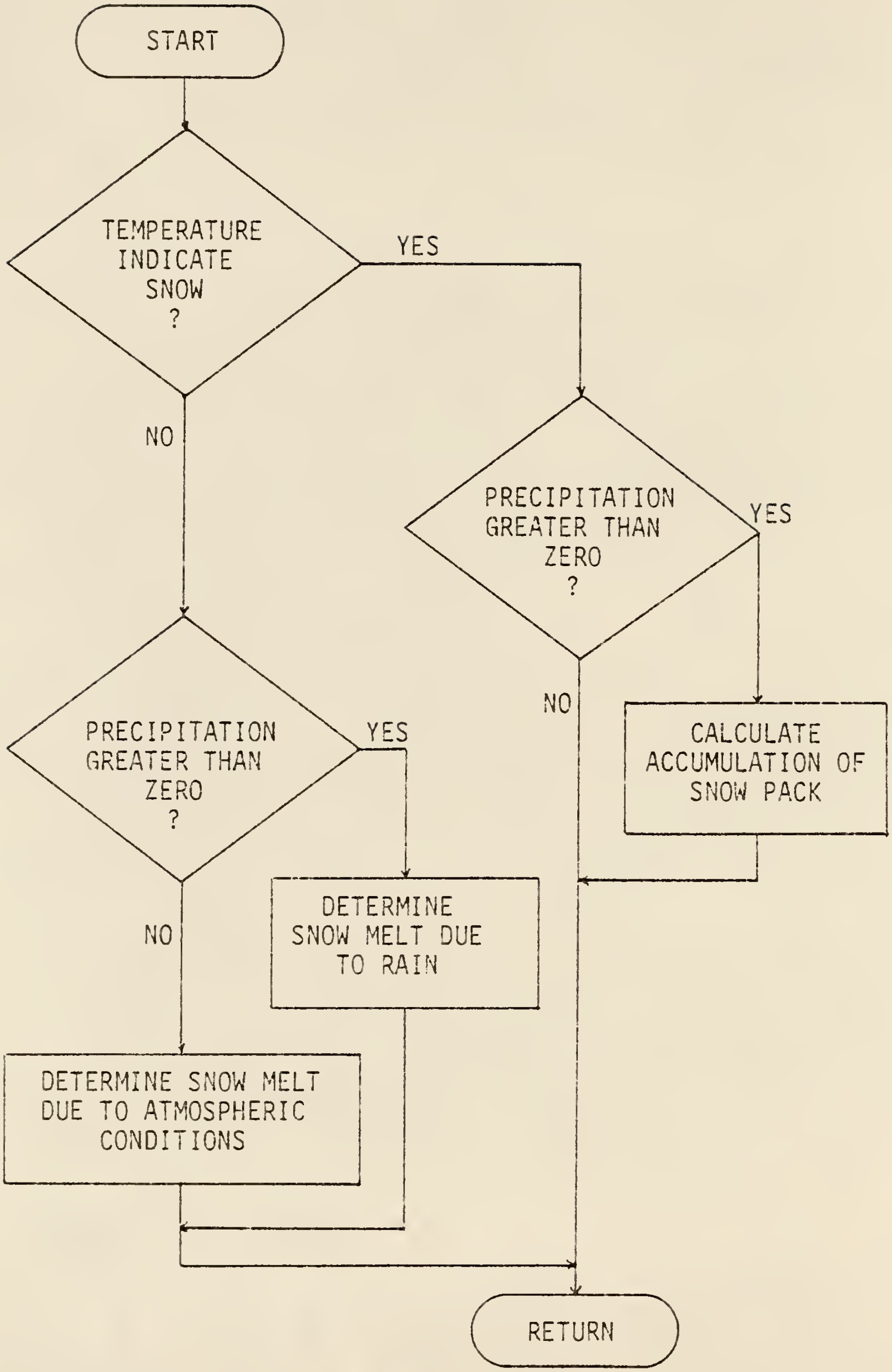


Figure 6. Generalized Flowchart for Subroutine SNOWRT

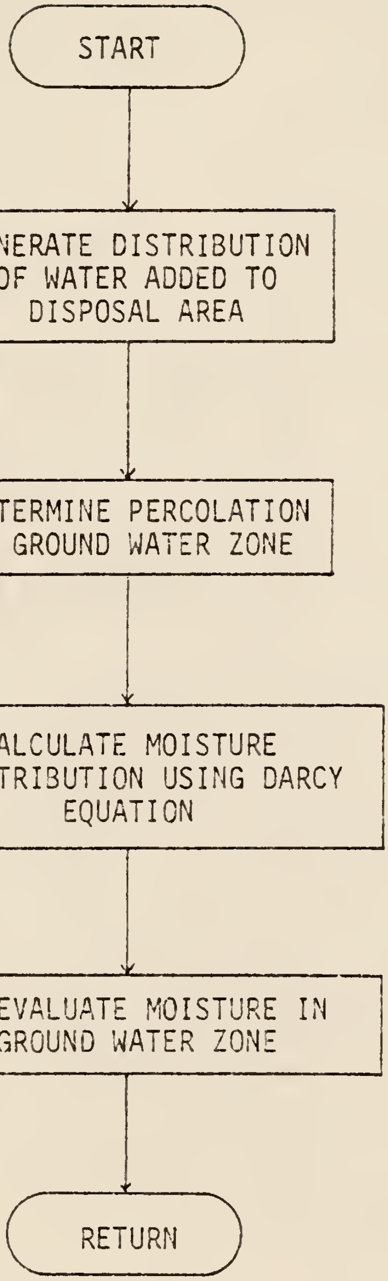


Figure 7. Generalized Flowchart for Subroutine DARCRT

conditions. This calculation is dependent upon ambient soil moisture, vegetation, and climatic conditions. The soil moisture distribution is then reevaluated. After the determination of the evapotranspiration is complete the possibility of using the stored water for irrigation is considered. By adjusting soil moisture values while decreasing the pond volume, irrigation can be simulated mathematically for specific disposal areas.

If feedlot and/or municipality wastes are to be considered, then subroutine STORAG is called. This subroutine generates the volume of potential feedlot runoff as inflow to the storage facility in addition to considering any variations in climatic conditions. Additional pond loading resulting from the inflow of municipal waste disposal can also be evaluated. A conceptual flowchart for subroutine STORAG is shown schematically in Figure 8.

Upon returning from subroutine STORAG the computer calculates the surface evaporation from the storage pond. The required volume of the storage pond is reevaluated by incorporating all the inflows to the system. If the combined inflows produce a volume greater than the maximum volume available for storage, then the amount of overflow is calculated and a message is issued to the user which indicates the base dimensions required to contain all the inflow. The main program then updates the daily and monthly accounts for the storage facility and disposal areas. A written summary is provided at the end of each set of yearly calculations prior to continuing on to the next year. The final operation of the computer program is to write an average annual summary which can be used for a prediction analysis.

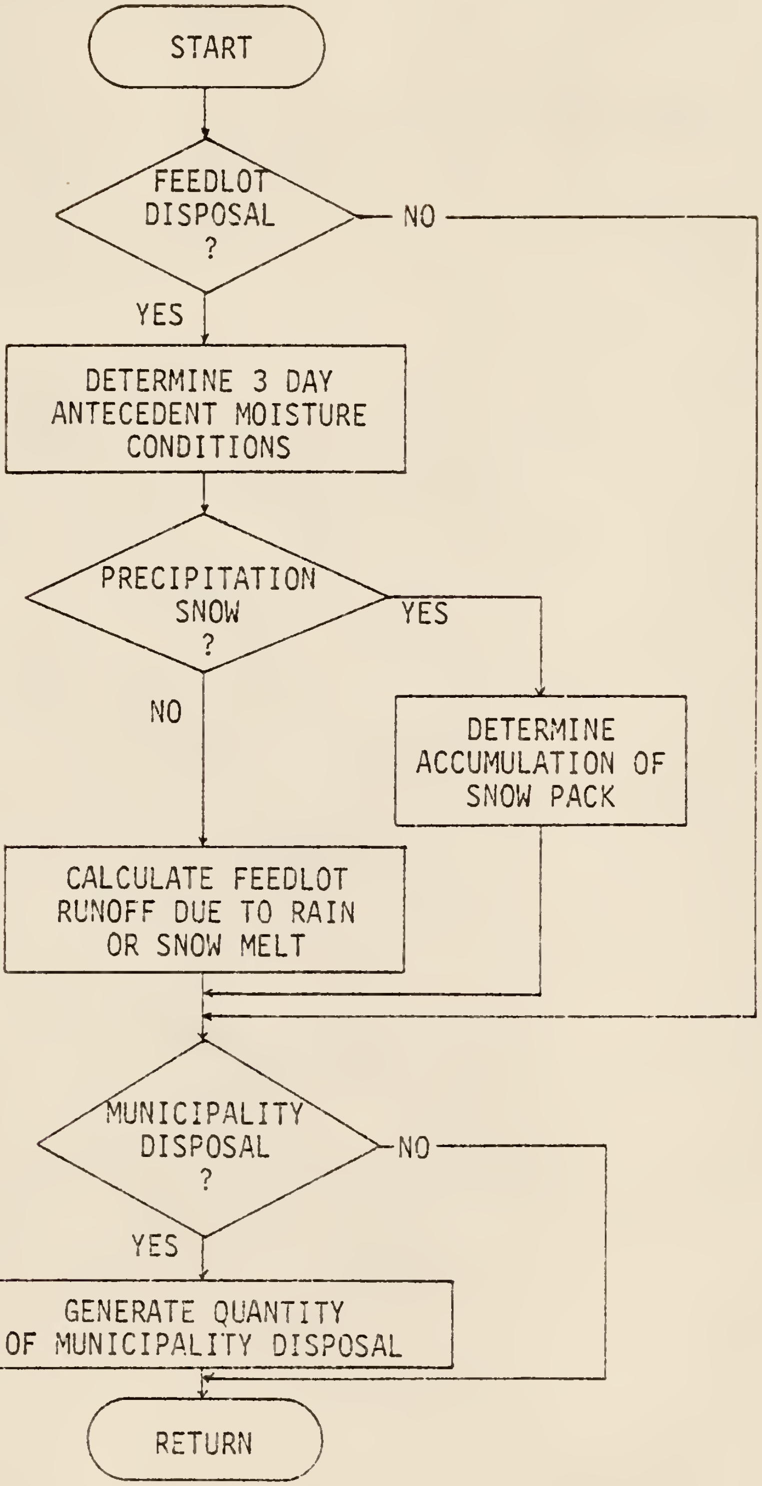


Figure 8. Generalized Flowchart for Subroutine STORAG

Capabilities

This section describes the capabilities of the computer program to simulate actual field conditions. The possible existence of varying climatic, soil and vegetation conditions as well as inflow and outflow sources requires that the program possess multiple capabilities.

The model simulates climatic conditions by utilizing previously recorded precipitation and temperature patterns on a daily basis for a specified geographic location. The required climatological data is obtained from a magnetic computer tape provided by the National Weather Service Climatic Center located in Asheville, North Carolina. Missing data on the tape is automatically adjusted in the program by assuming the previous day's value. In addition, the program can be used to predict the possible effects of weather modification based on historical precipitation patterns. The period and location to be evaluated is controlled by input parameters.

The major components used in the program are the inflows from the feedlot and/or municipal wastes, in addition to the size of the storage and disposal facilities to be used. The program is capable of evaluating the results from up to nine disposal areas under the following three conditions: (1) a watershed with runoff as inflow to the storage facility, (2) a watershed with runoff as inflow to the storage facility which is to be used as a major irrigation source, and (3) a disposal area requiring only supplemental irrigation. The components to be evaluated in any simulation model is regulated by means of the input data.

Variations in terms of area, soil type and crop for each disposal area can also be incorporated. The twelve soil types which can be evaluated by this program are presented in Appendix B. The variation in crops which can occur are: wheat, grain sorghum, corn, soybeans, pasture, alfalfa, and fallow. An annual crop rotation using periodic fallow conditions can be analyzed with crop cover occurring on either the odd or even years of the simulation period.

The hydrological effects on each area are evaluated using the operations defined earlier in the Chapter. The program is capable of evaluating the redistribution of soil moisture by using a modified one-dimensional Darcy equation using unsaturated flow conditions. This option can be used only when the unsaturated flow characteristics of the soil are known.

Irrigation can be rapidly evaluated by using the program. The irrigation application rate, in units of inches per day over the proposed areas, can be varied by input parameters. In addition, the application of irrigation can be optimized by specifying that the soil moisture within the top twelve inches must be below a specified percentage of field capacity before irrigation is implemented.

The disposal facility should be designed to provide one hundred percent control of inflow so that no overflow occurs. Incorporated into the program is a written statement to the user indicating the required base dimensions to provide for one hundred percent control. Statistical hydrological data is also available to the user for use in prediction analysis. Since the cost of irrigation is increasing, the computer program developed previously and modified during this research study provides an adequate and efficient means to design and evaluate performance of systems for utilizing runoff and wastes as a renewable irrigation resource.

Data Input

This section of the Chapter describes the format specified for the data to be entered into the computer program. The section is divided into seven subsections with each subsection describing the required format necessary for a particular set of data. All numeric data must be right-hand justified and a complete data set is required for a successful model analysis. Presented in Table II is a guide for data input.

Location and Model Identification

The first three data cards are written in alphanumeric notation for the purpose of aiding in identification of a particular analysis. The first card is used to describe the geographic location, stored as NAME OF CITY AND STATE. This description begins in column 20 and may contain a maximum of 20 alphanumeric characters. The second card is used to indicate if a weather modification technique is to be implemented. The term WEATH MODIF MODEL, which begins in column 2 with 20 characters, indicates that a weather modification scheme was used. If no weather modification technique was used then the card must be left blank. The third data card is used to identify the possible incorporation of municipal wastes to the storage pond. This is represented by the term INFLOW TO STORAGE POND, beginning in column 2 with 24 alphanumeric characters. A blank card will indicate no municipal wastes are to be considered.

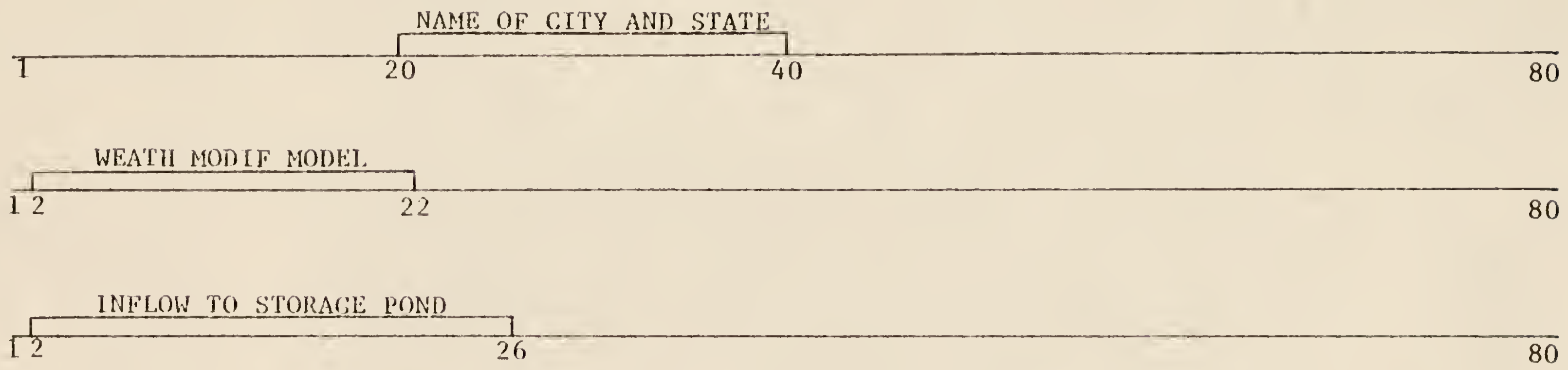
Simulation Model Parameters

The data cards described in this subsection utilize the NAMELIST feature of the Fortran IV language. The first column of the data card

TABLE II

GUIDE FOR DATA INPUT

Location and Model Identifiers



Simulation Model Parameters

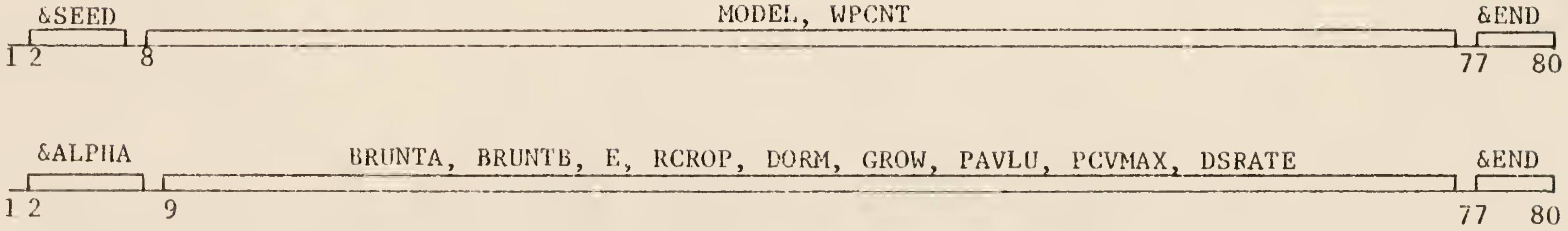
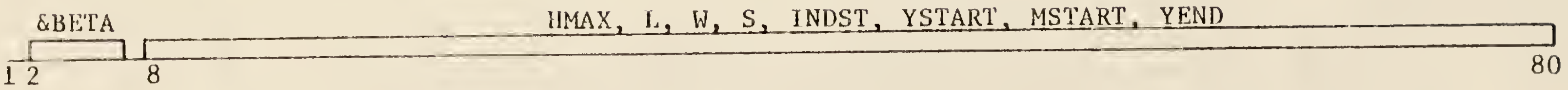


TABLE II (Continued)

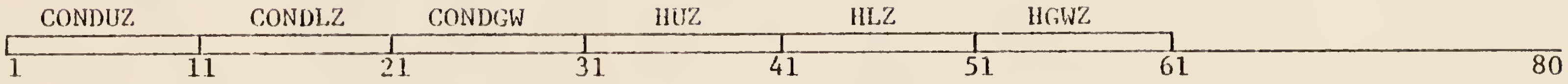


Meteorological Data (one card for each month)

Disposal Area Data (one card for each area)

TABLE II (Continued)

Unsaturated Flow Data (one card for each area)

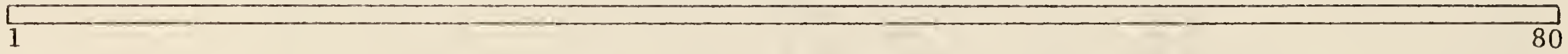


Municipal Waste Data (one card for each month)

TABLE II (Continued)

Climatological Data

Magnetic Tape Driver



utilizing this feature is required to be blank. The character '&' must appear in column 2 followed immediately by the NAMELIST name, with no embedded blanks. The NAMELIST name is followed by a blank space. All input items must appear in the form of a variable = constant, with each item separated by a comma. The list of items is terminated with the characters '&END' which allows for several data cards to be used as input under one NAMELIST.

The first data card featuring a NAMELIST option is termed SEED. The variables included are MODEL and WPCNT. MODEL is represented by the integer 1,2,3or4. When MODEL is equal to 1, there will be no modification of the precipitation data. When MODEL is equal to 2, the 'B-Zero' modification, previously described, is implemented. When 3 is used, rainfall is increased by the percentage inputted for WPCNT. The integer 4 indicates the implementation of the 'B-Zero Modified' alternation scheme.

The next set of data is read from the NAMELIST ALPHA. The following variables are included in this NAMELIST feature: BRUNTA, BRUNTB, E, RCROP, DORM, GROW, PAVLU, PCVMAX and DSRATE. The first four variables are used in computing the evapotranspiration potential. BRUNTA and BRUNTB are geographic constants, E is the wind coefficient, and RCROP describes the reflectance coefficient for use in the Penman equation described previously. The variables DORM and GROW, expressed in inches, are used in computing surface funoff from a feedlot area.

Scheduling irrigation requires the input of PAVLU, PCVMAX, and DSRATE. Irrigation is implemented only when the soil moisture is below a percentage, PAVLU, of field capacity. PCVMAX expresses the minimum pond volume, as a fraction of the maximum volume, required for irrigation. The disposal rate, in units of inches per day, is defined by DSRATE.

The final NAMELIST data set is represented by the name BETA. The variables, HMAX, L, W, and S are the base parameters, in units of feet, for maximum depth, length, width and side slope used in sizing the retention pond. Variables INDST, YSTART, MSTART, and YEND locate the appropriate block of precipitation and temperature data to be read from the magnetic tape. INDST is an index reference number for the geographic location. YSTART, MSTART and YEND define the starting year, month, and ending year of the simulation period.

The variable ROTAYR is represented by the integer 1 or 2. When ROTAYR is equal to 1, an annual crop/fallow rotation is implemented with the crop analysis on the first year of the simulation period. When ROTAYR is equal to 2, fallow is established on the first year of the simulation period.

DARCEQ is also represented by the integer 1 or 2. When DARCEQ is equal to 1, the redistribution of moisture within the soil profile is evaluated by the Darcy equation for one-dimensional unsaturated flow. When DARCEQ is equal to 2, the simplified method, described previously, is used for analyzing the redistribution of moisture. The unsaturated flow data cards, described below, are not required when DARCEQ is equal to 2.

The variable BYPASS establishes feedlot runoff and/or municipal waste as a source of inflow to the storage facility. BYPASS is represented by the integer 1,2,3or4 with each integer establishing the following analysis: (1) BYPASS equals 1- no feedlot runoff or municipal waste, (2) BYPASS equals 2- feedlot runoff, (3) BYPASS equals 3- municipal waste, and

(4) BYPASS equals 4- both feedlot runoff and municipal waste. Data cards for municipal waste input, described below, are required only when BYPASS is greater than or equal to 3.

The final three parameters included in BETA are LTAREA, STORM, and NPLOTS. The feedlot area, in acres, is represented by LTAREA. The statistical 25 year-24 hour storm is stored as STORM, in inches. NPLOTS indicates the number of disposal areas included in the analysis.

Meteorological Data

The data required for the meteorological conditions is entered on the next set of data cards. This data is entered on a monthly basis with each month appearing on a separate card, thus a total of twelve cards are necessary to describe the expected conditions.

The mean monthly sunshine and relative humidity are entered in columns 3 and 5, respectfully. Both variables are entered in units of percent and are stored by the variables PSUNS and RHD. RA, the mid-monthly intensity of solar radiation in mm of water evaporated per day, appears in column 7. In column 11 the mean monthly wind speed, WIND, is entered in the units of miles per hour. The final parameter is stored as MMAT, the mean monthly temperature in degrees Farenheit, and is located in column 14.

Disposal Area Data

The next group of data requires one card for each disposal area under analysis. The first card is read in matrix form (i,j) where i and j represent the reference number for crop and soil in column 3 and 6, respectfully. This information is stored by the computer under the parameter name IAREA. The area of each plot, stored as AREA, is entered on the second card in column 2, using units of acres. The parameter IPLAN on the third card indicates the reference number for irrigation or runoff collection for each disposal area. IPLAN is an integer located in column 2. Column 3 of this same card implements annual crop rotations through an integer reference number stored as ROTATE. All reference numbers are defined in Appendix B.

The final data card establishes the dates for planting and harvesting crops on each area. MGSBP and DGSBP indicate the month and date for the beginning of the growing season, located in column 2 and 5, respectfully. The ending month and date are stored as MGSEP and DGSEP in columns 8 and 11, respectfully. The monthly parameters are entered as integers with January represented by 1, February by 2, etc. The field for each integer is two spaces.

Unsaturated Flow Data

A data card for the hydraulic properties of each disposal area is required when the moisture redistribution is to be analyzed by the Darcy equation for one-dimensional unsaturated flow. The parameters CONDUZ, CONDLZ, CONDGW, entered in columns 1, 10, and 20, respectfully, are the computed hydraulic conductivities for the soil profile layers described previously. The soil-water potential variables, stored as HUZ, HLZ, HGWZ, are entered in columns 30, 40, and 50, respectfully.

Municipal Waste Data

The municipal waste data is entered on a monthly basis, requiring a total of 12 cards. The monthly values, stored as MUNDIS, are located in column 1. MUNDIS is in the units of gallons per day with each value being the average monthly disposal. These data cards are included only when municipal waste is included as input to the storage facility.

Climatological Data

The final set of data cards are IBM control cards generating the input of climatic data from a magnetic tape. The tapes, provided by the National Weather Service Climatic Center, are written in NWS Format II language. The data includes daily precipitation, inches, and temperature, degrees Farenheit, for the simulation period.

Data Output

This section of the Chapter describes the output data from the computer program. The section is divided into three subsections with each describing a portion of the program output. An example of the output data is presented in Appendix E.

Input Data

The first set of data to appear as output is a summary of input parameters. The first line, indicating the station and simulation period, is followed by the model identifiers and the size of the 25 year-24 hour storm. The retention pond variables are then listed. Included are the facilities base dimensions, side slope, maximum depth, maximum pond volume and the receiving area for precipitation.

Next the area variables are presented according to plot numbers. Under each plot the area, soil type and vegetative cover, including an annual crop rotation, is listed. The plan to be implemented on each area (irrigation and/or runoff collection) and the irrigation management scheme is also included.

The summary of input parameters described under this subsection is repeated as output prior to the final summary. The purpose for duplicating this information is to aid the user in analyzing the results.

Annual Summary

This subsection describes the annual summaries for the disposal facility and areas during each year of the simulation period. A message to the user is initiated at the beginning of the annual summary when the following events occur: (1) a storm of magnitude equal to or greater than the 25 year-24 hour storm, and (2) an overflow of the storage facility. The date of occurrence and also the dimensions required to prevent overflow are included in the statements.

The water budget for the storage facility is printed in tabular form. Each row tabulates the monthly summaries with the last row representing the annual totals. The units incorporated for inflow and outflow are acre-inches. Columns 2 through 5 correspond to inflows to the system while columns 7 through 9 represent outflows. The sources of inflow include precipitation, municipal waste, feedlot runoff and watershed runoff. Irrigation, surface evaporation and overflow are the sources of outflow. In addition, the number of days irrigation is implemented and the depth, in feet, of the storage facility at the end of each month is included in volumns 6 and 11, respectfully. Column 10 represents the change in volume in units of acre-inch. This column can be used as a water account check since the inflows minus outflows equals the change in volume.

Next the moisture budget for each area is printed in tabular form. Sources of moisture input for each area include precipitation and irrigation. The outputs are interception, surface runoff, percolation and evapotranspiration. A column indicating the total monthly and annual change in soil moisture is also included. All units are in terms of inches. The moisture account balances when inputs minus outputs minus change in snow storage equals change in soil moisture.

Following the monthly accounts for each area an annual summary of the operating parameters is printed. This includes statements indicating the percent of wastewater controlled and percent of maximum pond volume required. Also included is the accumulation of a snow pack during the season and the change in snow storage as compared to the previous year.

Final Summary

The final portion of output is a final summary utilizing average annual computations over the simulation period. The summaries include meteorological input, pond operations and individual disposal area averages which can be used in a cost to benefit prediction analysis. Also included is a summary of statistical data used to generate the precipitation and runoff frequency curves.

CHAPTER V

RESULTS AND DISCUSSION

This Chapter presents and discusses the results obtained from using the computer program to analyze the effects of weather modification and the design of a supplemental irrigation system using municipal wastewater. The first analysis presented is the evaluation of the hydrological effects of implementing a weather modification program in Kansas. The second analysis consists of an optimized design for using effluent municipal wastewater for supplemental irrigation.

Weather Modification

Ten locations representing a geographic cross-section of Kansas were used to test the effects of cloud seeding on the current hydrological environment within the state. The locations selected to represent the western section of Kansas were Colby, Dodge City, Garden City, Goodland and Hays. Belleville and Ellsworth were selected to represent the central section of the state. The eastern portion was represented by Horton, Independence and Topeka. These ten locations were chosen because of the availability of historical climatic data in these regions. Each location was analyzed for a crop cover of wheat without irrigation. The period simulated for each location used in the analysis is presented in Table III. The input data used for each location is presented in Appendix D.

TABLE III

SUMMARY OF RESULTS OF PRECIPITATION AND RUNOFF

Location	Time Period	Precipitation (in.)			Runoff (in.)		
		Natural	B-ZERO	B-ZERO MODIFIED	Natural	B-ZERO	B-ZERO MODIFIED
Colby	1950-1962	18.4	20.9	21.3	0.8	0.9	1.1
Dodge City	1949-1973	20.7	23.0	23.6	1.1	1.2	1.4
Garden City	1950-1974	18.2	20.2	20.7	0.8	0.8	1.0
Goodland	1949-1973	15.9	18.4	18.7	0.4	0.5	0.6
Hays	1948-1973	23.4	25.4	26.2	1.6	1.6	2.0
Belleville	1949-1973	30.0	32.1	33.2	3.4	3.5	4.0
Ellsworth	1946-1970	27.1	29.1	30.0	2.4	2.5	2.9
Horton	1946-1970	36.7	38.6	40.1	5.9	5.9	6.8
Independence	1948-1961	36.9	38.8	40.0	5.7	5.7	6.4
Topeka	1964-1973	37.0	38.7	40.1	5.6	5.5	6.4

Precipitation

Two weather modification schemes were used to modify the historical precipitation patterns for each of the ten locations during the months March through September. The first modifying scheme, Model B-ZERO, produces a seventy-five percent increase in precipitation from clouds producing normally 0.10 inch or less. Precipitational clouds which normally provide between 0.11 and 0.50 inches are increased thirty percent under Model B-ZERO conditions while amounts between 0.51 and 1.00 inches are increased ten percent. Large precipitational clouds are reduced ten percent by Model B-ZERO.

The second weather modification scheme analyzed is Model B-ZERO MODIFIED. This model modifies the daily rainfalls in Kansas the indicated percentages given for Model B-ZERO with the exception of large rainfalls. There is no modification to rainfalls of greater than 1.00 inch under this model. Model B-ZERO MODIFIED provides the potential range in precipitation increase using cloud seeding programs.

The results of modifying the daily rainfalls during the periods simulated for each location are presented in Table III. The average increase in the magnitude of precipitation for the time period considered within the state was approximately two inches per year using Model B-ZERO while approximately three inches per year was obtained using Model B-ZERO MODIFIED. These results agree with previous research estimates which indicated that a possible increase of ten percent could be obtained from using a cloud seeding program (7).

Although the increase in magnitude of rainfall was approximately equal throughout the state, the percentage of rainfall increase varied significantly for western, central and eastern portions of Kansas. In the western section of the state, Model B-ZERO indicated an average increase in precipitation of 11.6 percent while B-ZERO MODIFIED indicated a 14.5 percent increase. An increase of 7.3 and 10.7 percent resulted in the central portion of Kansas from using Models B-ZERO and B-ZERO MODIFIED respectfully. Increases in the eastern section were indicated to be only 5.0 percent for B-ZERO and 8.7 percent for B-ZERO MODIFIED. The range of this potential precipitational increase is shown schematically in Figures 9, 10 and 11 for the western, central and eastern sections respectfully. The time period chosen was from 1950 through 1962 because of the wealth of data available during this period for the ten locations.

Surface Runoff

The surface runoff which could be expected was estimated using the method developed by the Soil Conservation Service previously described in Chapter II. It should be noted that prior to any surface runoff an interception-storage requirement of 0.1 inch had to be satisfied. The results obtained for the surface runoff based on the ten locations previously defined are presented in Table III.

As can be seen in Table III the expected average amount of annual surface runoff in western Kansas is only 0.9 inches, while central and eastern Kansas averaged 2.9 and 5.7 inches respectfully. The use of Model B-ZERO increased the runoff in all three sections of Kansas approximately 0.1 inch. However, Model B-ZERO MODIFIED indicated an increase in the annual runoff of 0.2 inches in western Kansas, 0.5 inches in central Kansas and 0.8 inches in eastern Kansas. It is believed that the results

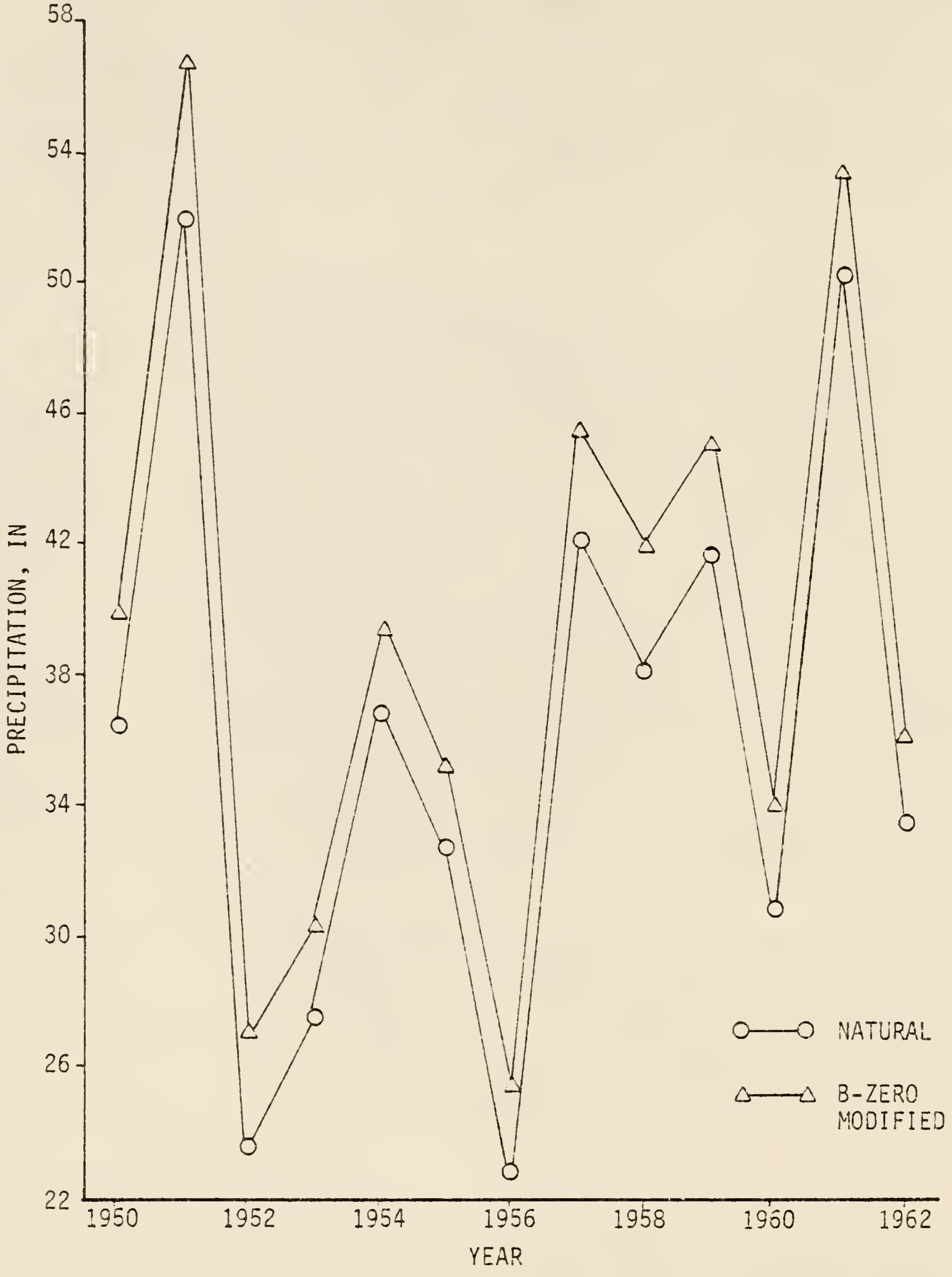


Figure 9. Natural and Enhanced Annual Precipitation for Western Kansas

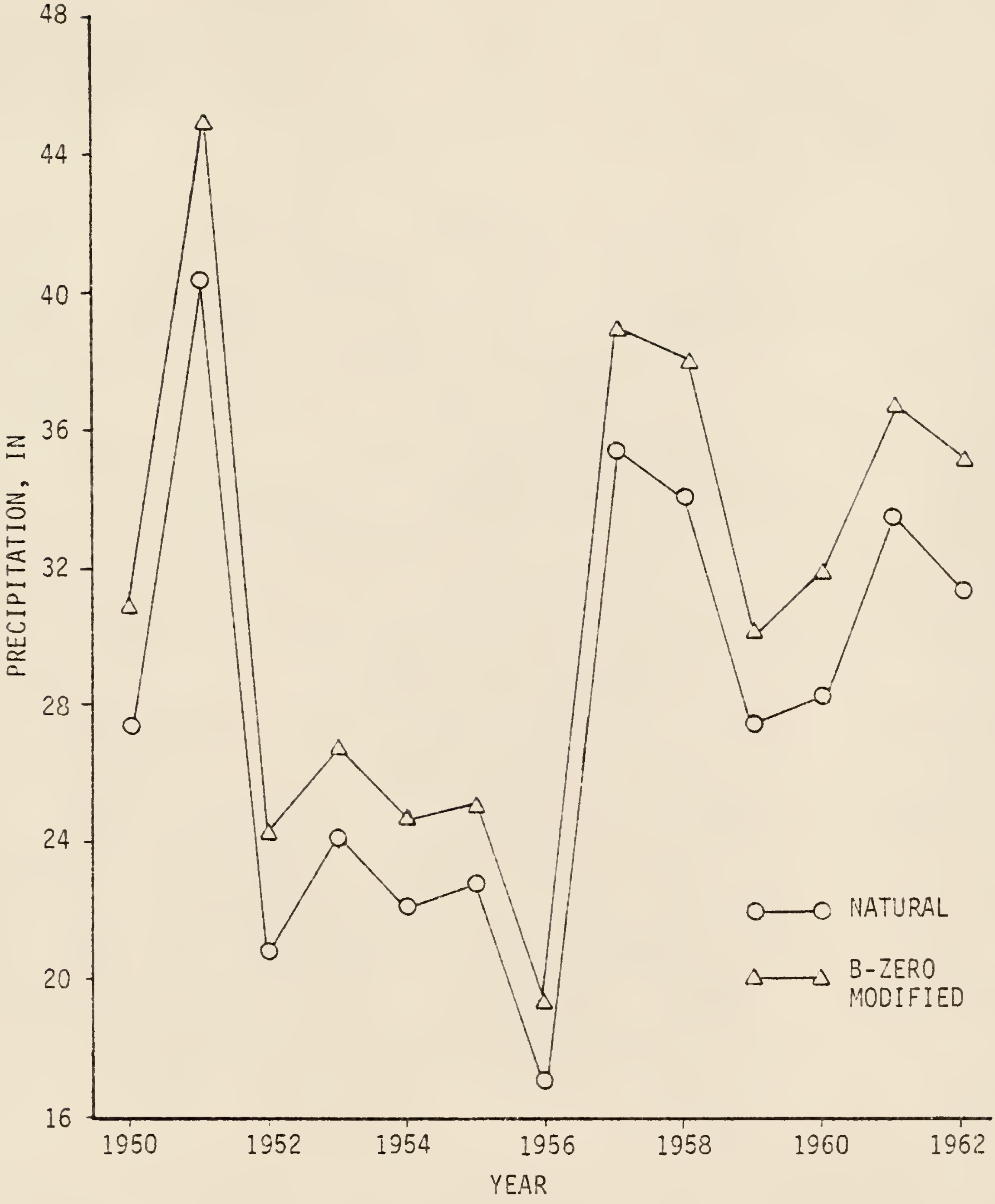


Figure 10. Natural and Enhanced Annual Precipitation for Central Kansas

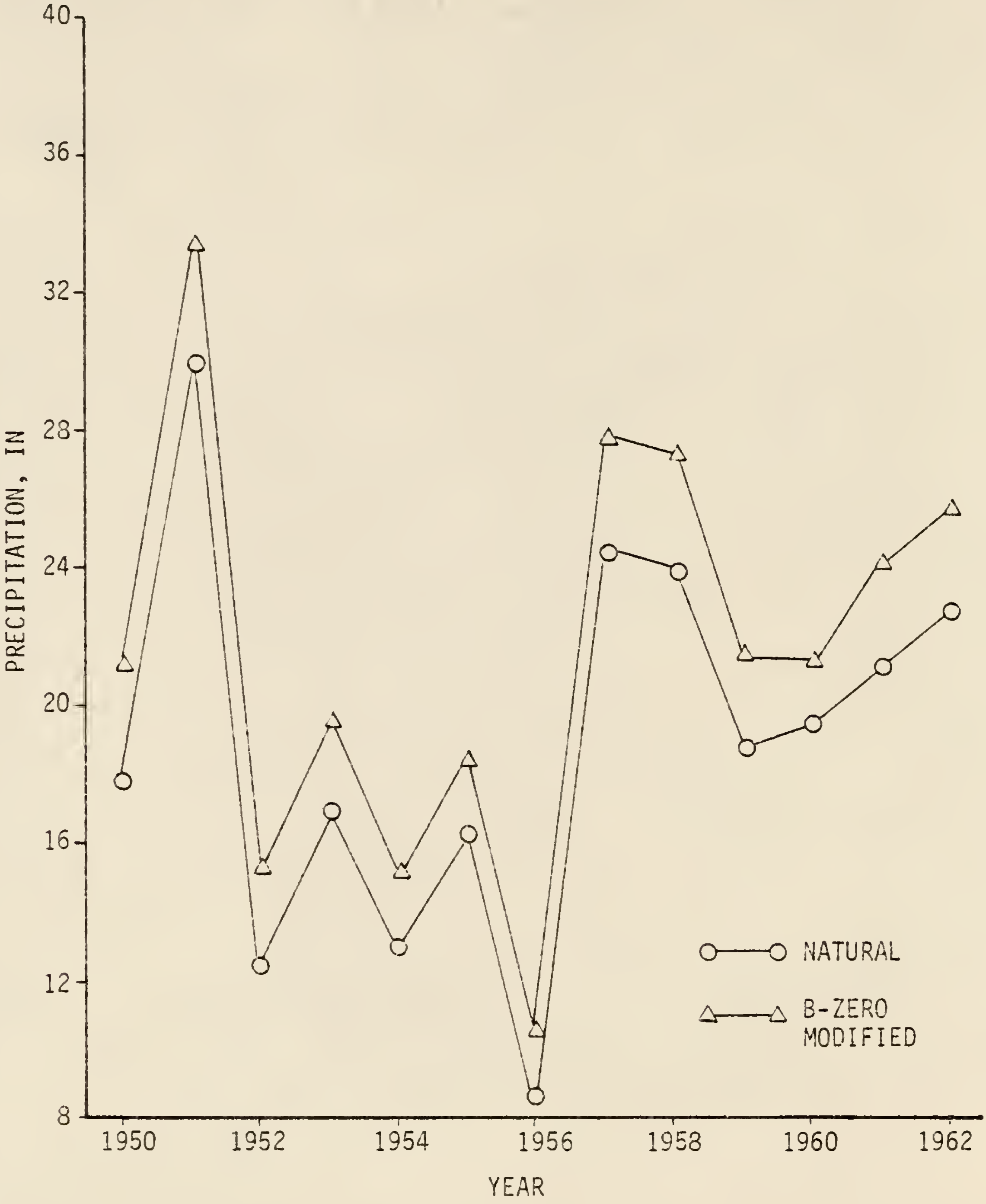


Figure 11. Natural and Enhanced Annual Precipitation for Eastern Kansas

obtained from using the two precipitation enhancement schemes accurately describe the expected range of increase in runoff. This belief is based on the results of the research conducted by Hanson and Woolhiser (18). Their research conducted on conditions in western South Dakota which were similar to those used in this study indicated a limited increase in runoff similar to B-ZERO and a 27 percent increase using a Model similar to B-ZERO MODIFIED.

Deep Percolation

The deep percolation values presented in Table IV represent the quantity of moisture passing through the lower zone of the soil profile as discussed previously. The natural amount of deep percolation under normal precipitational patterns in the western section of the state is apparently quite low. The computer analysis predicts an increase in the magnitude of deep percolation to be 0.1 inch annually using a precipitation enhancement program in western Kansas. The central section of the state, which currently has an average annual deep percolation of 0.7 inches could expect an increase of 0.5 to 0.8 inches.

The eastern portion of Kansas would receive the greatest benefit to potential groundwater recharge as a result of using a weather modification scheme. The average amount of deep percolation under natural conditions is currently estimated to be 3 inches annually. Models B-ZERO and B-ZERO MODIFIED predict that potential recharge could be increased to 4.0 and 4.5 inches respectfully. These values indicate that approximately 50 percent of any additional moisture which would result from cloud seeding in eastern Kansas could be considered as potential groundwater recharge.

TABLE IV

SUMMARY OF RESULTS FOR RECHARGE AND EVAPOTRANSPIRATION

Location	Time Period	Deep Percolation (in.)			Evapotranspiration (in.)		
		Natural	B-ZERO	B-ZERO MODIFIED	Natural	B-ZERO	B-ZERO MODIFIED
Colby	1950-1962	0	0	0	12.9	14.8	15.0
Dodge City	1949-1973	0	0.04	0.07	14.5	16.2	16.6
Garden City	1950-1974	0	0.03	0.05	12.9	14.4	14.8
Goodland	1949-1973	0	0	0	10.8	12.7	12.9
Hays	1948-1973	0.10	0.14	0.18	16.6	18.2	18.6
Belleville	1949-1973	1.24	1.99	2.36	19.3	20.1	20.3
Ellsworth	1946-1970	0.22	0.46	0.61	18.9	20.2	20.6
Horton	1946-1970	4.25	5.51	6.05	19.8	20.2	20.2
Independence	1948-1961	2.06	2.95	3.33	22.1	22.7	22.9
Topeka	1964-1973	3.01	3.63	4.05	21.2	21.9	22.0

Actual Evapotranspiration

Evapotranspiration (AET) as used in this study includes both bare soil evaporation and any transpiration. The AET values predicted for each location are presented in Table IV. Using the data presented in this Table the average annual AET values were estimated to be 13.5, 19.1 and 21.0 inches for western, central and eastern Kansas respectfully. These values indicate that nearly two-thirds of the total precipitation under natural conditions is dissipated by AET.

In western Kansas, Model B-ZERO predicted an increase in the AET value of 1.8 inches while Model B-ZERO MODIFIED indicated an increase of 2 inches. These values imply that 75 percent of the moisture added as a result of weather modification will be utilized in the ET process. In the central portion of the state, increases of 1.0 to 1.3 inches were predicted. These values represent nearly 50 percent of the precipitation added from a cloud seeding program. The increased values in evapotranspiration suggest an economic benefit through potential improvement of crop yields due to weather modification in western and central Kansas. Eastern Kansas is predicted to have a maximum AET increase of 0.7 inches which suggests that the soil moisture required for maximizing evapotranspiration is adequate in this portion of the state.

Municipal Wastewater Effluents

This section of the Chapter presents the results obtained by the computer program to analyze and design a supplemental irrigation system using the effluent from a municipal wastewater-treatment plant. The application of municipal wastewater as a supplement to an irrigation system requires the design of a storage facility. Since the volume of municipal wastewater is generally large and the flow rate is time dependent the storage facility must act as a fluid control system in addition to being based on an optimum design.

For comparative purposes two designs were made for a storage control facility to be located in the Topeka area during a ten year simulation period beginning in 1964 and ending in 1973. The first design was for a storage facility having the following natural sources of inflow: (1) precipitation directly into the facility, and (2) surface runoff from a 120 acre watershed area. The second design included municipal inflow into the storage facility using an average flow rate of 84,000 gallons per day. Both facilities were anaylized for supplying irrigation water for two 40 acre areas with the vegetative cover of corn and wheat. Results are presented in Table V.

The use of municipal wastes as supplemental irrigation water required a storage facility volume of 2720 acre-inches for controlling ninety-eight percent of the inflow while under the natural inflow conditions the storage volume required was 690 acre-inches. Utilizing the municipal effluent the total annual increase in the volume of irrigation water applied to the disposal areas was 838 acre-inches. Irrigation was applied at a disposal rate of 0.5 inches per day when the soil moisture was below ninety percent of field capacity.

The additional irrigation increased potential groundwater recharge an average of 4.6 inches annually. Evapotranspiration on the irrigated corn field increased 2.9 inches annually. On the wheat field

TABLE V

SUMMARY OF RESULTS FOR A DISPOSAL CONTROL FACILITY

Parameter	Natural Inflow	Natural and Municipal Inflow
Storage Volume	690 ac-in	2720 ac-in
Receiving Area	7.1 ac	26.5 ac
Precipitation	38.7 in	38.7 in
Moisture Deficit	3.5 in	3.5 in
Disposal Area - Corn		
Recharge	5.1 in	9.4 in
No. Irrigation Days	17	40
Evapotranspiration	25.0 in	27.9 in
Disposal Area - Wheat		
Recharge	6.7 in	11.6 in
No. Irrigation Days	14	33
Evapotranspiration	22.7 in	23.8 in

evapotranspiration was increased 1.1 inches annually. The increase in evapotranspiration indicates the possibility of maximizing crop production.

The computer program provides an effective means of evaluating the application of municipal wastewater effluent on agricultural land. To optimize the storage facility design various disposal rates as well as differing soil conditions should be considered.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The objective of this research study was to develop a new methodological approach to the problem of providing a dependable supply of water for man's use. This objective was accomplished by developing and testing a multipurpose hydrologic yield model. The model was used to evaluate the effects of weather modification schemes on the hydrological environment in Kansas. In addition, the utilization of municipal waste as a controllable source of water for irrigation was evaluated.

As a result of this study, the following conclusions can be made:

1. Cloud seeding programs in Kansas could produce a uniform increase in the total amount of precipitation.

2. Weather modification could be used to increase surface runoff, deep percolation and evapotranspiration.

3. Fifty percent of any moisture added as a result of cloud seeding in eastern Kansas could be used to recharge the groundwater supplies.

4. In western and central Kansas more than fifty percent of any moisture added because of cloud seeding could be used in the evapotranspiration process.

5. The computer program provides an effective method of evaluating the hydrological effects which result from the implementation of a weather modification scheme.

6. The computer program provides an effective means of predicting the optimized design for a disposal control facility.

Recommendations

With respect to future research, the following recommendations are made:

1. Additional verification of the simulation model should be conducted under both controlled laboratory conditions and field conditions.

2. A comprehensive study should be conducted to evaluate moisture redistribution utilizing Darcy's equation for unsaturated one-dimensional flow.

3. A comprehensive study should be undertaken to evaluate municipal wastewater as a controllable source of irrigation water for various geographic and climatic conditions.

4. A comprehensive study should be initiated to study the possibility of collecting surface runoff from natural watersheds as a supplemental irrigation water source.

5. The computer program should be modified to incorporate the following: (1) seepage from the storage facility, (2) the possibility of constructing multiple storage facilities, and (3) a cost optimization package.

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APPENDIX A

LIST OF SYMBOLS

AET	actual evapotranspiration
E_s	soil evaporation
ES	saturated vapor pressure
ETP	evapotranspiration potential
K	hydraulic conductivity
N	runoff curve number
P	precipitation
PSUNS	percent sunshine
Q	surface runoff
Ra	solar radiation
RHD	relative humidity
S	maximum potential difference
T	mean daily air temperature
Ta	mean daily air temperature
WVD	wind speed
a	geographic location constant
b	geographic location constant
c'	hydraulic coefficient
e	mass transfer coefficient
i	hydraulic gradient
k	crop consumptive use coefficient
q'	volume of water movement per unit area
r	reflectance coefficient
t	time after first stage evaporation

Δh	change in soil water potential
Δt	time increment
Δz	change in elevation
Θ_a	available soil moisture
Θ_{max}	maximum available soil moisture

APPENDIX B

REFERENCE IDENTIFIERS

TABLE VI

RUNOFF CURVE NUMBERS FOR ANTECEDENT SOIL MOISTURE CONDITION II*

Irrigation Soil Class	Crop						
	Wheat	Grain Sorghum	Corn	Soybeans	Pasture	Alfalfa	Fallow Soil
1	83	86	86	84	80	86	84
2	83	86	86	84	80	86	84
3	78	82	82	81	74	82	81
4	78	82	82	81	74	82	81
5	69	75	75	73	61	75	73
6	69	75	75	73	61	75	73
7	69	75	75	73	61	75	73
8	69	75	75	73	61	75	73
9	69	75	75	73	61	75	73
10	69	75	75	73	61	75	73
11	69	75	75	73	61	75	73
12	55	65	65	61	39	65	61

*From Bean, 1976

TABLE VII

SOIL CLASSIFICATION USED FOR IRRIGATION DESIGN*

Irrigation Soil Class	Profile Depth (ft.)	Soil Class Description
1	3'	Deep soils with silt loam or silty clay loam surface layers and slowly to very slowly permeable heavy clay and claypan subsoils.
2	3'	Deep soils with silty clay or clay textures throughout. Surface infiltration and subsoil permeability are very slow when the soil is moist. Shrinkage from drying causes extensive cracking, resulting in high infiltration rates until swelling occurs.
3	5'	Deep soils with silt loam, loam, clay loam, or silty clay loam surface layers and clay loam, silty clay loam, or silty clay subsoils. Subsoil permeability is slow to moderately slow. Shrinkage cracks resulting from drying in the soils with more clayey subsoil textures give a relatively high initial infiltration rate.
4	2.5'	Moderately deep soils with silt loam, clay loam, or silty clay loam surface layers and clay loam or silty clay subsoils with predominately moderately slow permeability.
5	5'	Deep soils with silt loam, loam, clay loam, or silty clay loam surface layers and subsoils. Subsoil permeability: moderate to moderately slow.
6	3'	Moderately deep soils with silt loam or loam surface layers and loam, clay loam, or silty clay loam subsoils with moderate to moderately slow permeability.
7	5'	Deep soils with silt loam, loam or very fine sandy loam surface layers and moderately permeable, medium textures subsoils.
8	2.5'	Moderately deep soils with silt loam, loam or very fine sandy loam surface layers and moderately permeable clay loam, loam, or silt loam subsoils.

TABLE VII (Continued)

9	5'	Deep soils with fine sandy loam and loam surface layers and subsoils that have moderately rapid permeability. Available water capacity is moderate to low.
10	5'	Soils are moderately deep over sand with sandy loam to loam surface layers and moderately rapid to rapidly permeable subsoils with low available water capacity.
11	5'	Deep soils with loam fine sand or loamy sand surface layers and moderately rapid to rapidly permeable subsoils.
12	5'	Deep rapidly permeable soils with sand or fine sand textures throughout.

*From Bean, 1976

TABLE VIII

CROP CODES USED IN THE COMPUTER PROGRAM

Crop	Reference Number
Wheat	1
Grain Sorghum	2
Corn	3
Soybean	4
Pasture	5
Alfalfa	6
Fallow Soil	7

TABLE IX

AREA CODES USED IN THE COMPUTER PROGRAM

Plan Indicated	Rotation Indicated	Reference Number
Collect Area Runoff	Crop - Fallow	1
Collect Area Runoff and Irrigate	None	2
Irrigate	——	3

APPENDIX C

LISTING OF COMPUTER PROGRAM

```
FORTRAN IV G LEVEL  21                 MAIN                 DATE = 79045          21/27/40

               C
               C      HYDROLOGICAL WATERSHED MODEL
               C
               C      KANSAS STATE UNIVERSITY   1978
               C
 0001                 INTEGER CROP,FREEZE,SOIL,STIND,T,YEAR,YEARS,YEND,YSTART
 0002                 INTEGER PLCT,PREVYR,BYPASS,NROPTS,DARCEQ,ROTAYR
 0003                 INTEGER DGSB,DGSE,DGSBP(9),DGSEP(9),DAY,ROTATE(9)
 0004                 REAL IA,IAADD,IAFT,KCROP,KS,LAKEVP,LKEVPI,LTAREA,L,M,MA,NIA,NOPERC
 0005                 REAL L1,MMAT(12),IRRVOL,IRRSUM,MAXVOL,MR,NRNOF,LZSM,MUNDIS(12)
 0006                 DIMENSION HUZ(9),HLZ(9),HGW(9),ED(9),T(9),SMPC(9),DISVOL(9)
 0007                 DIMENSION SM(9),SMUZ(9),SMLZ(9),SMGWZ(9),FCGW(12),CONDUZ(9)
 0008                 DIMENSION CONDLZ(9),CONDGW(9),CTP(25),ASTAT(25),CTR(25,4)
 0009                 DIMENSION AREA(9),IAREA(9,2),IPLAN(9),INCROP(9),MGSBP(9),MGSEP(9)
 0010                 DIMENSION CNS1(7),CNS3(7),CNS5(7),CNS12(7),FREQ(25),CTPR(25)
 0011                 DIMENSION CTPDAY(4),AETU(9),AETL(9),IAACC(9),IAET(9),NIA(9)
 0012                 DIMENSION AMONTH(13),AVLFCL(12),AVLFCU(12),C(12),FCL(12),FCU(12)
 0013                 DIMENSION KCROP(7,12),NDIM(12),PDACCT(13,11),PREC(31),PSUNS(12)
 0014                 DIMENSION PWPLZ(12),PWPUZ(12),RA(12),RCM(12,7),RCN(12,7),RHD(12)
 0015                 DIMENSION SMACCT(13,8,9),SMSATL(12),SMSATU(12),TAVG(31),TMAX(31)
 0016                 DIMENSION TMIN(31),U(12),WIND(12),PRECAC(25,4),RUNACC(25,9)
 0017                 DIMENSION DSRNFF(9),AINTER(9),AAETRS(9),ACHSOM(9),DSPERC(9)
 0018                 DIMENSION NRNOF(9),NOPERC(9),SMSATG(12),NAMES(6),DAYSDS(9),PWG(12)
 0019                 COMPLEX*16 KROP*16(7)/'WHEAT','SORGHUM','CORN','SOY BEANS',
                    1       'PASTURE','ALFALFA','FALLOW'/
 0020                 DATA CNS1/84.0,86.0,86.0,86.0,80.0,83.0,84.0/
 0021                 DATA CNS3/81.0,82.0,82.0,82.0,74.0,78.0,78.0/
 0022                 DATA CNS5/73.0,75.0,75.0,75.0,61.0,69.0,69.0/
 0023                 DATA CNS12/61.0,65.0,65.0,65.0,39.0,55.0,61.0/
 0024                 DATA NAMES/'IRR.','INT.','RNFF','PERC','AET ',' SM '/
 0025                 DATA AMONTH/'JAN.','FEB.','MAR.','APR.','MAY ','JUNE','JULY',
                    1       'AUG.','SEPT','OCT.','NOV.','DEC.','TOT.'/
 0026                 DATA ASTAT/'>0.0','>0.1','>0.2','>0.3','>0.4','>0.5','>0.6',
                    1       '>0.7','>0.8','>0.9','>1.0','>1.1','>1.2','>1.3','>1.4',
                    2       '>1.5','>1.6','>1.7','>1.8','>1.9','>2.0','>3.0','>4.0',
                    3       '>5.0','>10.'/
 0027                 DATA AVLFCU/2.6,1.5,2.5,2.4,2.5,2.6,2.4,2.4,2.4,2.2,1.5,1.0/
 0028                 DATA AVLFCL/2.7,2.9,5.7,2.5,6.7,4.2,6.6,3.3,5.2,4.1,4.1,2.5/
 0029                 DATA C/0.2,0.2,0.177,0.177,0.177,0.177,0.159,0.159,0.138,0.138,
                    1       0.134,0.131/
 0030                 DATA FCU/4.6,4.4,4.5,4.6,4.5,4.3,4.0,4.0,3.8,3.5,2.3,1.7/
 0031                 DATA FCL/9.4,9.4,14.2,7.0,13.9,9.1,13.7,6.8,9.2,7.0,7.0,4.3/
 0032                 DATA FCGW/7.0,6.9,9.4,5.8,9.2,6.7,8.8,5.4,6.5,5.2,4.6,3.0/
 0033                 DATA PWPUZ/2.0,2.9,2.0,2.2,2.0,1.7,1.6,1.6,1.4,1.3,0.8,0.7/
 0034                 DATA PWPLZ/6.7,6.5,9.5,4.5,7.2,4.9,7.1,3.5,4.0,2.9,2.9,1.8/
 0035                 DATA PWG/4.3,4.7,5.2,3.3,4.6,3.3,4.3,2.6,2.7,2.1,1.8,1.3/
 0036                 DATA SMSATU/5.8,6.2,5.7,5.7,5.7,5.5,5.4,5.4,5.3,5.2,4.8,4.8/
 0037                 DATA SMSATL/11.8,11.5,16.3,8.2,15.8,10.4,15.4,7.7,13.9,13.2,13.2,
                    1       12.9/
 0038                 DATA SMSATG/8.8,8.8,11.0,6.9,10.7,8.9,10.4,6.5,9.6,9.2,9.0,8.8/
 0039                 DATA U/0.47,0.47,0.39,0.39,0.39,0.39,0.35,0.35,0.31,0.31,0.28,
                    1       0.24/
 0040                 DATA NDIM/31,28,31,30,31,30,31,31,30,31,30,31/
 0041                 DATA FREQ/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0,1.1,1.2,
                    1       1.3,1.4,1.5,1.6,1.7,1.8,1.9,2.0,3.0,4.0,5.0,10.0/
 0042                 DATA PDT,SMMAXL,SMUZPR,SMPREV,EPRIM/37.5,2.2,3.25,12.60,0.5/
 0043                 DATA AVAILL,AVAILU,CM,DSCVOL,DSDAYS,EVAPLK,H,IRRSUM,
                    1       PEAK,PREVDS,SNOW,TPAREA,TPREC,UZSMCH,WASTWW,WET/16*0.0/
```

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 0044                DATA AET,AETLZ,AETUZ,B2,DPERC,EXCESS,IA,M,MA,MR,PACK,PACKPY,POVOL,
                   1      PERC,PONVOL,P1,P2,P3,SNOMLT,TOPERC,TRNOF,T1,T2/23*0.0/
 0045                DATA CTPDAY,WATER,STRVOL,VOLDIS,CROP,IDAY,MM,PLOT,SOIL/4*0.0,5*0/
 0046                DATA CTP,CTPR,CTRDAY,CTR/25*0.0,25*0.0,4*0.0,100*0.0/
 0047                NAMELIST/ALPHA/BRUNTA,BRUNTB,CROP,DORM,E,GROW,DSRATE,PAVLU,PCVMAX,
                   *RCROP
 0048                NAMELIST/BETA/NPLOTS,HMAX,INDST,L,LTAREA,MSTART,S,STORM,W,YEND,
                   *YSTART,DARCEQ,ROTAYR,BYPASS
 0049                NAMELIST/SEED/MODEL,WPCNT
              C
              C           ***** INPUTS *****
              C
              C***   READ PROGRAM IDENTIFIERS
 0050                READ(5,5)  NAME,OF,CITY,AND,STATE
 0051              5 FORMAT(20X,5A4)
 0052                READ(5,10) WEATH,MODIF,MOD,EL
 0053             10 FORMAT(1X,4A4)
 0054                READ(5,15) IN,FLOW,TC,STOR,AGE,POND
 0055             15 FORMAT(1X,6A4)
              C***   READ WEATHER MODIFICATION, FEEDLOT, POND AND PLOT PARAMETERS
 0056                READ(5,SEED)
 0057                READ(5,ALPHA)
 0058                READ(5,BETA)
 0059                PREVYR=YSTART
              C***   READ THE MONTHLY AVERAGE METEOROLOGICAL DATA
 0060                READ(5,20) (PSUNS(I),RHD(I),RA(I),WIND(I),MMAT(I),I=1,12)
 0061             20 FORMAT(2X,F2.2,F2.0,F4.2,F3.1,F3.1)
              C***   READ INPUTS FOR SOIL TYPE, CROP AND AREA FOR EACH PLOT
 0062                READ(5,25) ((IAREA(I,J),J=1,2),I=1,NPLOTS)
 0063             25 FORMAT(2X,I1,2X,I2)
 0064                READ(5,30) (AREA(I),I=1,NPLOTS)
 0065             30 FORMAT(1X,F6.0)
              C***   READ INPUTS FOR PLAN IMPLEMENTATION AND CROP ROTATION
 0066                READ(5,35) (IPLAN(J),ROTATE(J),J=1,NPLOTS)
 0067             35 FORMAT(1X,2I1)
 0068                READ(5,40) (MGSBP(I),DGSBP(I),MGSEP(I),DGSEP(I),I=1,NPLOTS)
 0069             40 FORMAT(4I3)
              C***   READ INPUTS FOR DARCY'S EQUATION AND MUNICIPAL DISPOSAL
 0070                IF(DARCEQ.EQ.1)  READ(5,45)(CONDUZ(I),CONDLZ(I),CONDGW(I),HUZ(I),
                   1HLZ(I),HGW(I),I=1,NPLOTS)
 0071             45 FORMAT(3F10.2,3E10.4)
 0072                IF(BYPASS.GE.3) READ(5,50)(MUNDIS(I),I=1,12)
 0073             50 FORMAT(F10.2)
              C
              C***   RUNOFF CURVE NUMBERS FOR SOIL AND CROP TYPES
 0074                DO 55 K=1,7
 0075                RCN(1,K)=CNS1(K)
 0076                RCN(2,K)=CNS1(K)
 0077                RCN(3,K)=CNS3(K)
 0078                RCN(4,K)=CNS3(K)
 0079                RCN(5,K)=CNS5(K)
 0080                RCN(6,K)=CNS5(K)
 0081                RCN(7,K)=CNS5(K)
 0082                RCN(8,K)=CNS5(K)
 0083                RCN(9,K)=CNS5(K)
 0084                RCN(10,K)=CNS5(K)
 0085                RCN(11,K)=CNS5(K)
 0086             55 RCN(12,K)=CNS12(K)
```

```
C***  SIZING POND VOLUME ROUTINE
      A1=L*W
      A2=S*(L+W)
      A3=4./3.*S**2
      A4=2.*A2
      A5=4.*S**2
C***  VOLMAX IS THE MAXIMUM VOLUME HELD BY THE STORAGE FACILITY
      VOLMAX=(A1*HMAX+A2*HMAX**2+A3*HMAX**3)/3630.
C***  PSAREA IS THE DIRECT RECEIVING AREA OF THE FACILITY
      PSAREA=((W+2.*S*HMAX)*(L+2.*S*HMAX))/43560.
C***  CALCULATE THE CROP COEFFICIENTS
      DO 60 K=1,NPLOTS
      MGSB=MGSBP(K)
      DGSB=DGSBP(K)
      MGSE=MGSEP(K)
      DGSE=DGSEP(K)
      CROP=IAREA(K,1)
      CALL CROPCO(CROP,MGSB,DGSB,MGSE,DGSE,KCROP,NDIM,MMAT)
      INCROP(K)=IAREA(K,1)
   60 CONTINUE
C***  INITIALIZE VARIABLES
      DO 70 I=1,25
      DO 65 J=2,9
      IF(J.LE.4) PRECAC(I,J)=0.0
   65 RUNACC(I,J)=0.0
   70 CONTINUE
      DO 75 J=1,12
   75 KCROP(7,J)=0.0
      DO 80  II=1,NPLOTS
      TPAREA=TPAREA+AREA(II)
      T(II)=0.0
      EO(II)=0.0
      IAET(II)=0.0
      IAACD(II)=0.0
      DISVOL(II)=0.0
      DAYSDS(II)=0.0
      DSRNFF(II)=0.0
      AINTER(II)=0.0
      AAETRS(II)=0.0
      ACHSOM(II)=0.0
      DSPERC(II)=0.0
      SMLZ(II)=9.35
      SMUZ(II)=3.25
      SMGWZ(II)=6.30
   80 SMPD(II)=SMLZ(II)+SMUZ(II)
      YEARS=YEND-YSTART+1
C
C***  PRINT INPUT PARAMETERS
      WRITE(6,85)  NAME,OF,CITY,AND,STATE,YSTART,YEND,WEATH,MODIF,MOD,EL
     1,IN,FLOW,TO,STOR,AGE,POND,LTAREA,STORM,L,W,S,HMAX,VOLMAX,PSAREA
   85 FORMAT('1',10X///////////10X,'STATION:',3X,5A4,10X,I4,'  TO  ',I4,
     1////10X,'MODEL:  ',4A4//18X,6A4//18X,'FEEDLOT AREA = ',F6.2,' ACRE
     2S'////10X,'SIZE OF CRITICAL EVENT:  ',F4.2////10X,'POND VARIABLES:
     3'//25X,'(A) BASE DIMENSION-- ',F7.2,' FEET BY',F7.2,' FEET'//25X,'
     4(B) SIDE SLOPE--   RUN:RISE = ',F3.0,' : 1'//25X,'(C) MAXIMUM DEPT
     5H--  ',F5.2,'  FEET'//25X,'(D) MAXIMUM POND VOLUME--  ',F9.2,' ACR
     6E-INCHES'//25X,'(E) DIRECT RECEIVING AREA (FOR PRECIPITATION) --
     7  ',F8.2,' ACRES'////10X,'AREA VARIABLES:')
```

```
      DO 130 J=1,NPLOTS
      PLAREA=AREA(J)
      CROP=IAREA(J,1)
      SOIL=IAREA(J,2)
      RPAVLU=PAVLU
      IF(IPLAN(J).EQ.1) PAVLU=0.0
      WRITE(6,90)  J,PLAREA,KROP(CROP),SOIL,DSRATE,PAVLU
   90 FORMAT(//15X,'PLOT ',I1//25X,'(A) AREA--  ',F6.2,'   ACRES'//25X,'
     1(B) CROP--  ',2A8//25X,'(C) SOIL TYPE--  ',I3,'  (SCS SOIL TYPE)'/
     2/25X,'(D) IRRIGATION RATE--  ',F5.2,'  INCHES/DAY '//25X,'(E) IRRI
     3GATION MANAGEMENT--   IRRIGATION BELOW  ',F5.2,'  FIELD CAPACITY')
      IF(IPLAN(J).EQ.1) WRITE(6,95)
      IF(IPLAN(J).EQ.2) WRITE(6,100)
      IF(IPLAN(J).EQ.3) WRITE(6,110)
   95 FORMAT(/25X,'(F) PLAN IMPLEMENTED--   RUNOFF')
  100 FORMAT(/25X,'(F) PLAN IMPLEMENTED--   RUNOFF AND IRRIGATION')
  110 FORMAT(/25X,'(F) PLAN IMPLEMENTED--   IRRIGATION')
      IF(ROTATE(J).EQ.1) WRITE(6,120)
  120 FORMAT(/25X,'(G) CROP ROTATION WITH --   FALLOW')
      PAVLU=RPAVLU
  130 CONTINUE
C
C
C          ***** ENTER YEARLY LOOP *****
C
      DO 980  NY=1,YEARS
C
      DO 160 I=1,13
      DO 150 J=1,11
      DO 140 K=1,NPLOTS
  140 IF(J.LE.8) SMACCT(I,J,K)=0.0
  150 PDACCT(I,J)=0.0
  160 CONTINUE
C***  ESTABLISH CROP ROTATIONS
      DO 170 K=1,NPLOTS
  170 IAREA(K,1)=INCROP(K)
      IF(ROTAYR.EQ.1) GO TO 190
      DO 180 J=1,NPLOTS
      IF(IAREA(J,1).EQ.1) GO TO 180
      IF(ROTATE(J).EQ.2) GO TO 180
      IAREA(J,1)=7
  180 CONTINUE
      ROTAYR=1
      GO TO 200
  190 ROTAYR=2
C***  INITIALIZE VARIABLES
  200 IDISDA=0.0
      MAXVOL=0.0
      LKEVPT=0.0
      VOLIRR=0.0
      VOLCHG = 0.0
      IF(NY.GT.1) MSTART=1
      WRITE(6,210)
  210 FORMAT('1',46X,'***** ANNUAL SUMMARY *****')
C
C
C          ***** ENTER MONTHLY LOOP *****
C
```

```
      DO 840  NM=MSTART,12
C
C***  ESTABLISH CROP ROTATIONS FOR WHEAT
      DO 230 II=1,NPLOTS
      IF(INCROP(II).NE.1) GO TO 230
      IF(ROTATE(II).EQ.2) GO TO 230
      IF(ROTAYR.EQ.2) GO TO 220
      IF(NM.GT.MGSEP(II)) IAREA(II,1)=7
      GO TO 230
  220 IF(NM.LT.MGSBP(II)) IAREA(II,1)=7
      IF(NM.GE.MGSBP(II)) IAREA(II,1)=INCROP(II)
  230 CONTINUE
C***  READ MONTHLY METEOROLOGICAL DATA
  240 READ(1,250,END=1520) KAN,STINO,YEAR,MONTH,(PREC(I),I=1,31),
     1(TMAX(I),I=1,31),(TMIN(I),I=1,31)
  250 FORMAT(I2,I4,2I2,31F4.2,62F3.0)
      IF(STINO.NE.INCST) GO TO 240
      IF(YEAR.LT.YSTART-1900) GO TO 240
      IF(YEAR.GT.YEND-1900) GO TO 990
      IF(MONTH.LT.MSTART.AND.YEAR.EQ.YSTART-1900) GO TO 240
      ACTIRR=0.0
      DSDAY=0
      NDIM(2)=28
      IF(NM.EQ.2.AND.TMAX(29).LT.900) NDIM(2)=29
      NDAYS=NDIM(NM)
C
C
C        ***** ENTER DAILY LOOP *****
C
      DO 800  ND=1,NDAYS
C
C***  THE FOLLOWING STATEMENTS CORRECT  FOR MISSING DATA ON INPUT TAPE
      IF(TMAX(ND).GT.250.0) TMAX(ND)=PDT+100.0
      IF(TMIN(ND).GT.250.0) TMIN(ND)=PDT+100.0
      IF(PREC(ND).GT.99.97) PREC(ND)=0.0
C***  TAVG IS THE AVERAGE DAILY AIR TEMPERATURE, DEGREE FAHRENHEIT
      TAVG(ND)=(TMAX(ND)+TMIN(ND))/2.0-100.0
C***  SUBROUTINE WTHRMD ADJUSTS THE PERCIPITATION RESULTING FROM
C***  SEEDING CLOUDS
      CALL WTRMOD(PREC(ND),NM,MODEL,WPCNT)
C***  THE FOLLOWING CARD EVALUATES WHETHER THE 24 HOUR DESIGN STORM
C***  HAS BEEN EXCEEDED.
      IF(PREC(ND).GE.STORM/1.14) WRITE(6,260) NM,ND,YEAR,PREC(ND)
  260 FORMAT(20X,I2,'/',I2,'/',I2,'  CRITICAL EVENT EXCEEDED  ',
     12X,F10.2,'  INCH STORM  ')
C
C
C     *** CALCULATION OF POTENTIAL EVAPOTRANSPIRATION BY MEANS OF
C                        PENMAN EQUATION ***
C
      R=RCROP
C***  THE FOLLOWING CARD CHECKS FOR SNOW COVER
      IF(PACK.GT.0.1) R=0.70
C***  THE NEXT TWO CARDS CONVERT TAVG TO ABSOLUTE, DEGREE KELVIN
      CENT=(TAVG(ND)-32.0)*100.0/180.0
      ABST=CENT+273.16
C***  ES IS THE DAILY CALCULATED SATURATED VAPOR PRESSURE, IN MILLIBARS
      ES=33.9*((0.00738*CENT+0.8072)**8-0.000019*ABS(1.8*CENT+48)
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                    1  +0.00136)
 0208                  IF(ES.LE.0.0) ES=0.0
              C***  ESA IS THE DAILY CALCULATED ACTUAL VAPOR PRESSURE, IN MILLIBARS
 0209                  ESA=ES*RHD(NM)/100.0
              C***  RN IS THE CALCULATED DAILY NET RADIATION, IN MM OF WATER
 0210                  RN=(1-R)*RA(NM)*(0.22+0.54*PSUNS(NM))-2.010E-09*ABST**4*
                      1(0.98*(1.-BRUNTA-BRUNTB*SQRT(ESA)))*(0.1+0.9*PSUNS(NM))
 0211                  IF(RN.LT.0.0) RN=0.0
              C***  WINDD IS THE MONTHLY AVERAGE WINDRUN, MILES/DAY AT 2 METERS HEIGHT
 0212                  WINDD=(WIND(NM)*24)*0.555
              C***  EA IS THE CONVECTIVE LOSSES, MM WATER
 0213                  EA=0.26*(E+0.01*WINDD)*(ES-ESA)
 0214                  EALAKE=0.26*(EPRIM+0.01*WINDD)*(ES-ESA)
 0215                  IF(TAVG(ND)) 270,270,280
 0216              270 DELTA=0.0
 0217                  GO TO 290
 0218              280 DELTA=0.039*TAVG(ND)**0.673
 0219              290 GAMMA=1-DELTA
              C***  PET IS THE CALCULATED DAILY POTENTIAL EVAPOTRANSPIRATION, INCHES
 0220                  PET=((DELTA*RN)+(GAMMA*EA))/25.4
              C
              C***  CALCULATE LAKE AND BARE SOIL EVAPORATION
 0221                  RNSOIL=RN*((1.0-0.20)/(1.0-R))
 0222                  RNLAKE=RN*((1.0-0.05)/(1.0-R))
 0223                  PETBS=((DELTA*RNSOIL)+(GAMMA*EA))/25.4
 0224                  LAKEVP=((DELTA*RNLAKE)+(GAMMA*EALAKE))/25.4
 0225                  POT=TAVG(ND)
 0226                  IF(TAVG(ND).LT.20.0) PET=0.0
 0227                  IF(TAVG(ND).LT.20.0) PETBS=0.0
 0228                  IF(TAVG(ND).LT.20.0) LAKEVP=0.0
 0229                  DO 300 MQ=1,NPLOTS
 0230                  IAADD(MQ)=IAET(MQ)-PET
 0231                  CCROP=IAREA(MQ,1)
 0232                  IF(KCROP(CCROP,NM).EQ.0.0) IAADD(MQ)=IAET(MQ)-PETBS
 0233                  IF(IAADD(MQ).GT.0.1) IAADD(MQ)=0.1
 0234                  IF(IAADD(MQ).LT.0.0) IAADD(MQ)=0.0
 0235              300 CONTINUE
              C***  SUBROUTINE SNOWRT CALCULATES THE MOISTURE ADDED TO THE DISPOSAL
              C***  SITE DUE TO SNOWMELT ON THE AREA
 0236                  PRECIP=PREC(ND)
 0237                  SNOVAP=0.0
 0238                  WATER=PRECIP
 0239                  CALL SNOWRT(PRECIP,WATER,PACK,PET,TAVG(ND),SNOVAP)
              C
              C
              C        *** EVALUATION OF SOIL MOISTURE AND CALCULATION
              C                     OF ACTUAL EVAPOTRANSPIRATION ***
              C
 0240                  STRVOL=0.0
 0241                  RUNMOS=0.0
 0242                  JJ=0
 0243                  NNN=0
 0244              330 NNN=NNN+1
 0245                  IF(NNN.GT.NPLOTS) GO TO 650
 0246                  STRNOF =0.0
 0247                  JJ=JJ+1
 0248              340 CROP=IAREA(JJ,1)
 0249                  SOIL=IAREA(JJ,2)
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      DSAREA=AREA(JJ)
      RAIN=WATER+DISVOL(JJ)/DSAREA
      IF(DISVOL(JJ).GT.0.0.AND.PRECIP.LT.0.4) GO TO 410
      IF(RAIN.LE.0.0) GO TO 400
C***  CALCULATE SURFACE RUNOFF VOLUME BY SCS METHOD
      IF(KCROP(CROP,NM).LE.0.0) GO TO 370
      IF(SMUZ(JJ).LT.(PWPUZ(SOIL)+0.5*AVLFCU(SOIL))) GO TO 350
      IF(SMUZ(JJ).GT.(PWPUZ(SOIL)+0.8*AVLFCU(SOIL))) GO TO 360
      GO TO 380
C***  MODIFY RUNOFF CURVE NUMBER TO CONDITION I ANTECEDENT MOISTURE
  350 RCM(SOIL,CROP)=RCN(SOIL,CROP)*0.39*EXP(0.009*RCN(SOIL,CROP))
      GO TO 390
C***  MODIFY RUNOFF CURVE NUMBER TO CONDITION III ANTECEDENT MOISTURE
  360 RCM(SOIL,CROP)=RCN(SOIL,CROP)*1.95*EXP(-0.00663*RCN(SOIL,CROP))
      GO TO 390
  370 IF(SMUZ(JJ).LT.0.6*FCU(SOIL)) GO TO 350
      IF(SMUZ(JJ).GT.0.9*FCU(SOIL)) GO TO 360
  380 RCM(SOIL,CROP)=RCN(SOIL,CROP)
  390 SI=1000.0/RCM(SOIL,CROP)-10.0
      ER=RAIN-0.2*SI
      IF(ER.LT.0.0) GO TO 410
      RNOF=ER**2/(RAIN+0.8*SI)
      GO TO 420
C***  EVALUATE INTERCEPTION STORAGE
  400 RNOF=0.0
      IA=0.0
      GO TO 430
  410 RNOF=0.0
  420 IA=0.1
      IF(IA.GT.RAIN) IA=RAIN
      IF((IA+IAADC(JJ)).GE.0.1) IA=0.1-IAADC(JJ)
C
C***  EVALUATE INFILTRATION INTO THE UPPER ZONE
  430 PERC=RAIN-RNOF-IA
      UZEVAP=0.0
      IF(DARCEQ.EQ.2) GO TO 435
C***  SUBROUTINE DARCRT EVALUATES THE FLOW WITHIN THE SOIL PROFILE
C***  BY APPLYING THE ONE-DIMENSIONAL DARCY EQUATION
      CALL DARCRT(PERC,FCU(SOIL),SMUZ(JJ),FCL(SOIL),SMLZ(JJ),FCGW(SOIL),
     1SMGWZ(JJ),DPERC,CONDUZ(JJ),CONDLZ(JJ),CONDGW(JJ),HUZ(JJ),HLZ(JJ),H
     2GW(JJ),PWPUZ(SOIL),PWPLZ(SOIL),PWG(SOIL))
      GO TO 450
C***  CALCULATE PRESENT STORAGE AVAILABLE IN UPPER ZONE
  435 SMMAXU=0.9*SMSATU(SOIL)-SMUZ(JJ)
C***  EVALUATE WATER CASCADED TO LOWER ZONE FOR STORAGE
      PERCL=PERC-SMMAXU
      IF(PERC.GT.SMMAXU) PERC=SMMAXU
      IF(PERCL.LT.0.0) PERCL=0.0
      IF (SMUZ(JJ).GT.FCU(SOIL)) GO TO 440
      EXCESS=0.0
      GO TO 450
C***  EVALUATE GRAVITATIONAL WATER IN UPPER ZONE
  440 EXCESS=SMUZ(JJ)-FCU(SOIL)
C
C***  IF THE CROP IS DORMANT OR THE SOIL LIES FALLOW, SOIL
C***  EVAPORATION IS EVALUATED
  450 IF(KCROP(CROP,NM).LE.0.0) GO TO 560
      T(JJ)=0.0
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             C***  MODIFY PET BY THE PLANT CONSUMPTIVE USE COEFFICIENT
 0292              AET=KCROP(CROP,NM)*PET
 0293              IF(PET.LE.IAET(JJ)) AET=0.0
             C***  CHECK WHETHER SOIL MOISTURE LIMITS AET FROM THE UPPER ZONE
 0294              IF(SMUZ(JJ)-(0.3*(AVLFCU(SOIL))+PWPUZ(SOIL))) 460,460,490
             C***  CALCUATE AET FROM THE UPPER ZONE WHEN LIMITED BY SOIL MOISTURE
 0295          460 AVAILU=SMUZ(JJ)-PWPUZ(SOIL)
 0296              IF(AVAILU.LE.0.0) AVAILU=0.0
 0297              AETUZ=0.7*AET*(AVAILU/(0.3*AVLFCU(SOIL)))
             C***  EVALUATE AVAILABLE WATER IN THE LOWER ZONE
 0298              AVAILL=SMLZ(JJ)-PWPLZ(SOIL)
 0299              IF(AVAILL.LE.0.0) AVAILL=0.0
             C***  CHECK WHETHER SOIL MOISTURE LIMITS AET FROM THE LOWER ZONE
 0300              IF(SMLZ(JJ)-(0.3*(AVLFCL(SOIL))+PWPLZ(SOIL))) 470,470,480
             C***  CALCUATE AET FROM THE LOWER ZONE WHEN LIMITED BY SOIL MOISTURE
 0301          470 AETLZ=0.3*AET*(AVAILL/(0.3*AVLFCL(SOIL)))
 0302              GO TO 500
 0303          480 AETLZ=AET-AETUZ
 0304              GO TO 500
             C***  EVALUATE AET FROM BOTH ZONES UNDER WET CONDITIONS
 0305          490 AETUZ=0.7*AET
 0306              AETLZ=0.3*AET
 0307              AVAILL=SMLZ(JJ)-PWPLZ(SOIL)
 0308              IF(SMLZ(JJ).LE.0.3*(AVLFCL(SOIL))+PWPLZ(SOIL)) GO TO 470
 0309          500 IF(DARCEQ.EQ.1.0) GO TO 605
 0310              IF(PERC-SMMAXU) 510,520,520
             C
             C***  EVALUATE SOIL MOISTURE
 0311          510 SMUZ(JJ)=SMUZ(JJ)+PERC-AETUZ-EXCESS
 0312              SMLZ(JJ)=SMLZ(JJ)-AETLZ+EXCESS
 0313              GO TO 610
 0314          520 SMUZ(JJ)=SMUZ(JJ)+SMMAXU-EXCESS-AETUZ
 0315          530 SMMAXL=0.9*FCL(SOIL)-SMLZ(JJ)
 0316              IF(PERCL+EXCESS-SMMAXL) 540,540,550
 0317          540 SMLZ(JJ)=SMLZ(JJ)+PERCL-AETLZ+EXCESS
 0318              GO TO 610
 0319          550 SMLZ(JJ)=SMLZ(JJ)+SMMAXL-AETLZ
 0320              DPERC=PERCL+EXCESS-SMMAXL
 0321              GO TO 620
             C***  CALCULATE EVAPORATION FROM BARE SOIL SURFACE(SEVAP) FOR MONTHS OCTOBER
             C***  THROUGH MARCH OR WHEN THE DISPOSAL AREA IS FALLOW
 0322          560 AETUZ=0.0
 0323              AETLZ=0.0
 0324              IF(PACK.GT.0.0) GO TO 590
 0325              IF(SMUZ(JJ).LT.(FCU(SOIL)-U(SOIL))) GO TO 570
 0326              EO(JJ)=FCU(SOIL)-SMUZ(JJ)
 0327              IF(SMUZ(JJ).GE.FCU(SOIL)) EO(JJ)=0.0
             C***  CALCULATE STAGE 1 SOIL EVAPORATION
 0328              UZEVAP=PETBS
 0329              EO(JJ)=EO(JJ)+UZEVAP
 0330              IF(EO(JJ).GT.U(SOIL)) UZEVAP=EO(JJ)-U(SOIL)
 0331              T(JJ)=0.0
 0332              GO TO 580
             C***  CALCULATE STAGE 2 SOIL EVAPCRATION
 0333          570 T(JJ)=T(JJ)+1
 0334              UZEVAP=C(SOIL)*(T(JJ)**0.5)-C(SOIL)*((T(JJ)-1)**0.5)
 0335          580 IF(UZEVAP.GT.(PETBS-IAET(JJ))) UZEVAP=PETBS-IAET(JJ)
 0336              IF(UZEVAP.LT.0.0) UZEVAP=0.0
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 0337                IF(SMUZ(JJ)-PWPUZ(SOIL).LT.UZEVAP) UZEVAP=SMUZ(JJ)-PWPUZ(SOIL)
 0338                GO TO 600
 0339            590 UZEVAP=0.0
 0340            600 IF(DARCEQ.EQ.1) PERC=0.0
 0341                IF(DARCEQ.EQ.I) EXCESS=0.0
 0342                SMUZ(JJ)=SMUZ(JJ)-UZEVAP+PERC-EXCESS
 0343                IF(SMUZ(JJ).LE.PWPUZ(SOIL)) SMUZ(JJ)=PWPUZ(SOIL)
 0344                IF(DARCEQ.EQ.2) GO TO 530
 0345            605 SMUZ(JJ)=SMUZ(JJ)-AETUZ
 0346                SMLZ(JJ)=SMLZ(JJ)-AETLZ
 0347            610 IF(SMLZ(JJ).LT.PWPLZ(SOIL)) AETLZ=AETLZ-(PWPLZ(SOIL)-SMLZ(JJ))
 0348                IF(SMLZ(JJ).LE.PWPLZ(SOIL)) SMLZ(JJ)=PWPLZ(SOIL)
 0349                IF(DARCEQ.EQ.I) GO TO 620
 0350                DPERC=SMLZ(JJ)-0.9*FCL(SOIL)
 0351                IF(DPERC.LT.0.0) DPERC=0.0
 0352                IF(SMLZ(JJ).GT.0.9*FCL(SOIL)) SMLZ(JJ)=0.9*FCL(SOIL)
 0353            620 AETUZ=AETUZ+UZEVAP
               C***  SM IS THE SOIL MOISTURE IN THE GROWING ZONE, IN INCHES
 0354                SM(JJ)=SMUZ(JJ)+SMLZ(JJ)
 0355                IAET(JJ)=IA+IAADD(JJ)
 0356                AETU(JJ)=AETUZ
 0357                AETL(JJ)=AETLZ
 0358                NDPERC(JJ)=DPERC
 0359                NIA(JJ)=IA
 0360                NRNOF(JJ)=RNOF
 0361                IF (IPLAN(JJ).LE.2) STRNOF = RNOF
 0362                STRVOL = STRVOL + STRNOF*AREA(JJ)
 0363                GO TO 330
 0364            650 CONTINUE
               C
               C
               C          *** EVALUATION OF VOLUME USED AS IRRIGATION ***
               C
               C***  T1 IS THE PREVIOUS DAY'S AVERAGE TEMPERATURE, IN FAHRENHEIT
               C***  DEGREES, T2 IS THE AVERAGE TEMPERATURE OF THE DAY TWO DAYS
               C***  PRIOR TO TODAY
 0365                VOLDIS=0.0
 0366                JDISDA=0
 0367                NCNT=0
 0368                DO 675 MS=I,NPLOTS
 0369                DISVOL(MS)=0.0
 0370                IF(IPLAN(MS).EQ.I) GO TO 660
 0371                THAWED=TAVG(ND)+T1+T2
 0372                FREEZE=TAVG(ND)+T1
 0373                T2=T1
 0374                T1=TAVG(ND)
 0375                IF(FREEZE.LT.64.0) FROZE=I
 0376                IF(THAWED.GT.I14.0) FROZE=0
               C***  WHEN FROZE EQUALS 1 THE SOIL IS CONSIDERED TO BE FROZEN IT IS THAWED
               C***  WHEN FROZE EQUALS 0
 0377                IF(FROZE.EQ.I) GO TO 660
               C***  SMUZ IS THE SOIL MOISTURE IN THE TOP I2 INCHES OVER EACH
               C***  PLOT; AVLFCU IS THE AVAILABLE WATER CAPACITY OF THAT SOIL.
               C***  IRRIGATION WILL NOT OCCUR ON DAYS THAT THE SOIL MOISTURE IS AT
               C***  A LEVEL GREATER THAN THAT OF THE PERCENTAGE OF AVAILABLE WATER
               C***  SPECIFIED BY THE VARIABLE PAVLU.
 0378                SOIL=IAREA(MS,2)
 0379                IF(SMUZ(MS).GT.(PAVLU*AVLFCU(SOIL))+PWPUZ(SOIL)) GO TO 660
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 0380              JDISDA=JDISDA+1
 0381              NCNT=NCNT+1
 0382              IF(PONVOL.LT.PCVMAX*VOLMAX) GO TO 660
 0383              DISVOL(MS)=DSRATE*AREA(MS)
          C***  IF THE POND VOLUME IS LESS THAN THE VOLUME REQUIRED FOR ONE FULL
          C***  DAY OF IRRIGATION, IT WILL BE ASSUMED THAT NO IRRIGATION WILL OCCUR
          C***  ON THAT DAY.
 0384              PONVOL=PONVOL-DISVOL(MS)
 0385              IF(PONVOL.GT.0.0) GO TO 670
 0386              DISVOL(MS)=DISVOL(MS)+PONVOL
 0387              PONVOL=0.0
 0388              GO TO 670
 0389          660 DISVOL(MS)=0.0
 0390          670 SMACCT(NM,3,MS)=SMACCT(NM,3,MS)+DISVOL(MS)/AREA(MS)
 0391              VOLDIS=VOLDIS+DISVOL(MS)
 0392              IF(DISVOL(MS).GT.0.0) DAYSDS(MS)=DAYSDS(MS)+1.0
 0393          675 CONTINUE
 0394              IF(NCNT.GT.0) IDISDA=IDISDA+JDISDA/NCNT
          C***  UPDATE DISPOSAL DAY ACCOUNT
 0395              IF(VOLDIS.GT.0.0) DSDAY=DSDAY+1
 0396              IF(BYPASS.NE.1) GO TO 680
 0397              RUNOFF=0.0
 0398              GO TO 730
          C***  SUBROUTINE STORAG CALCULATES ADDITIONAL LOADING TO THE STORAGE
          C***  POND DUE TO FEEDLOT RUNOFF OR MUNICIPALITY DISPOSAL
 0399          680 CALL STORAG(P1,P2,P3,PRECIP,SNOW,FROZE,MONTH,GROW,DORM,RUNOFF,MUND
                  1IS(NM),RUNMDS)
          C
          C
          C      *** CALCULATION OF SURFACE AREA AND DETERMINATION OF SURFACE
          C                   EVAPORATION FROM STORAGE FACILITY ***
          C
          C***  THE FOLLOWING CALCULATION EXPRESSES THE VOLUME OF WATER IN THE
          C***  STORAGE FACILITY IN CUBIC FEET.
 0400          730 IF(PONVOL.LE.0.0) GO TO 750
 0401              V=PONVOL*3630
          C*** THE FOLLOWING CALCULATIONS DETERMINE THE SURFACE AREA OF THE STORAGE
          C***  FACILITY AS A FUNCTION OF STORAGE VOLUME.  AREA IS IN SQUARE FEET
          C***  VOLUME IS IN CUBIC FEET.  THE STORAGE FACILITY IS SHAPED LIKE AN INVERTED
          C***  FRUSTRUM OF A PYRAMID.  INPUT PARAMETERS TO SIZE THE FACILITY ARE LENGTH
          C***  (L) OF THE BASE IN FEET, WIDTH OF THE BASE(W) IN FEET AND SLOPE OF
          C***  INSIDE EMBANKMENTS GIVEN AS A RATIO OF RUN TO RISE(S).  IT IS ASSUMED
          C***  THE POND DOES NOT LEAK.  INPUTS TO THE STORAGE WILL BE NATURAL
          C***  RUNOFF, FEEDLOT RUNOFF, MUNICIPALITY DISPOSAL AND PRECIPITATION.
          C***  LOSSES FROM THE POND INCLUDE EVAPORATION AND DISPOSAL VOLUME.
          C***  B2 IS THE AREA OF THE SURFACE LIQUID IN SQUARE FEET.
 0402              HAPRX=(PONVOL/VOLMAX)*HMAX
 0403          740 VC=A1*HAPRX+A2*HAPRX**2+A3*HAPRX**3
 0404              DV=V-VC
 0405              DVDH=A1+A4*HAPRX+A5*HAPRX**2
 0406              H=HAPRX+DV/DVDH
 0407              IF(ABS(H-HAPRX).LT.0.1) GO TO 750
 0408              HAPRX=H
 0409              GO TO 740
 0410          750 IF (H.GT.HMAX) H=HMAX
 0411              B2=(W+2.*S*H)*(L+2.*S*H)
 0412              IF(FROZE.EQ.1) LAKEVP=0.0
 0413              LKEVPT=LKEVPT+LAKEVP
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 0414                SEVAP=82*(LAKEVP/12)
               C***  SEVAP IS THE VOLUME OF WATER EXTRACTED FROM THE STORAGE FACILITY BY
               C***  FREE SURFACE EVAPORATION.
 0415                IF((SEVAP/3630).GT.PONVOL) SEVAP=PONVOL*3630
 0416                PONVOL=PONVOL-(SEVAP/3630)
 0417                IF(PONVOL.LE.0.0) PONVOL=0.0
               C
               C***  THE VOLUMES OF CALCULATED RUNOFF, FEEDLOT RUNOFF, MUNICIPALITY
               C***  DISPOSAL, AND PRECIPITATION FALLING ON THE FACILITY ARE ADDED
               C***  TO THE VOLUME OF WATER IN THE STORAGE FACILITY (ACRE-IN).
 0418                PONVOL=PONVOL+(RUNOFF*LTAREA)+(PRECIP*PSAREA)+STRVOL+RUNMDS
               C***  THE VOLUME OF WATER REMAINING AT THE END OF THE DAY IS EXPRESSED
               C***  IN ACRE-IN.
               C
               C***  THE FOLLOWING STATEMENTS DETERMINE WHETHER THE STORAGE FACILITY HAS
               C***  OVERFLOWED AND IF SO, THE QUANTITY DISCHARGED
 0419                DSCHRG=0.0
 0420                IF(PONVOL-VOLMAX)  780,780,760
 0421            760 DSCHRG=PONVOL-VOLMAX
 0422                DSCVOL=DSCVOL+DSCHRG
               C***  VOLUME CALCULATIONS TO INCREASE THE POND SIZE
 0423                CONTRL = 1.0
 0424                PCNTRL = CONTRL*100.0
 0425                VOLCHG = CONTRL*PONVOL-VOLMAX+VOLCHG
 0426                VOLMX1 = VOLMAX+VOLCHG
 0427                VCB = 2.0 * S * HMAX
 0428                VCC = ((4./3.)*S**2) - (VOLMX1*3630./HMAX)
 0429                VCD = VCB**2 - (4.*VCC)
 0430                VC1 = SQRT(VCD)
 0431                DIM = (VC1-VCB)/2.0
 0432                WRITE(6,770) NM,ND,YEAR,DSCHRG,VOLMX1,PCNTRL,DIM
 0433            770 FORMAT(/,1X,I2,'/',I2,'/',I2,' - DISCHARGE OF ',F7.2,' ACRE-IN REQ
                    2UIRES VOLUME OF ',F8.2,' ACRE-IN FOR ',F6.2,' % CONTROL WHERE L =
                    2W = ',F8.2)
 0434                PONVOL=VOLMAX
 0435                IF(DSCHRG.GE.PEAK) PEAK=DSCHRG
 0436                IF(YEAR.GT.PREVYR.OR.CM.LT.1.0) MM=MM+1
 0437                PREVYR=YEAR
 0438                CM=CM+1.0
 0439            780 CONTINUE
               C
               C***  UPDATE SOIL MOISTURE ACCOUNT FOR EACH PLOT
 0440                DO 785  KI=1,NPLOTS
 0441                SMACCT(NM,2,KI)=SMACCT(NM,2,KI)+PRECIP
 0442                SMACCT(NM,4,KI)=SMACCT(NM,4,KI)+NIA(KI)
 0443                SMACCT(NM,5,KI)=SMACCT(NM,5,KI)+NRNOF(KI)
 0444                SMACCT(NM,6,KI)=SMACCT(NM,6,KI)+NOPERC(KI)
 0445                SMACCT(NM,7,KI)=SMACCT(NM,7,KI)+AETU(KI)+AETL(KI)+SNOVAP
 0446                SMACCT(NM,8,KI)=SMACCT(NM,8,KI)+SM(KI)-SMPD(KI)
 0447            785 SMPD(KI)=SM(KI)
               C
               C***  UPDATE POND ACCOUNT
 0448                ACTIRR=ACTIRR+VOLDIS
 0449                PDACCT(NM,3)=PDACCT(NM,3)+RUNMDS
 0450                PDACCT(NM,4)=PDACCT(NM,4)+RUNOFF*LTAREA
 0451                PDACCT(NM,5)=PDACCT(NM,5)+STRVOL
 0452                PDACCT(NM,8)=PDACCT(NM,8)+SEVAP/3630
 0453                PDACCT(NM,9)=PDACCT(NM,9)+DSCHRG
```

```
      PDACCT(NM,10)=PDACCT(NM,10)+(PONVOL-PDVOL)
      IF(ND.EQ.NDAYS) PDACCT(NM,11)=H
      PDVOL=PONVOL
      IF(PONVOL.GT.MAXVOL) MAXVOL=PONVOL
C
C***  STATISTICAL PRECIPITATION AND RUNOFF FREQUENCY DATA
      IF(PREC(ND).GT.0.0) CTPDAY = CTPDAY+1.0
      IPLOT=NPLOTS
      IF(NPLOTS.GT.4) NPLOTS=4
      DO 795 II=1,25
      IF(PREC(ND).GT.FREQ(II))CTP(II)=CTP(II)+1.0
      CNTR=0.0
      DO 790 KI=1,NPLOTS
      IF(NRNOF(KI).GT.0.0.AND.II.EQ.1) CTRDAY(KI)=CTRDAY(KI)+1.0
      IF(NRNOF(KI).GT.0.0) CNTR=1.0
  790 IF(NRNOF(KI).GT.FREQ(II)) CTR(II,KI)=CTR(II,KI)+1.0
  795 IF(PREC(ND).GT.FREQ(II).AND.CNTR.EQ.1.0) CTPR(II)=CTPR(II)+1.0
      NPLOTS=IPLOT
  800 CONTINUE
C
C
C          ***** EXIT DAILY LOOP *****
C
C***  UPDATE ACCOUNTS
      PDACCT(NM,1)=AMONTH(NM)
      PDACCT(NM,2)=SMACCT(NM,2,1)*PSAREA
      PDACCT(NM,6)=OSDAY
      PDACCT(NM,7)=ACTIRR
      DO 810  J=2,10
  810 PDACCT(13,J)=PDACCT(13,J)+PDACCT(NM,J)
      DO 830  MP=1,NPLOTS
      DO 820  J=2,8
  820 SMACCT(13,J,MP)=SMACCT(13,J,MP)+SMACCT(NM,J,MP)
      SMACCT(NM,1,MP)=AMONTH(NM)
  830 SMACCT(13,1,MP)=AMONTH(13)
      PDACCT(13,1)=AMONTH(13)
      VOLIRR=VOLIRR+ACTIRR
  840 CONTINUE
C
C
C          ***** EXIT MONTHLY LOOP *****
C
      DSNOW=PACK-PACKPY
      PACKPY=PACK
      PCWW=((PDACCT(13,2)+PDACCT(13,3)+PDACCT(13,4)+PDACCT(13,5)-PDACCT(
     113,9))/(PDACCT(13,2)+PDACCT(13,3)+PDACCT(13,4)+PDACCT(13,5)))*100.
      WASTWW=WASTWW+PCWW
      PDACCT(13,11)=PDACCT(12,11)
      DO 850  KT=1,NPLOTS
      DSRNFF(KT)=DSRNFF(KT)+SMACCT(13,5,KT)
      AINTER(KT)=AINTER(KT)+SMACCT(13,4,KT)
      AAETRS(KT)=AAETRS(KT)+SMACCT(13,7,KT)
      ACHSCM(KT)=ACHSCM(KT)+SMACCT(13,8,KT)
  850 OSPERC(KT)=OSPERC(KT)+SMACCT(13,6,KT)
      IRRSUM=IRRSUM+VOLIRR
      TPREC=TPREC+SMACCT(13,2,1)
      IF((YEAR+1900).EQ.YSTART) DRY=SMACCT(13,2,1)
      IF(SMACCT(13,2,1).GE.WET) WET=SMACCT(13,2,1)
```

```
      IF(SMACCT(13,2,1).LE.DRY) DRY=SMACCT(13,2,1)
C
C***  PRINT POND ACCOUNT
      WRITE(6,860) YEAR
  860 FORMAT('0',27X,'       WATER ACCOUNT FOR STORAGE FACILITY (IN ACRE-
     1INCHES)           - 19',I2//9X,'----------------------------------
     2--------------------------------------------------------------------
     3---------------'/28X,'INFLOWS',48X,'OUTFLOWS'/12X,'--------------
     4----------------------',17X,'--------------------------------------
     5-----'/3X,'MONTH',4X,'PRECIP.   MUNICIPAL   FEEDLOT   RUNOFF',4X,'
     6IRR. DAYS',4X,'DISPOSAL VOL.   SURFACE EVAP.   DISCHARGE',4X,'VOL.
     7 CHANGE   HEIGHT')
      WRITE(6,870)  ((PDACCT(I,K),K=1,11),I=1,13)
  870 FORMAT(4X,A4,F10.1,F12.1,2F10.1,F10.0,F16.1,F17.1,F13.1,F15.1,F10.
     12)
C
C***  PRINT SOIL MOISTURE ACCOUNTS
      DO 910  JM=1,NPLOTS
      CROP=IAREA(JM,1)
      SOIL=IAREA(JM,2)
      WRITE(6,880)  JM,KROP(CROP),SOIL,AREA(JM)
  880 FORMAT(////,60X,'PLOT NO.',I3,////,25X,'CROP--',2A8,5X,'SOIL TYPE-
     1-',I3,5X,'DISPOSAL AREA--',F6.2,' ACRES')
      WRITE(6,890)  YEAR
  890 FORMAT('0',35X,'WATER BALANCE (INCHES) IN THE DISPOSAL AREA - 19',
     1I2/10X,'-----------------------------------------------------------
     2--------------------------------------------------------'/32X,
     3 'INPUTS',38X,'OUTPUTS'/21X,'---------------------------',3X,    '
     4---------------------------------------------------'/9X,'MONTH',
     57X,'PRECIPITATION',4X,'IRRIGATION',3X,'INTERCEPTION',2X,'SURFACE R
     6UNOFF',3X,'PERCOLATION',8X,'AET',8X,'CHANGE IN SM')
      WRITE(6,900)  ((SMACCT(I,K,JM),K=1,8),I=1,13)
  900 FORMAT(10X,A4,7F15.2)
  910 CONTINUE
      WRITE(6,920)  PCWW
  920 FORMAT('0',10X,'PERCENT OF WASTEWATER CONTROLLED=',F10.2)
      WRITE (6,930)  IDISDA
  930 FORMAT('0',10X,'POTENTIAL DISPOSAL DAYS=',I4)
      WRITE(6,940)  PACK,DSNOW
  940 FORMAT('0',10X,'PACK ON DECEMBER 31 =',F5.2,15X,
     1'CHANGE IN SNOW STORAGE=',F5.2)
      WRITE(6,950)
  950 FORMAT('0',10X,'INPUTS-OUTPUTS-CHANGE IN SNOW STORAGE=CHANGE IN
     1SOIL MOISTURE')
      MAXVOL=MAXVOL*100.0/VOLMAX
      WRITE(6,960)  MAXVOL
  960 FORMAT('0',10X,'PERCENT OF MAXIMUM POND VOLUME REQUIRED =',F7.2)
      EVAPLK=EVAPLK+LKEVPT
      WRITE(6,970)  LKEVPT
  970 FORMAT('0',10X,'ESTIMATED LAKE EVAPORATION, INCHES =',F6.2)
  980 CONTINUE
C
C
C          ***** EXIT YEARLY LOOP *****
C
  990 CONTINUE
 1520 CONTINUE
C***  CALCULATE AVERAGE ANNUAL VALUES
```

```
      EVAP=EVAPLK/YEARS
      CMNEW=CM
      IF(MM.EQ.0)  MM=1
      COUNT=CM/MM
      IF(COUNT.EQ.0.0) MM=0
      IF(CM.EQ.0.0) CM=YEARS
      DSCRG=DSCVCL/CM
      CM=CMNEW
      CONTRL=WASTWW/YEARS
      IRRVOL=IRRSUM/YEARS
      APREC=TPREC/YEARS
      RANGE=WET-DRY
      AVGMD=EVAP-APREC
      DO 1000 J=1,NPLOTS
      DSPERC(J)=DSPERC(J)/YEARS
      DSRNFF(J)=DSRNFF(J)/YEARS
      ACHSCM(J)=ACHSCM(J)/YEARS
      AINTER(J)=AINTER(J)/YEARS
      AAETRS(J)=AAETRS(J)/YEARS
 1000 DAYSDS(J)=DAYSDS(J)/YEARS
      IF(NPLOTS.GT.4) NPLOTS=4
      DO 1020 J=1,25
      PRECAC(J,3)=CTP(J)
      IF(CTPDAY.GT.0.0) CTP(J)=CTP(J)/CTPDAY*100.0
      PRECAC(J,1)=ASTAT(J)
      PRECAC(J,2)=CTP(J)
      PRECAC(J,4)=CTPR(J)
      DO 1010 I=1,NPLOTS
      INUM1=5+I
      RUNACC(J,INUM1)=CTR(J,I)
      IF(CTRDAY(I).GT.0.0) CTR(J,I)=CTR(J,I)/CTRDAY(I)*100.0
      INUM=I+1
 1010 RUNACC(J,INUM)=CTR(J,I)
 1020 RUNACC(J,1)=ASTAT(J)
      NPLOTS=IPLOT
C
C***  PRINT INPUT PARAMETERS
      WRITE(6,85)  NAME,OF,CITY,AND,STATE,YSTART,YEND,WEATH,MODIF,MOD,EL
     1,IN,FLOW,TC,STOR,AGE,POND,LTAREA,STORM,L,W,S,HMAX,VOLMAX,PSAREA
      DO 1080 J=1,NPLOTS
      CROP=INCROP(J)
      PLAREA=AREA(J)
      SOIL=IAREA(J,2)
      RPAVLU=PAVLU
      IF(IPLAN(J).EQ.1) PAVLU=0.0
      WRITE(6,1030)J,PLAREA,KROP(CROP),SOIL,DSRATE,PAVLU
 1030 FORMAT(//15X,'PLOT ',I1//25X,'(A) AREA--  ',F6.2,'   ACRES'//25X,'
     1(B) CROP--  ',2A8//25X,'(C) SOIL TYPE--  ',I3,'  (SCS SOIL TYPE)'/
     2/25X,'(D) IRRIGATION RATE--  ',F5.2,'  INCHES/DAY '//25X,'(E) IRRI
     3GATION MANAGEMENT--   IRRIGATION BELOW  ',F5.2,'  FIELD CAPACITY')
      IF(IPLAN(J).EQ.1) WRITE(6,1040)
      IF(IPLAN(J).EQ.2) WRITE(6,1050)
      IF(IPLAN(J).EQ.3) WRITE(6,1060)
 1040 FORMAT(/25X,'(F) PLAN IMPLEMENTED--   RUNOFF')
 1050 FORMAT(/25X,'(F) PLAN IMPLEMENTED--   RUNOFF AND IRRIGATION')
 1060 FORMAT(/25X,'(F) PLAN IMPLEMENTED--   IRRIGATION')
      IF(ROTATE(J).EQ.1) WRITE(6,1070)
 1070 FORMAT(/25X,'(G) CROP ROTATION WITH --   FALLOW')
```

```
      PAVLU=RPAVLU
 1080 CONTINUE
C
C***  PRINT FINAL SUMMARY
      WRITE(6,1090)
 1090 FORMAT(////,47X,'***** FINAL SUMMARY *****')
      WRITE(6,1100)
 1100 FORMAT('0',10X,'METEOROLOGICAL SUMMARY')
      WRITE(6,1110) EVAP
 1110 FORMAT('0',25X,'AVERAGE ANNUAL LAKE EVAPORATION=',F6.2,' INCHES')
      WRITE(6,1120) APREC
 1120 FORMAT('0',25X,'AVERAGE ANNUAL PRECIPITATION=',F6.2,' INCHES')
      WRITE(6,1130) RANGE,DRY,WET
 1130 FORMAT('0',25X,'PRECIPITATION RANGE=',F6.2,' INCHES   (FROM A LOW
     1OF',F6.2,' INCHES  TO A HIGH OF ',F6.2,' INCHES)')
      WRITE(6,1140) AVGMD
 1140 FORMAT('0',25X,'AVERAGE ANNUAL MOISTURE DEFICIT=',F6.2,' INCHES')
      WRITE(6,1150)
 1150 FORMAT('0',10X,'SUMMARY OF POND OPERATIONS')
      WRITE(6,1160) NM
 1160 FORMAT('0',25X,'NO. OF YEARS HAVING A DISCHARGE=',I6)
      WRITE(6,1170) COUNT
 1170 FORMAT('0',25X,'AVERAGE NO. OF DISCHARGES / YEAR HAVING A DISCHARG
     1E=',F6.2)
      WRITE(6,1180) DSCRG
 1180 FORMAT('0',25X,'AVERAGE DISCHARGE=',F6.2,1X,'ACRE-INCHES')
      WRITE(6,1190) CONTRL
 1190 FORMAT('0',25X,'AVERAGE PERCENT OF WASTEWATER CONTROLLED=',F6.2)
      WRITE(6,1200) DSCVOL
 1200 FORMAT('0',25X,'TOTAL DISCHARGE VOLUME=',F9.2,' ACRE-INCHES')
      WRITE(6,1210) CM
 1210 FORMAT('0',25X,'TOTAL NO. OF DISCHARGES=',F4.0)
      WRITE(6,1220) PEAK
 1220 FORMAT('0',25X,'MAXIMUM DISCHARGE=',F6.2,' ACRE-INCHES')
      WRITE(6,1230) IRRVOL
 1230 FORMAT('0',25X,'AVERAGE ANNUAL VOLUME OF WASTEWATER APPLIED=',F8.2
     1,' ACRE-INCHES')
      WRITE(6,1240)
 1240 FORMAT('0',10X,'SUMMARY OF DISPOSAL PLOTS')
      DO 1320 J=1,NPLOTS
      WRITE(6,1250) J
 1250 FORMAT('0',15X,'PLOT ',I1)
      WRITE(6,1260) DSRNFF(J)
 1260 FORMAT('0',25X,'AVERAGE ANNUAL DISPOSAL AREA RUNOFF=',F6.2,' INCHE
     1S')
      WRITE(6,1270) DSPERC(J)
 1270 FORMAT('0',25X,'AVERAGE ANNUAL DISPOSAL AREA PERCOLATION=',F6.2,'
     1INCHES')
      WRITE(6.1280) DAYSDS(J)
 1280 FORMAT('0',25X,'AVERAGE ANNUAL NO. OF DISPOSAL DAYS=',F6.1)
      WRITE(6,1290) AINTER(J)
 1290 FORMAT('0',25X,'AVERAGE ANNUAL DISPOSAL AREA INTERCEPTION=',F6.2,'
     1 INCHES')
      WRITE(6,1300) AAETRS(J)
 1300 FORMAT('0',25X,'AVERAGE ANNUAL DISPOSAL AREA EVAPOTRANSPIRATION=',
     1F6.2,' INCHES')
      WRITE(6,1310) ACHSOM(J)
 1310 FORMAT('0',25X,'AVERAGE ANNUAL DISPOSAL AREA CHANGE IN SOIL MOISTU
```

```
                 1RE=',F6.2,' INCHES')
 0633          1320 CONTINUE
 0634                WRITE(6,1330)
 0635          1330 FORMAT('0',10X,'SUMMARY OF STATISTICAL DATA')
 0636                WRITE(6,1340)
 0637          1340 FORMAT('0',41X,'PRECIPITATION FREQUENCY DATA',//27X,'INTENSITY',5X
                   1,'FREQUENCY',5X,'FREQUENCY',5X,'RUNOFF FREQ.',/29X,'(IN.)',10X,'(%
                   2)',9X,'(DAYS)',10X,'(DAYS)',/)
 0638                WRITE(6,1350)((PRECAC(I,J),J=1,4),I=1,25)
 0639          1350 FORMAT(29X,A4,3F15.2)
 0640                WRITE(6,1360)
 0641          1360 FORMAT('0',///60X,'RUNOFF FREQUENCY DATA',//27X,'INTENSITY',15X.'F
                   1REQUFNCY (%)',26X,'FREQUENCY (DAYS)',/29X,'(IN.)',7X,'PLOT 1   PLO
                   3T 2   PLOT 3   PLOT 4',3X,'PLOT 1   PLOT 2   PLOT 3   PLOT 4',/)
 0642                WRITE(6,1370)((RUNACC(I,J),J=1,9),I=1,25)
 0643          1370 FORMAT(29X,A4,5X,4F9.2,4X,4F9.2)
 0644                STOP
 0645                END
```

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FORTRAN IV G LEVEL  21               CROPCO           DATE = 79045        21/27/40

0001              SUBROUTINE CROPCO (CROP,MGSB,DGSB,MGSE,DGSE,KCROP,NDIM,MMAT)
            C***  SUBROUTINE CROPCO CALCULAIES THE CROP COEFFICIENTS FOR USE IN
            C***  THE MAIN PROGRAM.  THE CROP COEFFICIENTS ARE CALCULATED BY THE
            C***  PROCEDURES OUTLINED IN THECHNICAL RELEASE NO 21, IRRIGATION
            C***  WATER REQUIREMENTS, UNITED STATES DEPARTMENT OF AGRICULTURE,
            C***  SOIL CONSERVATION SERVICE, ENGINEERING DIVISION, APRIL 1967.
            C***  SLIGHT MODIFICATIONS HAVE BEEN MADE FOR ADAPTAION TO THE MODEL.
            C***  EQUATIONS FOR THE CROP GROWTH STAGE COEFFICIENT CURVES WERE
            C***  DEVELOPED WHICH ELIMINATES THE NECESSITY OF READING THE VALUES
            C***  FROM THE CURVES.  INPUTS TO THE SUBROUTINE INCLUDE THE CROP,
            C***  MONTH AND DAY GROWING BEGINS AND ENDS, NUMBER OF DAYS IN EACH
            C***  MONTH, AND THE MEAN MONTHLY AVERAGE TEMPERATURES IN FAHRENHEIT
            C***  DEGREES.
0002              INTEGER CROP,DGSB,DGSE
0003              INTEGER NDIM(12),SHIFT
0004              REAL MID(12)/12*0./,DBMD(12)/12*0./,ACC(12)/12*0./,PCGS(12)/12*0./
0005              REAL MMAT(12),KT(12),KCROP(7,12),PCGS1(12)
            C***  MGSB= MONTH GROWING SEASON BEGINS EXPRESSED NUMERICALLY IE 1-12
            C***  DGSB= DAY GROWING SEASON BEGINS EXPRESSED NUMERICALLY
            C***  MGSE= MONTH GROWING SEASON ENDS EXPRESSED NUMERICALLY IE 1-12
            C***  DGSE= DAY GROWING SEASON ENDS EXPRESSED NUMERICALLY
            C***  MID=MEDIAN DATES OF THE MONTHS IN THE GROWING SEASON
            C***  DBMD= DAYS BETWEEN MID DATES
            C***  ACC= ACCUMULATIVE DAYS IN GROWING SEASON
            C***  PCGS= PERCENI OF GROWING SEASON REACHED AT MID DATES
            C***  MMAT=MEAN MONTHLY AVERAGE TEMPERATURES
            C***  MGSB1=TEMPORARY STORAGE FOR MGSB
            C***  MGSE1=TEMPORARY STORAGE FOR MGSE
            C***  PCGS1=TEMPORARY STORAGE FOR PCGS
0006              MGSB1=MGSB
0007              MGSE1=MGSE
0008              IF(MGSB.GT.MGSE) GO TO 10
0009              GO TO 20
            C***  WHEN MGSB IS GREATER THAN MGSE SUCH AS IN WINTER WHEAT THE
            C***  SUBROUTINE "SHIFTS" OR ADDS 1 TO MGSB AND MGSE UNTIL MGSB = 13
            C***  WHICH CORRESPONDS TO JANUARY.  THIS SHIFT WAS NECESSARY TO
            C***  FACILITATE PROGRAM LOOPING.  AFTER CALCULATIONS ARE MADE THE
            C***  CROP COEFFICIENTS ARE  "SHIFTED" BACK TO THEIR ORIGINAL MONTHS.
            C***************************************************************************
            C***************************************************************************
            C***************************************************************************
            C***                                                                     ***
            C***                                                                     ***
            C***                                                                     ***
            C***  *** CAUTION TO USER ***  THIS ROUTINE WILL NOT WORK IF THE         ***
            C***  GROWING SEASON EXCEEDS ONE YEAR.                                   ***
            C***                                                                     ***
            C***                                                                     ***
            C***                                                                     ***
            C***************************************************************************
            C***************************************************************************
            C***************************************************************************
0010           10 SHIFT=13-MGSB
0011              MGSE=MGSE+SHIFT
0012              MGSB=1
0013           20 NPLUS=MGSB+1
0014              NMINUS=MGSE-1
0015              MID(MGSB)=((NDIM(MGSB)-DGSB)/2.)+DGSB
```

```
0016                DO 30 N=NPLUS,NMINUS
0017             30 MID(N)=NDIM(N)/2.0
0018                MID(MGSE)=DGSE/2.0
0019                DBMD(MGSB)=MID(MGSB)-DGSB
0020                DO 40 N=NPLUS,NMINUS
0021             40 DBMD(N)=NDIM(N-1)-MID(N-1)+MID(N)
0022                DBMD(MGSE)=NDIM(MGSE-1)-MID(MGSE-1)+DGSE
0023                ACC(MGSB)=DBMD(MGSB)
0024                DO 50 N=NPLUS,MGSE
0025             50 ACC(N)=ACC(N-1)+DBMD(N)
0026                ACC(MGSE)=ACC(MGSE)-MID(MGSE)
0027                DO 60 N=MGSB,MGSE
0028             60 PCGS(N)=(ACC(N)*100.)/(ACC(MGSE)+MID(MGSE))
0029                IF(MGSB1.LE.MGSE1) GO TO 100
0030                DO 80 N=1,12
0031                NN=N-SHIFT
0032                IF(NN.LE.0) NN=NN+12
0033                IF(NN.GT.MGSE1.AND.NN.LT.MGSB1) GO TO 70
0034                PCGS1(NN)=PCGS(N)
0035                GO TO 80
0036             70 PCGS1(NN)=0.0
0037             80 CONTINUE
0038                DO 90 N=1,12
0039             90 PCGS(N)=PCGS1(N)
0040            100 MGSB=MGSB1
0041                MGSE=MGSE1
0042                DO 110 J=1,12
              C***  KT IS A CLIMATIC COEFFICIENT APPLIED TO THE CROP GROWTH
              C***  COEFFICIENT.  IT IS CALCULATED BY THE FOLLOWING EQUATION:
0043                KT(J)=.0173*MMAT(J)-.314
0044                IF(MMAT(J).LT.36.) KT(J)=.3
0045            110 CONTINUE
              C***  CROP=1 FOR WHEAT
              C***  CROP=2 FOR SORGHUM
              C***  CROP=3 FOR CORN
              C***  CROP=4 FOR SOYBEANS
              C***  CROP=5 FOR PASTURE
              C***  CROP=6 FOR ALFALFA
              C***  CROP=7 FOR FALLOW
0046                GO TO (120,130,140,150,160,180,200),CROP
0047            120 XBAR=50.
0048                A=1.39093399                                                 WHEAT
0049                B=-0.00368378                                                WHEAT
0050                C=-0.00004976                                                WHEAT
0051                D=-0.00000233                                                WHEAT
0052                E=-0.00000004                                                WHEAT
0053                GO TO 210
0054            130 XBAR=50.
0055                A=1.05528355                                               SORGHUM
0056                B=0.00198600                                               SORGHUM
0057                C=-0.00051577                                              SORGHUM
0058                D=0.00000045                                               SORGHUM
0059                E=0.00000011                                               SORGHUM
0060                GO TO 210
0061            140 XBAR=50.
0062                A=1.02805328                                                  CORN
0063                B=0.00980046                                                  CORN
0064                C=-0.00031919                                                 CORN
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FORTRAN IV G LEVEL  21                CROPCC              DATE = 79045           21/27/40

 0065                 D=-0.00000194                                                        CORN
 0066                 E=0.00000007                                                         CORN
 0067                 GO TO 210
 0068             150 XBAR=50.
 0069                 A=0.74790430                                                     SOYBEANS
 0070                 B=0.01474796                                                     SOYBEANS
 0071                 C=-0.00013486                                                    SOYBEANS
 0072                 D=-0.00000443                                                    SOYBEANS
 0073                 E=0.                                                             SOYBEANS
 0074                 GO TO 210
             C***     FOR PERENNIAL CROPS SUCH AS ALFALFA AND PASTURE, VALUES OF THE
             C***     CROP COEFFICIENTS ARE BEST PLOTTED ON A MONTHLY BASIS THEREFORE
             C***     EQUATIONS WERE NOT DEVELOPED.  MONTHLY VALUES WERE INTEGRATED
             C***     WITHIN THE ROUTINE FOR PASTURE AND ALFALFA.
 0075             160 KCROP(5,1)=0.49
 0076                 KCROP(5,2)=0.57                                                   PASTURE
 0077                 KCROP(5,3)=0.73                                                   PASTURE
 0078                 KCROP(5,4)=0.85                                                   PASTURE
 0079                 KCROP(5,5)=0.90                                                   PASTURE
 0080                 KCROP(5,6)=0.92                                                   PASTURE
 0081                 KCROP(5,7)=0.92                                                   PASTURE
 0082                 KCROP(5,8)=0.91                                                   PASTURE
 0083                 KCROP(5,9)=0.87                                                   PASTURE
 0084                 KCROP(5,10)=0.79                                                  PASTURE
 0085                 KCROP(5,11)=0.67                                                  PASTURE
 0086                 KCROP(5,12)=0.55                                                  PASTURE
 0087                 DO 170 J=1,12
 0088                 KCROP(5,J)=KCROP(5,J)*KT(J)                                       PASTURE
 0089                 IF(PCGS(J).LE.0.0) KCROP(5,J)=0.0                                 PASTURE
 0090             170 CONTINUE
 0091                 GO TO 230
 0092             180 KCROP(6,1)=0.63
 0093                 KCROP(6,2)=0.73                                                   ALFALFA
 0094                 KCROP(6,3)=0.86                                                   ALFALFA
 0095                 KCROP(6,4)=0.99                                                   ALFALFA
 0096                 KCROP(6,5)=1.08                                                   ALFALFA
 0097                 KCROP(6,6)=1.13                                                   ALFALFA
 0098                 KCROP(6,7)=1.11                                                   ALFALFA
 0099                 KCROP(6,8)=1.06                                                   ALFALFA
 0100                 KCROP(6,9)=0.99                                                   ALFALFA
 0101                 KCROP(6,10)=0.91                                                  ALFALFA
 0102                 KCROP(6,11)=0.78                                                  ALFALFA
 0103                 KCROP(6,12)=0.64                                                  ALFALFA
 0104                 DO 190 J=1,12
 0105                 KCROP(6,J)=KCROP(6,J)*KT(J)                                       ALFALFA
 0106             190 IF(PCGS(J).LE.0.0) KCROP(6,J)=0.0
 0107                 GO TO 230
 0108             200 XBAR=0.
 0109                 A=0.                                                               FALLOW
 0110                 B=0.                                                               FALLOW
 0111                 C=0.                                                               FALLOW
 0112                 D=0.                                                               FALLOW
 0113                 E=0.                                                               FALLOW
 0114             210 DO 220 J=1,12
 0115                 Z=PCGS(J)-XBAR
 0116                 KCROP(CROP,J)=(A+B*Z+C*Z**2+D*Z**3+E*Z**4)*KT(J)
 0117                 IF (PCGS(J).LE.0.0) KCROP(CROP,J)=0.0
 0118             220 CONTINUE
```

```
 0119            230 CONTINUE
               C***  SINCE THE MAIN PROGRAM APPLIES THE CROP COEFFICIENT (KCROP) TO
               C***  THE ENTIRE MONTH, THE KCROP WAS PROPORTIONED ACCORDINGLY TO
               C***  COMPENSATE FOR THIS.  THE NEXT TWO CARDS DO THIS.
 0120                KCROP(CROP,MGSB)=KCROP(CROP,MGSB)*(NDIM(MGSB)-DGSB+1)/NDIM(MGSB)
 0121                KCROP(CROP,MGSE)=KCROP(CROP,MGSE)*DGSE/NDIM(MGSE)
 0122                RETURN
 0123                END
```

```
FORTRAN IV G LEVEL  21                  WTRMOD             DATE = 79045          21/27/40

      SUBROUTINE WTRMOD(PRECIP,MONTH,MODEL,WPCNT)
C
C***  SUBROUTINE WTRMOD ADJUSTS THE PRECIPITATION RESULTING FROM
C***  SEEDING CLOUDS
C
C***  NO PRECIPITATION MODIFICATION
C***  MODEL 2:   INCREASE PRECIPITATION DURING MARCH THROUGH SEPTEMBER BY
C***             THE FOLLOWING PERCENTAGES - 75% FOR RAINFALLS < 0.10 IN,
C***             30% FOR RAINFALLS < 0.50 IN, 10% FOR RAINFALLS < 1.0 IN,
C***             -10% FOR RAINFALLS > 1.0 IN
C***  MODEL 3:   INCREASE ALL RAINFALLS DURING EVERY MONTH BY A SPECIFIED
C***             PERCENTAGE, WPCENT
C***  MODEL 4:   INCREASE PRECIPITATION DURING MARCH THROUGH SEPTEMBER BY
C***             THE FOLLOWING PERCENTAGES - 75% FOR RAINFALLS < 0.10 IN,
C***             30% FOR RAINFALLS < 0.50 IN, 10% FOR RAINFALLS < 1.0 IN,
C***             NO ADJUSTMENT FOR RAINFALLS > 1.0 IN
C
      IF(MODEL.EQ.1) GO TO 40
      IF(MONTH.LT.3) GO TO 10
      IF(MONTH.GT.9) GO TO 10
      ADJ=1.75
      IF(PRECIP.GT.0.10) ADJ=1.30
      IF(PRECIP.GT.0.50) ADJ=1.10
      IF(MODEL.EQ.4) GO TO 20
      IF(PRECIP.GT.1.0) ADJ=0.90
      GO TO 30
   10 ADJ=1.0
      IF(MODEL.EQ.3) ADJ=WPCNT
      GO TO 30
   20 IF(PRECIP.GT.1.0) ADJ=1.0
   30 PRECIP=PRECIP*ADJ
   40 RETURN
      END
```

```
FORTRAN IV G LEVEL  21                     SNOWRT               DATE = 79045            21/27/40

                   SUBROUTINE SNOWRT(PRECIP,WATER,PACK,PET,TEMPAV,SNOVAP)
       C
       C           *** CALCULATION OF MOISTURE ADDED TO DISPOSAL AREA DUE TO
       C                          SNOWMELT ON THE AREA ***
       C
                   REAL M,MA,MR
                   M=0.0
                   IF(PACK.GT.0.1) SNOVAP=PET
                   PACK=PACK-SNOVAP
                   IF(SNOVAP.GT.0.0) PET=0.0
                   IF(TEMPAV-32.) 10,10,20
                10 IF(PRECIP) 70,70,30
                20 IF(PACK) 90,90,40
                30 PACK=PACK+PRECIP
                   WATER=0.0
                   GO TO 90
       C***        MA IS SNOWMELT DUE TO ATMOSPHERIC CONDITIONS
                40 MA=0.05*(TEMPAV-34.)
                   IF(MA.LT.0.0) MA=0.0
                   IF(PACK-MA) 60,60,50
       C***        MR IS SNOWMELT DUE TO RAIN
                50 MR=(PRECIP*(TEMPAV-32.))/144
                   M=MR+MA
                   IF(PACK-M) 60,70,70
                60 M=PACK
                   PACK=0.0
                   GO TO 80
                70 PACK=PACK-M
                80 WATER=M+PRECIP
                90 RETURN
                   END
```

```
      SUBROUTINE DARCRT(PERC,FCU,SMUZ,FCL,SMLZ,FCGW,SMGWZ,DPERC,CONDUZ,C
     1ONDLZ,CONDGW,HUZ,HLZ,HGW,PWU,PWL,PWG)
      DIMENSION H(3),H1(3),SMD(3),WF(3),COND(3),DEP(3),C(2)
      DATA DEP,RCHGS,EXCESS,RCHGR/30.48,91.44,60.96,3*0.0/
C
C***  DISTRIBUTION OF WATER ADDED TO EACH PLOT
C
      EXCESS=0.0
      IF(PERC.LE.0.0) GO TO 10
      SMAVUZ=FCU-SMUZ
      IF(SMAVUZ.LT.0.0) SMAVUZ=0.0
      EXCESS=PERC-SMAVUZ
      IF(EXCESS.LT.0.0) EXCESS=0.0
      SMUZ=SMUZ+PERC-EXCESS
      SMAVLZ=FCL-SMLZ
      IF(SMAVLZ.LT.0.0) SMAVLZ=0.0
      EXTRA=EXCESS
      EXCESS=EXCESS-SMAVLZ
      IF(EXCESS.LT.0.0) EXCESS=0.0
      SMLZ=SMLZ+EXTRA-EXCESS
      SMAVGW=FCGW-SMGW
      IF(SMAVGW.LT.0.0) SMAVGW=0.0
      EXTRA=EXCESS
      EXCESS=EXCESS-SMAVGW
      IF(EXCESS.LT.0.0) EXCESS=0.0
      SMGWZ=SMGWZ+EXTRA-EXCESS
      RCHGR=EXTRA-EXCESS
      IF(RCHGR.LT.0.0) RCHGR=0.0
C
C***  MOISTURE REDISTRIBUTION USING THE ONE-DIMENSIONAL DARCY EQUATION
C***  FOR UNSATURATED FLOW
C
   10 LCOUNT=1
      DTIME=0.1667
      IF(PERC.LE.0.0) DTIME=1.0
      IF(PERC.LE.0.0) LCOUNT=6
      DPERC=EXCESS
      WF(1)=PWU/12.
      WF(2)=PWL/36.
      WF(3)=PWG/24.
      SMD(1)=SMUZ/12.
      SMD(2)=SMLZ/36.
      SMD(3)=SMGWZ/24.
      DO 20 K=1,3
   20 IF(SMD(K).GT.1.0) SMD(K)=1.
C
C***  CALCULATE SOIL MOISTURE TENSION IN CM
      H1(1)=SMD(1)-HUZ
      H1(2)=SMD(2)-HLZ
      H1(3)=SMD(3)-HGW
      DO 30 K=1,3
      H(K)=EXP(H1(K))
      IF(H(K).GT.1500.) H(K)=1500.
      IF(H(K).LT.0.0) H(K)=0.0
      XXX=SMD(K)-WF(K)
      IF(XXX.LT.0.01) SMD(K)=WF(K)+0.01
C
C***  CALCULATE UNSATURATED HYDRAULIC CONDUCTIVITY IN CM PER DAY
```

```
FORTRAN IV G LEVEL  21                  OARCRT               DATE = 79045          21/27/40

 0047               IF(K.EQ.1) COND(K)=CONDUZ*(EXP(72.039*SMD(K)))/(SMD(K)-WF(K))
 0048               IF(K.EQ.2) COND(K)=CONDLZ*(EXP(75.595*SMD(K)))/(SMD(K)-WF(K))
 0049               IF(K.EQ.3) COND(K)=CONDGW*(EXP(70.588*SMD(K)))/(SMD(K)-WF(K))
 0050               IF(COND(K).GT.10.0) COND(K)=10.0
 0051            30 IF(COND(K).LT.1.0E-07) COND(K)=1.0E-07
              C
              C***  CALCULATE MOISTURE FLOW, IN INCHES
 0052            40 DO 50 K=1,2
 0053               Q(K)=(COND(K)+COND(K+1))/2*DTIME*(H(K+1)-H(K)+DEP(K))/DEP(K)
 0054            50 Q(K)=Q(K)/2.54
 0055               SMUZ=SMUZ-Q(1)
 0056               SMLZ=SMLZ+Q(1)
 0057               SMLZ=SMLZ-Q(2)
 0058               SMGWZ=SMLZ+Q(2)
 0059               RCHGS=RCHGS+Q(2)
 0060               LCOUNT=LCOUNT+1
 0061               IF(LCOUNT.LE.6) GO TO 40
 0062               DPERC=DPERC+RCHGS+RCHGR
 0063               RETURN
 0064               END
```

```
FORTRAN IV G LEVEL  21                  STORAG              DATE = 79045            21/27/40

      SUBROUTINE STORAG(P1,P2,P3,PRECIP,SNOW,FROZE,MONTH,GROW,DORM,RUNOF
     1F,WWINPT,RUNOFT)
C
C
C                ***  CALCULATION OF FEEDLOT RUNOFF ***
C
      IF(BYPASS.EQ.3) GO TO 60
C***  CALCULATE 3 DAY ANTECEDENT MOISTURE
      AM=P1+P2+P3
      P1=P2
      P2=P3
      P3=PRECIP
      IF (SNOW.GT.0.0.AND.FROZE.EQ.0) GO TO 10
      IF(PRECIP.LE.0.0) GO TO 50
      IF (FROZE.EQ.1) GO TO 40
      IF(AM.LE.0.5.AND.PRECIP.LE.0.5) GO TO 50
C***  CALCULATE FEEDLOT RUNOFF USING 3 DAY ANTECEDENT MOISTURE CONDITIONS
C***  MODIFICATION OF THE SCS METHOD
   10 AM1=AM+PRECIP
      PRESIP=PRECIP+SNOW
      RC=97.0
      IF(MONTH.LT.4.OR.MONTH.GT.10) GO TO 20
      IF(AM.LT.0.75) RC=91.0
      IF(AM1.GT.GROW.AND.PRECIP.GT.GROW) PRESIP=GROW
      GO TO 30
   20 IF(AM.LT.0.50) RC=91.0
      IF (SNOW.GT.0.0) RC=97.0
      IF(AM1.GT.DORM.AND.PRECIP.GT.DORM) PRESIP=DORM
   30 CS=1000.0/RC-10.0
      RUNOFF=(PRESIP-0.2*CS)**2/(PRESIP+0.8*CS)
      RUNOFF=RUNOFF+PRECIP-PRESIP+SNOW
      SNOW=0.0
      IF(RUNOFF.GT.0.06) RUNOFF=RUNOFF-0.06
      IF(PRESIP-0.2*CS.LT.0.0) GO TO 50
      GO TO 60
   40 SNOW=SNOW+PRECIP
   50 RUNOFF=0.0
      IF(BYPASS.EQ.2) GO TO 70
   60 RUNOFT=WWINPT/(3630*7.48)
   70 RETURN
      END
```

APPENDIX D

INPUT FOR COMPUTER ANALYSIS

TABLE X

INPUT DATA FOR NAMELIST ALPHA

Location	BRUNTA	BRUNTB	E	RCROP	DORM	GROW	PAVLU	PCVMAX	DSRATE
Belleville	0.62	0.039	0.75	0.23	1.0	1.25	0.0	0.05	0.5
Colby	0.79	0.035	0.75	0.23	1.0	1.25	0.0	0.05	0.5
Dodge City	0.79	0.035	0.75	0.23	1.0	1.25	0.0	0.05	0.5
Ellsworth	0.60	0.033	0.75	0.23	1.0	1.25	0.0	0.05	0.5
Garden City	0.80	0.034	0.75	0.23	1.0	1.25	0.0	0.05	0.5
Goodland	0.75	0.036	0.75	0.23	1.0	1.25	0.0	0.05	0.5
Hays	0.78	0.035	0.75	0.23	1.0	1.25	0.0	0.05	0.5
Horton	0.60	0.040	0.75	0.23	1.0	1.25	0.0	0.05	0.5
Independence	0.59	0.039	0.75	0.23	1.0	1.25	0.0	0.05	0.5
Topeka	0.66	0.041	0.75	0.23	1.0	1.25	0.0	0.05	0.5

TABLE XI

INPUT DATA FOR NAMELIST BETA

Location	H	L	W	S	INDST	YSTART	YEND
Belleville	6.0	950	950	3.0	0682	1949	1973
Colby	6.0	230	230	3.0	1699	1950	1962
Dodge City	6.0	400	400	3.0	2164	1949	1973
Ellsworth	6.0	725	725	3.0	2459	1946	1970
Garden City	9.0	380	380	3.0	2980	1950	1974
Goodland	6.0	325	325	3.0	3153	1949	1973
Hays	6.0	600	600	3.0	3527	1948	1973
Horton	9.0	2000	2000	3.0	3810	1946	1970
Independence	9.0	800	800	3.0	3954	1948	1972
Topeka	9.0	1070	1070	3.0	8167	1949	1973

TABLE XI (Continued)

Location	MSTART	ROTAYR	DARCEQ	BYPASS	LTAREA	STORM	NPLOTS
Belleville	1	1	2	1	0	5.1	1
Colby	1	1	2	1	0	4.5	1
Dodge City	1	1	2	1	0	4.6	1
Ellsworth	1	1	2	1	0	5.4	1
Garden City	1	1	2	1	0	4.5	1
Goodland	1	1	2	1	0	4.3	1
Hays	1	1	2	1	0	4.7	1
Horton	1	1	2	1	0	5.9	1
Independence	1	1	2	1	0	6.7	1
Topeka	1	1	2	1	0	6.1	1

TABLE XII

INPUT DATA FOR DISPOSAL AREAS

Location	CROP	SOIL	AREA	IPLAN	ROTATE	MGSBP	DGSBP	MGSEP	DGSEP
Belleville	Wheat	5	80	1	2	9	15	7	10
Colby	Wheat	5	40	1	2	9	15	7	10
Dodge City	Wheat	5	80	1	2	9	15	7	10
Ellsworth	Wheat	5	80	1	2	9	15	7	10
Garden City	Wheat	5	80	1	2	9	15	7	10
Goodland	Wheat	5	80	1	2	9	15	7	10
Hays	Wheat	5	80	1	2	9	15	7	10
Horton	Wheat	5	80	1	2	9	15	7	10
Independence	Wheat	5	40	1	2	9	15	7	10
Topeka	Wheat	5	80	1	2	9	15	7	10

APPENDIX E

OUTPUT OF COMPUTER PROGRAM

```
STATION:   TOPEKA, KANSAS                1964  TO  1973


MODEL:  MODEL B-ZERO

        MUNICIPAL INPUT

        FEEDLOT AREA =    0.0  ACRES


SIZE OF CRITICAL EVENT:  6.10


POND VARIABLES:

               (A) BASE DIMENSION-- 1020.00 FEET BY1020.00 FEET

               (B) SIDE SLOPE--    RUN:RISE =  3. : 1

               (C) MAXIMUM DEPTH--    9.00  FEET

               (D) MAXIMUM POND VOLUME--    2718.48 ACRE-INCHES

               (E) DIRECT RECEIVING AREA (FOR PRECIPITATION) --       26.48 ACRES


AREA VARIABLES:

     PLOT 1

               (A) AREA--    40.00    ACRES

               (B) CROP--  CORN

               (C) SOIL TYPE--    5  (SCS SOIL TYPE)

               (D) IRRIGATION RATE--   0.50  INCHES/DAY

               (E) IRRIGATION MANAGEMENT--   IRRIGATION BELOW   0.90  FIELD CAPACITY

               (F) PLAN IMPLEMENTED--   RUNOFF AND IRRIGATION
```

```
PLOT 2

          (A) AREA--   40.00   ACRES
          (B) CROP--  WHEAT
          (C) SOIL TYPE--    5  (SCS SOIL TYPE)
          (D) IRRIGATION RATE--   0.50  INCHES/DAY
          (E) IRRIGATICN MANAGEMENT--   IRRIGATICN BELCW   0.90  FIELD CAPACITY
          (F) PLAN IMPLEMENTED--   IRRIGATION

PLOT 3
          (A) AREA--   40.00   ACRES
          (B) CROP--  WHEAT
          (C) SOIL TYPE--    5  (SCS SOIL TYPE)
          (D) IRRIGATION RATE--   0.50  INCHES/CAY
          (E) IRRIGATICN MANAGEMENT--   IRRIGATICN BELOW   0.0   FIELD CAPACITY
          (F) PLAN IMPLEMENTED--   RUNOFF
          (G) CROP ROTATION WITH --   FALLCW

PLOT 4
          (A) AREA--   40.00   ACRES
          (B) CROP--  PASTURE
          (C) SOIL TYPE--    5  (SCS SOIL TYPE)
          (D) IRRIGATION RATE--   0.50  INCHES/CAY
          (E) IRRIGATION MANAGEMENT--   IRRIGATICN BELOW   0.0   FIELD CAPACITY
          (F) PLAN IMPLEMENTED--   RUNOFF



                              ***** ANNUAL SUMMARY *****
6/22/69 - DISCHARGE OF    4.06 ACRE-IN REQUIRES VOLUME OF  2722.54 ACRE-IN FOR 100.00 % CONTROL WHERE L - W -  1021.24
```

```
                              ***** ANNUAL SUMMARY *****

6/22/69 - DISCHARGE OF    4.06 ACRE-IN REQUIRES VOLUME OF  2722.54 ACRE-IN FOR 100.00 % CONTROL WHERE L = W =  1021.24

6/23/69 - DISCHARGE OF    9.43 ACRE-IN REQUIRES VOLUME OF  2731.96 ACRE-IN FOR 100.00 % CONTROL WHERE L = W =  1023.05

6/25/69 - DISCHARGE OF    3.00 ACRE-IN REQUIRES VOLUME OF  2734.96 ACRE-IN FOR 100.00 % CONTROL WHERE L = W =  1023.63

6/26/69 - DISCHARGE OF   39.89 ACRE-IN REQUIRES VOLUME OF  2774.85 ACRE-IN FOR 100.00 % CONTROL WHERE L = W =  1031.26

                     WATER ACCOUNT FOR STORAGE FACILITY (IN ACRE-INCHES)         - 1969

      ---------------------------------------------------------------------------------------------------------
                   INFLOWS                                                  OUTFLOWS
          -----------------------------------                  ---------------------------------------
MONTH     PRECIP.   MUNICIPAL   FEEDLOT   RUNOFF   IRR. DAYS   DISPOSAL VOL.   SURFACE EVAP.   DISCHARGE   VOL. CHANGE   HEIGHT
 JAN.       22.2       85.6       0.0       0.0       0.            0.0            5.1            0.0         102.8       7.86
 FEB.       11.1       82.5       0.0       1.6       1.           20.0           16.5            0.0          58.8       8.05
 MAR.       43.5       91.3       0.0      14.9       5.          100.0           48.7            0.0           1.1       8.06
 APR.      173.3       93.9       0.0     299.5      12.          260.0          112.3            0.0         194.4       8.68
 MAY       103.0      102.8       0.0      40.8       5.          120.0          148.7            0.0         -22.2       8.60
 JUNE      225.4      105.0       0.0     182.5       8.          180.0          168.2           56.4         108.3       8.85
 JULY      106.5      108.5       0.0      46.6       8.          160.0          193.6            0.0         -92.0       8.66
 AUG.       30.5      102.8       0.0       2.4      15.          340.0          162.0            0.0        -366.3       7.50
 SEPT       54.7       93.9       0.0      16.6       9.          220.0          126.1            0.0        -180.9       6.91
 OCT.      105.4       91.3       0.0      36.0       2.           40.0           70.2            0.0         122.5       7.30
 NOV.        2.6       88.4       0.0       0.0       5.          100.0           32.9            0.0         -41.9       7.16
 DEC.       32.8       85.6       0.0       0.8       0.            0.0            2.7            0.0         116.6       7.53
 TOT.      911.2     1131.6       0.0     641.7      70.         1540.0         1066.9           56.4           1.1       7.53


                                            PLOT NO.  1


                   CROP--CORN                SOIL TYPE--  5     DISPOSAL AREA-- 40.00 ACRES

                          WATER BALANCE (INCHES) IN THE DISPOSAL AREA - 1969
        ----------------------------------------------------------------------------------------------------
                          INPUTS                                    OUTPUTS
                ---------------------------    -----------------------------------------------------------
MONTH           PRECIPITATION    IRRIGATION    INTERCEPTION   SURFACE RUNOFF   PERCOLATION         AET           CHANGE IN SM
 JAN.               0.84            0.0            0.24            0.0            0.11             0.23             -0.05
 FEB.               0.42            0.50           0.46            0.03           0.38             0.65             -0.09
 MAR.               1.64            1.50           0.72            0.19           0.81             1.28              0.14
 APR.               6.54            3.50           0.97            4.19           2.49             2.25              0.15
 MAY                3.89            0.50           0.82            0.83           1.21             1.74             -0.21
 JUNE               8.51            1.50           1.22            3.00           2.06             3.49              0.24
 JULY               4.02            4.00           1.71            0.75           0.12             6.17             -0.73
 AUG.               1.15            4.50           1.17            0.06           0.0              5.79             -1.37
 SEPT               2.07            3.00           0.82            0.41           0.0              3.80             -0.46
 OCT.               3.98            0.0            0.95            0.59           0.0              0.82              2.12
 NOV.               0.10            1.50           0.40            0.0            0.01             0.99              0.20
 DEC.               1.24            0.0            0.27            0.02           0.38             0.39              0.02
 TOT.              34.41           20.50           9.76           10.07           7.57            27.59             -0.04
```

```
                                        PLOT NO.  2


              CROP--WHEAT               SOIL TYPE--  5     DISPCSAL AREA-- 40.00 ACRES

                            WATER BALANCE (INCHES) IN THE DISPOSAL AREA - 1969
------------------------------------------------------------------------------------------------------------------
                      INPUTS                                    OUTPUTS
             ---------------------------  -------------------------------------------------------------
MONTH        PRECIPITATION    IRRIGATION  INTERCEPTION  SURFACE RUNOFF  PERCOLATION       AET        CHANGE IN SM
 JAN.            0.64            0.0          0.24           0.0           0.10          0.23          -0.04
 FEB.            0.42            0.0          0.42           0.02          0.28          0.37          -0.16
 MAR.            1.64            1.00         0.53           0.15          1.03          0.98          -0.04
 APR.            6.54            3.00         0.87           3.59          1.72          2.96          -0.11
 MAY             3.89            2.50         1.30           0.73          0.49          4.23           0.14
 JUNE            8.51            3.00         1.42           3.39          1.91          4.50           0.30
 JULY            4.02            0.0          1.11           0.39          1.57          1.29          -0.34
 AUG.            1.15            4.00         1.07           0.03          0.96          2.72           0.37
 SEPT            2.07            2.50         0.62           0.91          0.54          2.95          -0.45
 OCT.            3.98            1.00         0.95           0.73          1.17          1.79           0.34
 NOV.            0.10            1.00         0.16           0.0           0.03          0.80          -0.39
 DEC.            1.24            0.0          0.37           0.01          0.58          0.28           0.33
 TOT.           34.41           18.00         9.06           9.95         10.39         23.10          -0.06


                                        PLCT NO.  3


              CROP--FALLOW              SOIL TYPE--  5     DISPCSAL AREA-- 40.00 ACRES

                            WATER BALANCE (INCHES) IN THE DISPOSAL AREA - 1969
------------------------------------------------------------------------------------------------------------------
                      INPUTS                                    OUTPUTS
             ---------------------------  -------------------------------------------------------------
MONTH        PRECIPITATION    IRRIGATICN  INTERCEPTICN  SURFACE RUNOFF  PERCOLATICN       AET        CHANGE IN SM
 JAN.            0.84            0.0          0.24           0.0           0.10          0.23          -0.04
 FEB.            0.42            0.0          0.42           0.02          0.28          0.37          -0.16
 MAR.            1.64            0.0          0.42           0.15          0.04          1.07          -0.04
 APR.            6.54            0.0          0.54           1.73          1.41          2.96          -0.11
 MAY             3.89            0.0          0.82           0.12          0.0           4.23          -1.28
 JUNE            8.51            0.0          1.12           1.21          0.22          4.50           1.47
 JULY            4.02            0.0          1.11           0.39          1.32          1.29          -0.09
 AUG.            1.15            0.0          0.39           0.00          0.0           1.51          -0.75
 SEPT            2.07            0.0          0.32           0.01          0.0           1.55           0.20
 OCT.            3.98            0.0          0.86           0.29          0.88          1.14           0.81
 NOV.            0.10            0.0          0.10           0.0           0.0           1.01          -1.01
 DEC.            1.24            0.0          0.27           0.0           0.0           0.31           0.50
 TOT.           34.41            0.0          6.60           3.92          4.26         20.18          -0.51
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PLOT NO. 4

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          CROP--PASTURE             SOIL TYPE--  5     DISPOSAL AREA-- 40.00 ACRES

                         WATER BALANCE (INCHES) IN THE DISPOSAL AREA - 1969
-----------------------------------------------------------------------------------------------
                  INPUTS                                  OUTPUTS
           ---------------------------   --------------------------------------------------
MONTH      PRECIPITATION    IRRIGATION   INTERCEPTION  SURFACE RUNOFF   PERCOLATION       AET        CHANGE IN SM
 JAN.           0.84           0.0           0.24          0.0             0.13          0.17          -0.01
 FEB.           0.42           0.0           0.42          0.0             0.32          0.22          -0.04
 MAR.           1.64           0.0           0.42          0.03            0.66          0.62          -0.08
 APR.           6.54           0.0           0.54          1.56            2.54          2.00          -0.10
 MAY            3.89           0.0           0.82          0.06            0.23          3.40          -0.63
 JUNE           8.51           0.0           1.12          0.35            1.55          4.77           0.73
 JULY           4.02           0.0           1.11          0.03            0.0           5.99          -3.11
 AUG.           1.15           0.0           0.39          0.0             0.0           3.76          -3.01
 SEPT           2.07           0.0           0.32          0.0             0.0           2.05          -0.30
 OCT.           3.98           0.0           0.85          0.01            0.0           0.53           2.53
 NOV.           0.10           0.0           0.10          0.0             0.0           0.34          -0.34
 DEC.           1.24           0.0           0.27          0.0             0.0           0.23           0.58
 TOT.          34.41           0.0           6.60          2.05            5.43         24.11          -3.75
  PERCENT OF WASTEWATER CONTROLLED=     97.90

  POTENTIAL DISPOSAL DAYS=  70

  PACK ON DECEMBER 31 = 0.16              CHANGE IN SNOW STORAGE=-0.03

  INPUTS-OUTPUTS-CHANGE IN SNOW STORAGE=CHANGE IN   SOIL MOISTURE

  PERCENT OF MAXIMUM POND VOLUME REQUIRED = 100.00

  ESTIMATED LAKE EVAPORATION, INCHES = 41.41
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STATION:   TOPEKA, KANSAS                1964  TO  1973

MODEL:  MODEL B-ZERO
        MUNICIPAL INPUT
        FEEDLCT AREA =   0.0  ACRES

SIZE OF CRITICAL EVENT:  6.10

POND VARIABLES:
               (A) BASE DIMENSICN-- 1020.00 FEET BY1020.00 FEET
               (B) SIDE SLCPE--   RUN:RISE =  3. : 1
               (C) MAXIMUM DEPTH--   9.CO  FEET
               (D) MAXIMUM POND VCLUME--    2718.48 ACRE-INCHES
               (E) DIRECT RECEIVING AREA (FOR PRECIPITATION) --       26.48 ACRES

AREA VARIABLES:

     PLOT 1
               (A) AREA--   40.00   ACRES
               (B) CRCP--  CORN
               (C) SOIL TYPE--    5  (SCS SOIL TYPE)
               (D) IRRIGATION RATE--   0.50  INCHES/CAY
               (E) IRRIGATICN MANAGEMENT--   IRRIGATICN BELOW   0.90  FIELD CAPACITY
               (F) PLAN IMPLEMENTED--   RUNOFF AND IRRIGATICN

     PLOT 2
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             (A) AREA--    40.00    ACRES

             (B) CROP--   WHEAT

             (C) SOIL TYPE--     5  (SCS SOIL TYPE)

             (D) IRRIGATION RATE--    0.50   INCHES/DAY

             (E) IRRIGATION MANAGEMENT--    IRRIGATION BELOW   0.90  FIELD CAPACITY

             (F) PLAN IMPLEMENTED--    IRRIGATION

    PLOT 3

             (A) AREA--    40.00    ACRES

             (B) CROP--   WHEAT

             (C) SOIL TYPE--     5  (SCS SOIL TYPE)

             (D) IRRIGATION RATE--    0.50   INCHES/DAY

             (E) IRRIGATION MANAGEMENT--    IRRIGATION BELOW   0.0   FIELD CAPACITY

             (F) PLAN IMPLEMENTED--    RUNOFF

             (G) CROP ROTATION WITH --    FALLOW

    PLOT 4

             (A) AREA--    40.00    ACRES

             (B) CROP--   PASTURE

             (C) SOIL TYPE--     5  (SCS SOIL TYPE)

             (D) IRRIGATION RATE--    0.50   INCHES/DAY

             (E) IRRIGATION MANAGEMENT--    IRRIGATION BELOW   0.0   FIELD CAPACITY

             (F) PLAN IMPLEMENTED--    RUNOFF


                                 ***** FINAL SUMMARY *****

METEOROLOGICAL SUMMARY

              AVERAGE ANNUAL LAKE EVAPORATION= 42.15 INCHES

              AVERAGE ANNUAL PRECIPITATION= 38.69 INCHES

              PRECIPITATION RANGE= 40.30 INCHES   (FROM A LOW OF 21.17 INCHES  TO A HIGH OF  61.46 INCHES)

              AVERAGE ANNUAL MOISTURE DEFICIT=  3.51 INCHES
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SUMMARY OF POND OPERATIONS
               NO. OF YEARS HAVING A DISCHARGE=      2
               AVERAGE NO. OF DISCHARGES / YEAR HAVING A DISCHARGE= 26.50
               AVERAGE DISCHARGE= 16.86 ACRE-INCHES
               AVERAGE PERCENT OF WASTEWATER CONTROLLED= 97.87
               TOTAL DISCHARGE VOLUME=    893.39 ACRE-INCHES
               TOTAL NO. OF DISCHARGES= 53.
               MAXIMUM DISCHARGE=259.69 ACRE-INCHES
               AVERAGE ANNUAL VOLUME OF WASTEWATER APPLIED= 1454.00 ACRE-INCHES
SUMMARY OF DISPOSAL PLOTS
     PLOT 1
               AVERAGE ANNUAL DISPOSAL AREA RUNOFF= 10.63 INCHES
               AVERAGE ANNUAL DISPOSAL AREA PERCOLATION=  9.37 INCHES
               AVERAGE ANNUAL NO. OF DISPOSAL DAYS=  39.9
               AVERAGE ANNUAL DISPOSAL AREA INTERCEPTION= 10.22 INCHES
               AVERAGE ANNUAL DISPOSAL AREA EVAPOTRANSPIRATION= 27.68 INCHES
               AVERAGE ANNUAL DISPOSAL AREA CHANGE IN SOIL MOISTURE=  0.44 INCHES
     PLOT 2
               AVERAGE ANNUAL DISPOSAL AREA RUNOFF=  9.53 INCHES
               AVERAGE ANNUAL DISPOSAL AREA PERCOLATION= 11.61 INCHES
               AVERAGE ANNUAL NO. OF DISPOSAL DAYS=  32.8
               AVERAGE ANNUAL DISPOSAL AREA INTERCEPTION=  9.60 INCHES
               AVERAGE ANNUAL DISPOSAL AREA EVAPOTRANSPIRATION= 23.81 INCHES
               AVERAGE ANNUAL DISPOSAL AREA CHANGE IN SOIL MOISTURE=  0.44 INCHES
     PLOT 3
               AVERAGE ANNUAL DISPOSAL AREA RUNOFF=  5.04 INCHES
               AVERAGE ANNUAL DISPOSAL AREA PERCOLATION=  7.19 INCHES
               AVERAGE ANNUAL NO. OF DISPOSAL DAYS=   0.0
               AVERAGE ANNUAL DISPOSAL AREA INTERCEPTION=  7.13 INCHES
               AVERAGE ANNUAL DISPOSAL AREA EVAPOTRANSPIRATION= 18.79 INCHES
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          AVERAGE ANNUAL DISPOSAL AREA EVAPOTRANSPIRATION= 18.79 INCHES




          AVERAGE ANNUAL DISPOSAL AREA CHANGE IN SOIL MOISTURE=  0.44 INCHES

     PLOT 4

          AVERAGE ANNUAL DISPOSAL AREA RUNOFF=  2.58 INCHES

          AVERAGE ANNUAL DISPOSAL AREA PERCOLATION=  4.57 INCHES

          AVERAGE ANNUAL NO. OF DISPOSAL DAYS=   0.0

          AVERAGE ANNUAL DISPOSAL AREA INTERCEPTION=  7.13 INCHES

          AVERAGE ANNUAL DISPOSAL AREA EVAPOTRANSPIRATION= 23.88 INCHES

          AVERAGE ANNUAL DISPOSAL AREA CHANGE IN SOIL MOISTURE=  0.44 INCHES

   SUMMARY OF STATISTICAL DATA

                     PRECIPITATION FREQUENCY DATA

           INTENSITY     FREQUENCY      FREQUENCY      RUNOFF FREQ.
             (IN.)          (%)           (DAYS)          (DAYS)

             >0.0         100.00         939.00          404.00
             >0.1          66.67         626.00          402.00
             >0.2          50.05         470.00          401.00
             >0.3          40.68         382.00          362.00
             >0.4          35.68         335.00          320.00
             >0.5          30.14         283.00          272.00
             >0.6          23.43         220.00          211.00
             >0.7          19.06         179.00          171.00
             >0.8          16.19         152.00          148.00
             >0.9          13.31         125.00          122.00
             >1.0          10.97         103.00          100.00
             >1.1           8.41          79.00           77.00
             >1.2           7.35          69.00           68.00
             >1.3           6.28          59.00           58.00
             >1.4           5.64          53.00           52.00
             >1.5           4.79          45.00           44.00
             >1.6           4.05          38.00           37.00
             >1.7           3.51          33.00           32.00
             >1.8           3.19          30.00           29.00
             >1.9           2.56          24.00           23.00
             >2.0           1.81          17.00           17.00
             >3.0           0.32           3.00            3.00
             >4.0           0.11           1.00            1.00
             >5.0           0.0            0.0             0.0
             >10.           0.0            0.0             0.0
```

RUNOFF FREQUENCY DATA

INTENSITY (IN.)	FREQUENCY (%) PLOT 1	PLOT 2	PLOT 3	PLOT 4	FREQUENCY (DAYS) PLOT 1	PLOT 2	PLOT 3	PLOT 4
>0.0	100.00	100.00	100.00	100.00	411.00	393.00	271.00	165.00
>0.1	49.39	46.82	38.38	32.73	203.00	184.00	104.00	54.00
>0.2	37.71	33.59	25.09	22.42	155.00	132.00	68.00	37.00
>0.3	27.74	23.16	17.34	18.18	114.00	91.00	47.00	30.00
>0.4	19.46	18.58	13.65	13.33	80.00	73.00	37.00	22.00
>0.5	16.06	16.03	11.07	9.70	66.00	63.00	30.00	16.00
>0.6	12.41	12.47	9.96	6.06	51.00	49.00	27.00	10.00
>0.7	9.73	9.41	7.75	4.85	40.00	37.00	21.00	8.00
>0.8	8.03	7.63	5.90	4.24	33.00	30.00	16.00	7.00
>0.9	7.54	6.11	4.43	4.24	31.00	24.00	12.00	7.00
>1.0	5.11	4.33	3.32	3.03	21.00	17.00	9.00	5.00
>1.1	3.89	3.82	2.21	3.03	16.00	15.00	6.00	5.00
>1.2	3.16	3.05	1.85	0.61	13.00	12.00	5.00	1.00
>1.3	2.68	2.54	1.48	0.61	11.00	10.00	4.00	1.00
>1.4	2.68	2.04	1.48	0.0	11.00	8.00	4.00	0.0
>1.5	2.43	1.79	1.48	0.0	10.00	7.00	4.00	0.0
>1.6	1.70	1.78	1.11	0.0	7.00	7.00	3.00	0.0
>1.7	1.70	1.53	0.74	0.0	7.00	6.00	2.00	0.0
>1.8	1.22	1.53	0.37	0.0	5.00	6.00	1.00	0.0
>1.9	0.97	1.27	0.37	0.0	4.00	5.00	1.00	0.0
>2.0	0.97	1.02	0.0	0.0	4.00	4.00	0.0	0.0
>3.0	0.24	0.25	0.0	0.0	1.00	1.00	0.0	0.0
>4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>10.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

DEVELOPMENT AND TESTING OF A MULTIPURPOSE HYDROLOGIC YIELD MODEL

by

JUDITH MARIE HAYDEN

B.S., Oklahoma State University, 1977

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1979

ABSTRACT

Providing a dependable supply of water for industrial, domestic and agricultural use in the United States has increased in importance during the past few years. One method which is gaining in acceptance for increasing the water supply in a particular locality is weather modification. This research was conducted to study the effects of a weather modification program on the hydrological environment in Kansas. Ten locations were tested using two rainfall alteration models which produced variable percentage changes in the natural daily rainfall.

In addition to supplying new sources of water, a method to increase the efficiency of available water supplies was investigated. The method of optimizing available water supplies considered in this study was the utilization of effluent from wastewater-treatment plants for irrigation purposes. The scope of this study included the development of a procedure to design wastewater control facilities.

A multipurpose computer program was developed to evaluate the effects of rainfall augmentation on surface water hydrology and to provide an efficient means of designing a disposal control facility. The computer program is capable of evaluating the hydrologic response of various crops and soils to added rainfall and of considering selective land disposal and evaporative techniques to optimize a disposal system.

The rainfall alteration models resulted in two to three inch increases in annual rainfall throughout the State. Most of this added rainfall results in increased evapotranspiration, with smaller increases noted in surface runoff and deep percolation.