SIZING TAILWATER RECOVERY SYSTEMS TO UTILIZE RUNOFF FROM PRECIPITATION ON IRRIGATED LANDS

by

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INTRODUCTION

Water is an important natural resource. In many areas, insufficient water limits the development of agriculture and industry, and the growth of population. In the western half of Kansas, the main water supply is ground water, most of which is used for irrigation. According to Hay and Pope (1974), the U.S. and Kansas Geological Survey and the State Board of Agriculture, Division of Water Resources, have reported that the ground water level is being lowered continuously. The reason is that the ground water is being depleted faster than it is recharged. Since the available ground water is insufficient to supply all the water required and the development of irrigation is still increasing, it becomes essential to improve irrigation management and develop alternative sources of water at a competitive price.

Considering the management of irrigation water, it is noticed that 27 to 43 percent of the irrigation water is lost by evaporation, deep percolation, and runoff (Fischbach & Somerhalder, 1971). Many tailwater recovery systems have been built to collect the water from irrigation runoff and then pump it back onto the field for reuse. Tailwater is the term commonly used in the gravity irrigation industry to describe water accumlating at the lower (tail) end of the irrigation run (Hay & Pope, 1977). Reuse of surface runoff from furrow irrigation can improve irrigation application efficiency from a range of 60 to 75 percent to a range of 85 to 95 percent, which would be very desirable. Although tailwater pits are only designed to handle the runoff from irrigation, they do catch some runoff from precipitation. Since the soil moisture content is higher in the irrigated land than in the non-irrigated land, greater rainfall runoff is expected from irrigated land. A study of the effect of irrigation on runoff by Brill and Blake (1958) showed that about 23 percent more runoff is produced from irrigated land than from non-irrigated land. Therefore, it becomes worthwhile to study the possibility of using runoff from precipitation as a source of irrigation water.

The only way to utilize the runoff from precipitation is to excavate a pit larger than the normal tailwater pit in order to trap and use this water. The economic feasibility of increasing the pit size depends upon the volume of water utilized, pumping lift, type of energy, and its current price. The purpose of this study was to estimate the amount of runoff utilized by different sizes of tailwater pits and to determine the optimum size for different soils and locations in Western Kansas.

REVIEW OF LITERATURE

After a broad search of the current literature, it was found that no work had been done previously to determine the optimum size of tailwater recovery systems to utilize runoff from precipitation. However, there are many studies about the reuse of surface runoff from furrow irrigation. These studies provide the background for the design and management of tailwater recovery systems. There are a few studies on the determination of rainfall runoff from irrigated land which point out that the runoff from precipitation can be considered as a water source.

Design and Management of Tailwater Recovery Systems

Causes of Tailwater

Large streams move water through the field quickly and provide a more uniform penetration throughout the run than smaller streams. In a non-cutback system, 20% to 30% of the irrigation water may runoff (Fischbach and Somerhalder, 1970). Davis (1964) stated that the occurrence of tail-water may be an economic necessity after comparing the cost of capital, labor, and water. Fischbach and Somerhalder (1971) also indicated that if a small stream is used for each furrow (avoiding runoff at the end of the field), crop yield may be reduced at both ends; the upper end because of excessive deep percolation and the lower end because of insufficient water penetration into the soil.

System Description

Tailwater recovery systems normally consist of a channel or ditch to collect the runoff at the lower end of the field, a small reservoir or pit to store runoff, and a pump and a pipeline to return the runoff water back to the field. A dike should be built around the pit to prevent the entrance of excess runoff from heavy downpours. The depth of the pit should be at least 5 feet in order to discourage the growth of aquatic plants.

System Management

Bondurant (1969) classified tailwater recovery systems according to the method of handling runoff water. If the water is returned to a field at a higher elevation than the collection point, it is called a return-flow system. If the water is applied to a field at a lower elevation than the collection point, it is termed a sequence system. Hay and Pope (1977) identified the following four types of systems:

(1) Continuous Pump System: This system utilizes a pit with enough storage capacity to collect the runoff from one or two irrigation sets. The pit stores the runoff volume in excess of the tailwater pump

capactiy. The stored water is then pumped during times when the rate of runoff is small. The tailwater pumping rate is selected to be slightly larger than the average rate of runoff.

(2) Intermittent System: This system is designed with enough pit volume to store runoff water from several irrigation sets. The water can then be used to irrigate one separate set every few days when enough water has accumulated. This type of system is well adapted to irrigate a separate field rather than returning runoff to the field from which it was collected.

(3) Cycling Sump System: This system usually has an automatically cycled pump to return the runoff water immediately. Because of the small storage capacity of the sump, a relatively large pump is required to pump at the highest runoff rate.

(4) Rainfall and Tailwater Reuse: This system involves the construction of a larger than normal storage pit to collect not only runoff from irrigation, but part or all of the runoff from rainfall. The pump and other system components should be operated in the same manner as Type 1 or Type 2 during normal irrigation runoff.

Stringham and Hamad (1975) presented a design for an irrigation runoff recovery system that provides a constant furrow discharge. This is accomplished by irrigating the first set entirely from supply water and the last set entirely from pumped runoff water. All of the remaining sets are irrigated by both supply water and runoff water. This design provides procedures for determining the number of furrows to be irrigated from supply and runoff water, number of sets and number of furrows in each set, etc.

Amount of Runoff from Irrigation

The amount of runoff water is the main factor in determining the volume of the storage facility, the diameter of the pipeline, and the capacity of the pump. Many investigations have been made to determine the amount of runoff by direct measurement or by estimation from the analysis of field conditions and irrigation practices.

Bondurant (1969) presented a graphical method for estimating the amount of runoff. The data required are intake rate and stream advance for the particular field.

Ohmes and Manges (1972) estimated irrigation runoff rate from a graded furrow by hydrographic techniques and confirmed them by direct measurement. They found that the runoff volume can be determined by integrating the runoff rate equations which are in terms of runoff time for the rising portion of the hydrograph and the maximum runoff rate for the constant runoff rate portion.

Pope and Barefoot (1973) investigated the amount and time distribution of surface runoff from six furrow irrigated fields in Oklahoma. The runoff percentages for the individual irrigation sets were found to approximate a log-normal distribution. The runoff varied from 4.2 to 28.2 percent for different conditions.

Wilke (1973) constructed a theoretical equation to estimate irrigation tailwater volume. The equation was quite complicated so he prepared a dimensionless graph for its solution. The graph gives the ratio of runoff generated to water applied. Parameters needed to estimate runoff are time of progression of flow down the furrow, furrow length and inflow rate to the furrow. The equation was derived under the assumptions that runoff ceases when the furrow inflow ceases and inflow is constant during the irrigation period.

Fischbach and Somerhalder (1971) used an automatic surface irrigation system with a runoff reuse system to simulate cut-back type furrow irrigation. They selected 35 percent of the well pumping capacity as the re-use pumping rate and three times the basic intake rate as furrow size, which can not exceed the maximum allowable furrow stream size for prevention of erosion. Water application efficiency was

64.8 and 91.9 percent with and without a reuse system, respectively.

Runoff from Precipitation

The concern of this study was toward the amount of surface runoff from precipitation. Laflen and Saveson (1970) investigated rainfall runoff from lands of low slope in Louisiana. They expressed peak rate and total amount of surface runoff as functions of precipitation, row slope, row length, and antecedent soil moisture. The prediction equations obtained by multiple regression analysis to estimate peak rate of surface runoff and total runoff were:

$$Q_r = -.297 + P_{35}(0.206 + 1313\ S/L) + 0.157M_c \quad (1)$$

$$(R^2 = 0.63;\ \text{standard error} = 0.38)$$

$$Q_t = -0.087 + P_t(0.099 + 637(S/L) + 0.180M_c) \quad (2)$$

$$(R^2 = 0.59;\ \text{standard error} = 0.30)$$

where

Q_r = peak rate of surface runoff, inches per hour

Q_t = total runoff, inches

P_{35} = maximum storm intensity for a duration of 35 minutes, inches per hour

S = slope, percent

L = length, feet

M_c = antecedent available soil moisture in the top 12 in, inches

P_t = total precipitation, inches

Kincaid and Swanson (1974) used field-plot rainfall simulators to study rainfall runoff from irrigation furrows in Nebraska. Rainfall intensity, rainfall amount, soil type, and soil water depletion were the main factors considered. Prediction equations were developed by multiple regression analysis. The equation for percent runoff for silt or clay loam soil is:

$$P_r = 31.2 + 9.0I - 33.3D_p \qquad (R = 0.56) \tag{3}$$

where

P_r = total rainfall occurring as runoff, percent

I = rainfall intensity, inches per hour

D_p = soil water depletion in the upper foot of soil, inches

The equation for total runoff for the silt and clay loam soil is:

$$D_r = -0.14 + 0.10I + 0.41(D_a-D_p) \qquad (R = 0.78) \tag{4}$$

where

D_r = total runoff, inches

D_a = total rainfall applied, inches

Since equations obtained for the two methods were developed by regression analysis under specified field conditions and climates, the coefficients should be modified for different locations and soil types.

Watershed Models

Bean (1976) developed a continuous watershed simulation model to evaluate and design feedlot runoff control systems. The three main components in Bean's model are the feedlot, the storage reservoir, and the disposal area. Figure 1 shows a schematic of the feedlot runoff model as reported by Zovne et. al. (1977) and Figure 2 gives the general algorithm for the model (Bean, 1976).

Peterson (1977) modified the disposal area portion of the model from a single plot to multiple plots to better simulate actual irrigation practices.

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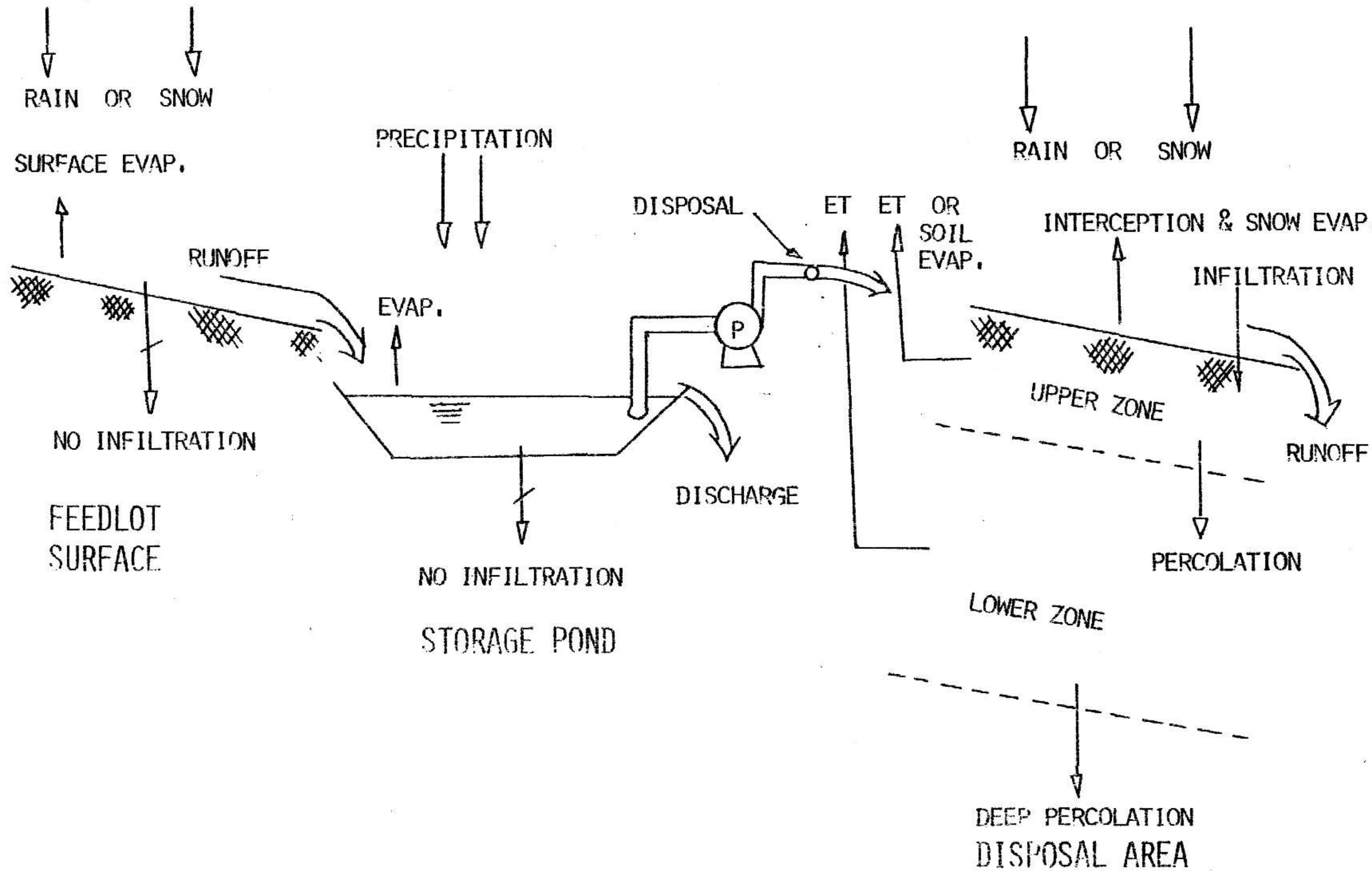

Figure 1. Process Schematic of *Feedlot Runoff Model*. (Bean's Model as Reproduced from Zovne et al., 1977)

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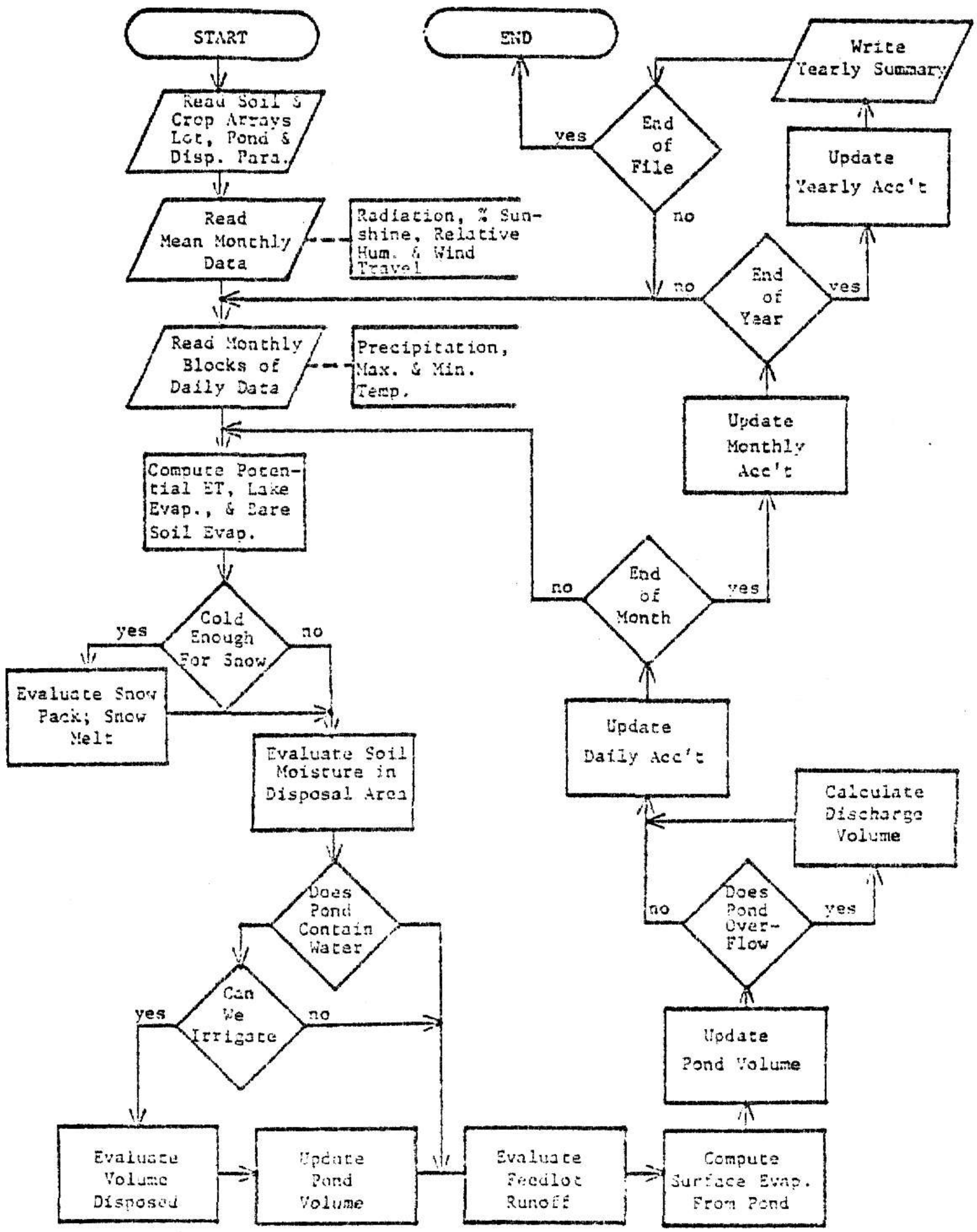

Figure 2. General Algorithm for Feedlot Model. (Reproduced from Bean, 1976)

INVESTIGATION

Study Constraints

First of all, it should be pointed out that in this study the evaluation of runoff was only from precipitation and did not include the evaluation of runoff from irrigation. Wells are the main water supply for irrigation in the western half of Kansas. It is further assumed that tailwater recovery systems for handling runoff from irrigation will be built regardless of whether runoff collected from precipitation will be efficiently used for irrigation.

Objectives

The objectives of this study were:

(1) To estimate daily runoff from irrigated land in Western Kansas using actual climatological data

(2) To estimate the amount of runoff stored in tailwater recovery pits of various sizes on a daily basis

(3) To simulate distribution of the stored runoff back onto the land using a continuous pumping system

(4) To determine the amount of runoff recovered by various sizes of systems

(5) To determine the sizes of tailwater recovery pits that would be economically feasible under various conditions of well pumping lift, type of fuel, and fuel price

Procedures

Development of the Model

The continuous watershed simulation model developed by Bean (1976) and modified by Peterson (1977) was adapted to this study. To fulfill the specified purpose of this research, two main revisions were made to the original feedlot model. One revision removed the feedlot portion of the model so that the source of water entering the pit was changed to runoff from precipitation on irrigated land. The other revision was that the management of irrigation for both ground water from the well and runoff collected by the pit took the place of the disposal scheme. Figure 3 is a schematic of the tailwater management model.

Figure 4 shows the modified general algorithm for the tailwater management model. A detailed description of the original feedlot model was provided by Zovne et. al (1977). Peterson (1977) described the expansion of the disposal area from one to multiple plots. In the following description of the tailwater model, emphasis is placed on revisions and additions to Beans's model.

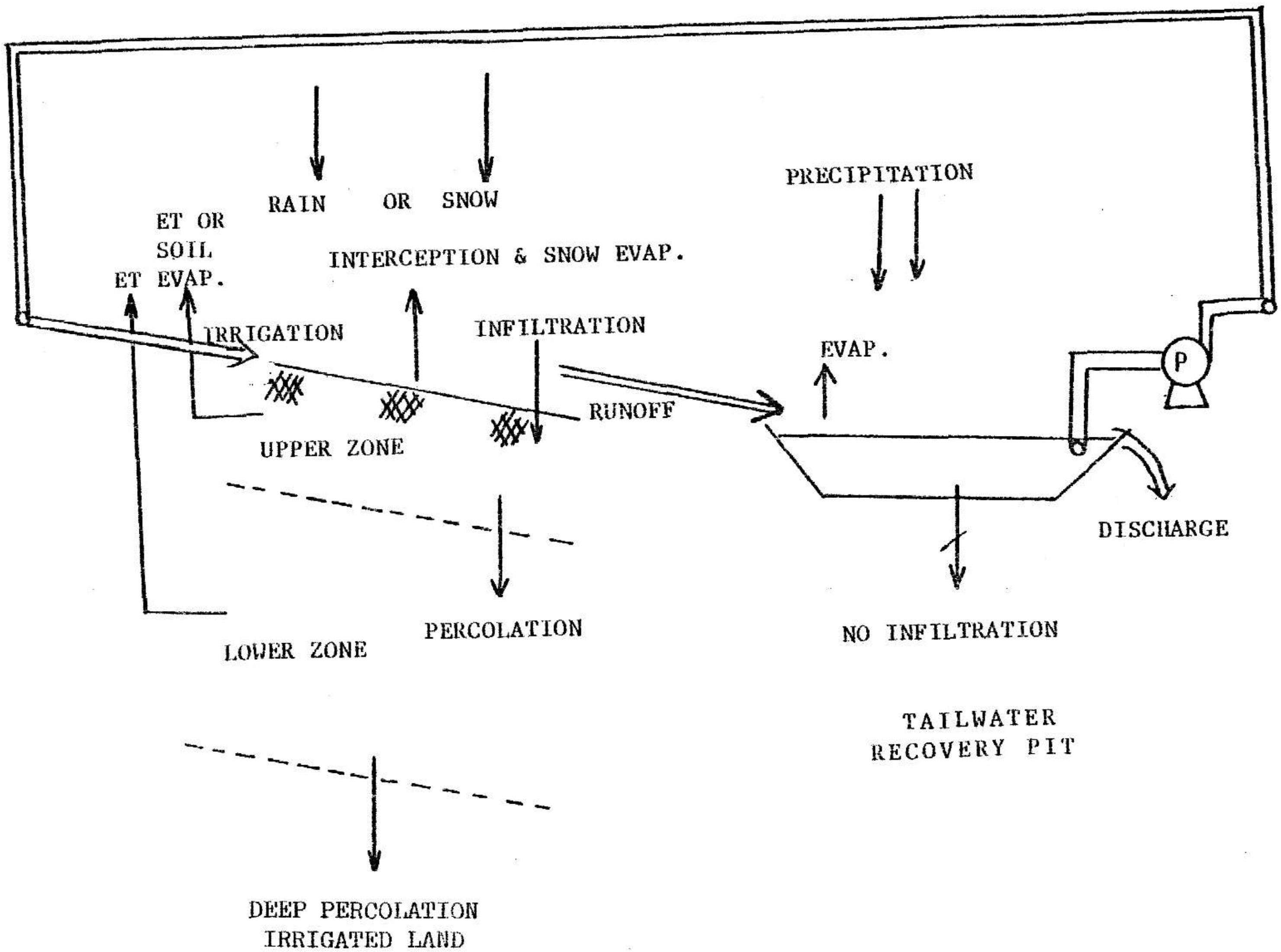

Figure 3. Process Schematic of Tailwater Management Model.

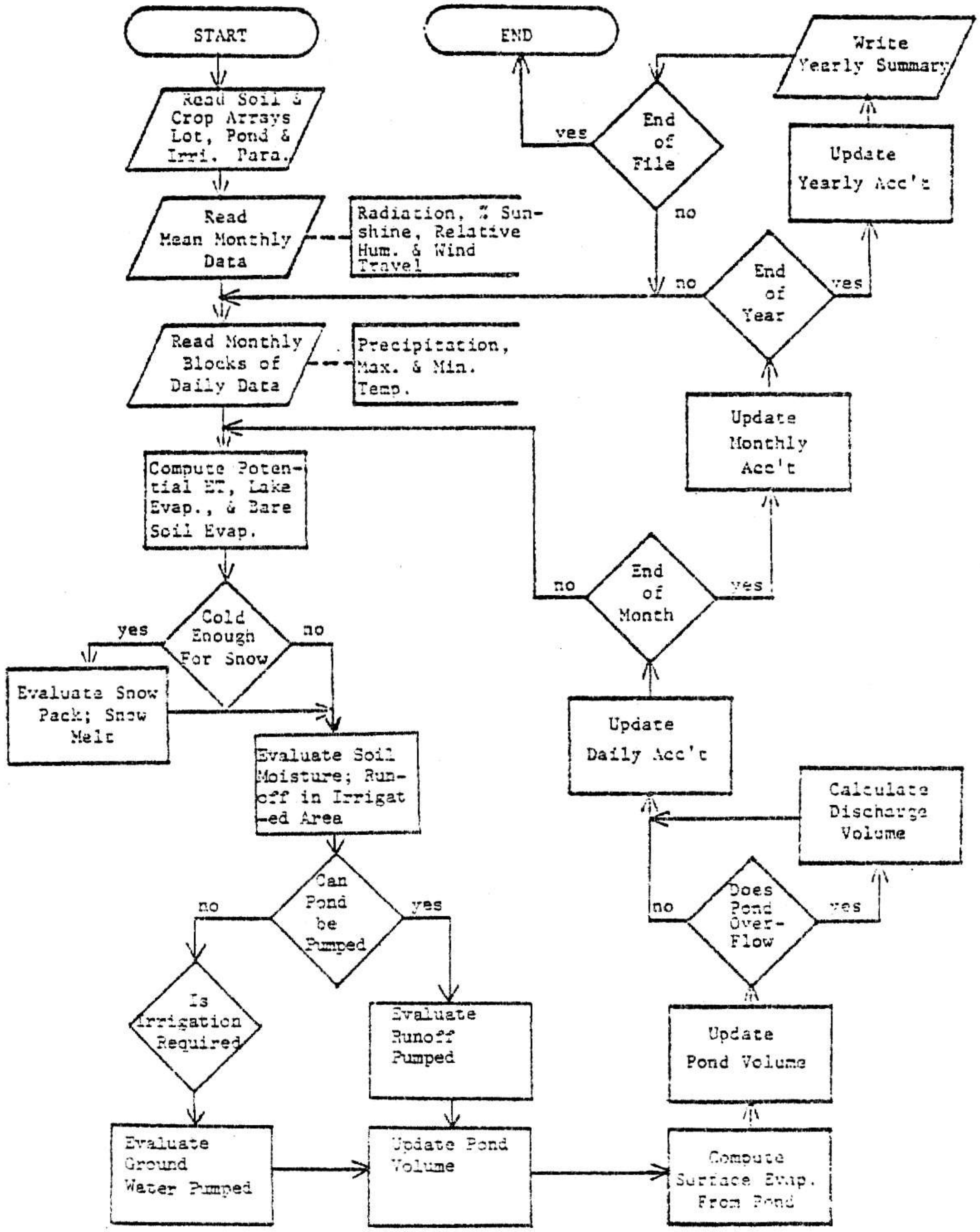

Figure 4. General Algorithm for Tailwater Management Model.

Model Description

The model consists of two parts. One part consists of the hydrological considerations for irrigation areas and the other is the tailwater recovery system. A scheme of irrigation management is also presented.

Hydrological Considerations for Irrigated Area

In this model, potential evapotranspiration (PET) is calculated by the Penman Combination Equation. The advantage of this equation is that it can derive the PET for lake water, bare soil, and vegetated areas by using different coefficients and then directly estimate actual evapotranspiration for each case. The actual evapotranspiration (AET) is obtained by multiplying the Blaney-Criddle factor (K) and the PET. When the soil moisture content is below 0.3 of the maximum available moisture (Θ_{max}), AET becomes:

$$AET = PET \times K \times \frac{\Theta_a}{0.3\Theta_{max}} \tag{5}$$

where

Θ_a = actual available moisture

Evaporation from soil occurs in two stages. When soil is very wet, the soil evaporation rate is equal to PET calculated for bare soil. When soil moisture content reaches a threshold amount U, Stage 2 evaporation (E_s) occurs and is expressed as:

$$E_s = c't^{\frac{1}{2}} - c'(t-1)^{\frac{1}{2}} \tag{6}$$

where

t = time after Stage 1 evaporation

c' = hydraulic coefficient

Values of U and c' depend upon soil type.

The interception storage volume is fixed as 0.1 inch in this model. The soil layer is allowed to take on an equivalent amount of water to raise storage to a level of 0.9 saturation with any excess amount being cascaded to the next successive layer. This continues until all water available for infiltration is stored. As to distribution, the upper soil zone (1 foot) can hold the total field capacity moisture content, while the excess will percolate to the next zone in two days. The lower zone (1 to 4 feet) can hold a moisture content up to 90 percent of field capacity, then the excess becomes deep percolation. In addition, snowmelt is also considered in this model.

The Soil Conservation Service (SCS) method was selected to estimate surface runoff from precipitation. By introducing soil-complex curve number (N), land use, irrigation practice, hydrologic condition, soil group, and antecedent soil content can all be considered.

Antecedent Moisture Conditions (AMC) are classified in three groups. When the soil moisture content is between 0.5

and 0.8 of the available moisture content during the growing season, or between 0.6 and 0.9 of the available moisture content during the dormant season, it is termed as AMC II. If the soil moisture is less than 0.6 or 0.5 of the available moisture content, depending upon the season, it is defined as AMC I; if the soil moisture concent is greater than the upper limit set for the season, it is defined as AMC III. The values of the runoff curve number (N) used in this program for different soils and crops for AMC II are shown in Tables 1 and 2. The curve number for AMC I is:

$$N_I = N \times 0.39e^{-(0.009 \times N)} \tag{7}$$

where

N_I = runoff curve number for AMC I

The curve number for AMC III is:

$$N_{III} = N \times 1.95e^{(-0.00663 \times N)} \tag{8}$$

where

N_{III} = runoff curve number for AMC III

The equation to estimate surface runoff from rainfall is

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{9}$$

Table 1. SCS Runoff Curve Numbers for Condition II.*
(Reproduced from Bean, 1976)

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

*Condition II - During the growing season, soil moisture in the top 1' is between 0.5 and 0.8 of field capacity. For the non-growing season, the range is 0.6 to 0.9 of field capacity.

Table 2. Irrigation Design Class Descriptions for Soil in the Irrigated Area. (Reproduced from Bean, 1976)

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 perm: 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 textured subsoils.
8	2.5'	Moderately deep soils with silt loam, loam or very fine sandy loam surface layers and moderately permeable clay loam, or silt loam subsoils.
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.

Table 2, cont.

Irrigation Soil Class	Profile Depth (ft.)	Soil Class Description
11	5'	Deep soils with loamy 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.

where

Q = direct surface runoff, inches

P = storm rainfall, inches

S = maximum potential difference between rainfall and runoff, inches

S can be obtained by substituting the runoff curve number in the following equation:

$$S = \frac{1000}{N} - 10 \tag{10}$$

Runoff and soil moisture content are calculated for each plot in a daily loop. The program first checks whether irrigation took place during the previous day; if yes, it recalculates the soil moisture content for the irrigated plot which had the lowest soil moisture content for the previous day. The total amount of runoff generated is the summation of the runoff from all of the irrigated plots. A flow chart for calculating this runoff is shown in Figure 5.

Tailwater Recovery System

From the point of view of controlling more runoff and investing less capital in pump facilities, a continuous pumping system was deemed economical, and so has been selected in this study.

The storage volume for a typical tailwater pit is designed to be able to hold the runoff from one day's irrigation. The

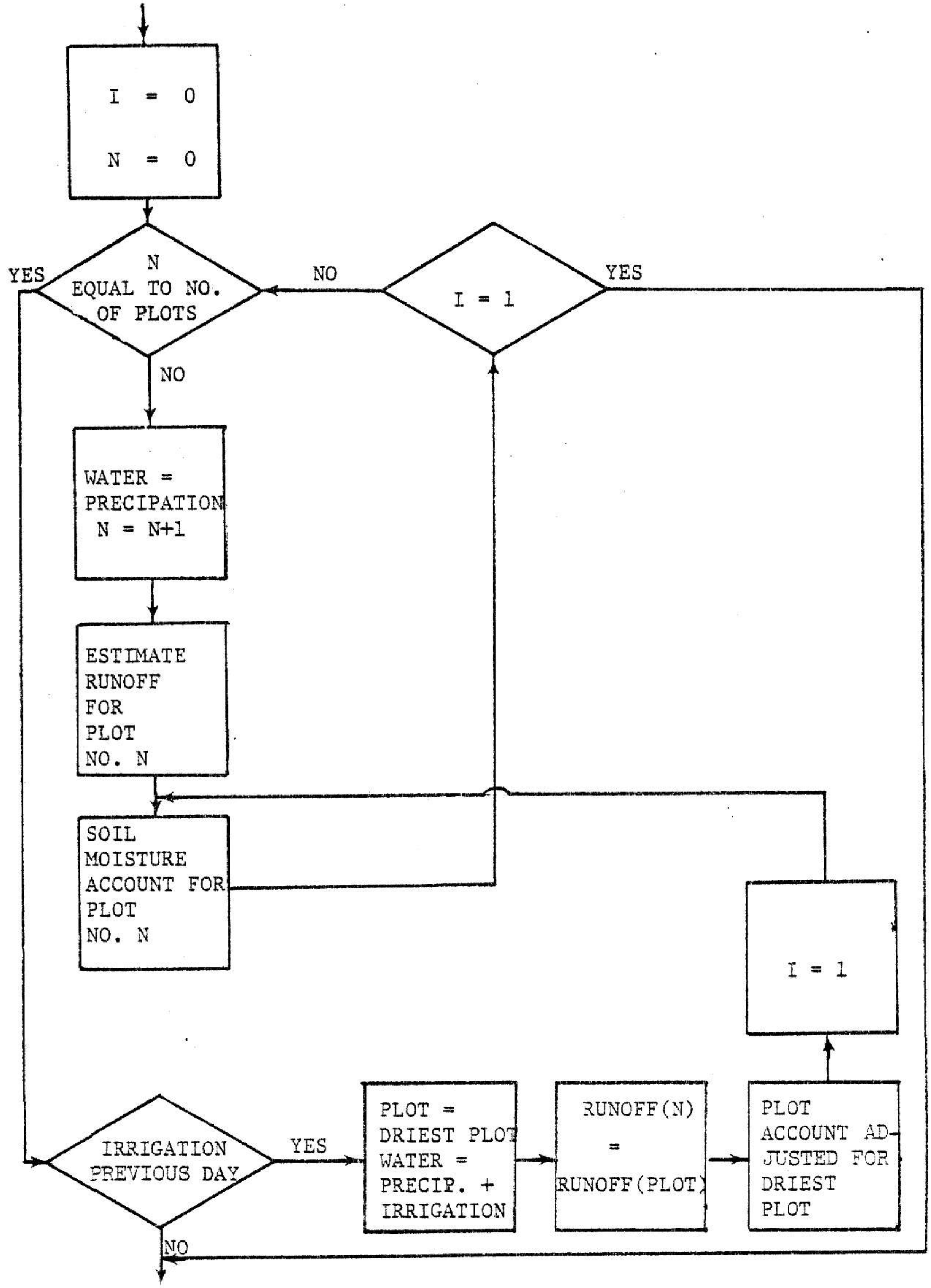

Figure 5. Flow Chart for Calculation of Runoff for Multiple Irrigated Areas.

percentage of runoff is affected by the soil type. Hay and Pope (1977) predicted normally 15 percent runoff will occur for high intake soils (sandy and sandy loams), 20 percent runoff will occur for medium intake soils (fine sandy loams, silt loams, etc.), and 25 percent runoff will occur for heavier soils with slow intake (clay loam, silty clay loam, etc.) and for fields with short lengths.

Table 3 shows the relationship between ground water pumping rate and tailwater pumping rate, and also the storage volumes required. Because it assumes that the tailwater would be pumped back to the upper end of the field, additional runoff would be produced. Therefore, the actual amounts of runoff are 17, 24, and 31 percent of the original water delivered.

Although in this study various sizes of pits are tested to evaluate the percentages of runoff utilized, the pumping rate and pipeline size still remain the same as what are used in normal tailwater recovery systems.

This study assumes that the ground water application efficiency increases to 85 percent by using the tailwater recovery system. Since all the water eventually soaks into the soil, it does not matter whether it comes directly from the well or from recovered runoff. We do not simulate the operation of the tailwater recovery system; we presume that where such a system is used, ground water application efficiency will increase to 85 percent. This assumption

Table 3. Amount of Water Diverted and Runoff Expected from Irrigation for Continuous Pumping System. (Reproduced from Hay and Pope, 1976)

Rate Water Delivered to Field(s)		Volume Delivered in 24 Hours	Pump Size and Storage Volume Required at 15, 20, or 25% Runoff Amounts.*					
			17%		24%		31%	
GPM	Ac In/hr	Acre Inches	GPM	Ac In	GPM	Ac In	GPM	Ac In
450	1.0	24.0	75	4.1	110	5.8	140	7.4
700	1.6	37.3	120	6.3	170	9.0	220	11.6
900	2.0	48.0	150	8.2	220	11.5	280	14.9
1100	2.4	58.7	190	10.0	265	14.1	340	18.2
1350	3.0	72.0	230	12.2	325	17.3	420	22.3
1600	3.6	85.3	270	14.5	385	20.5	500	26.4
1800	4.0	96.0	300	16.3	430	23.0	560	29.8
2000	4.4	106.7	340	18.1	480	25.6	620	33.1
2250	5.0	120.0	380	20.4	540	28.8	700	37.2
2700	6.0	144.0	460	24.5	650	34.6	840	44.6

*Tailwater repumped is also assumed to produce runoff so actual amounts are 17%, 24% and 31% of original water diverted.

implies that the tailwater recovery system is already included in the system. Therefore, whenever this paper mentions the water in the storage facility, it only deals with the surface runoff from precipitation.

Irrigation Management

Before the criteria for irrigation management were established, it was decided that for each irrigation, only one kind of water supply would be used. To determine when and what source of water should be used for irrigation, the following three steps should be checked.

When the soil is not frozen, and the mean daily temperature is greater than 0°C (32°F), there exists the possibility of executing irrigation.

Next, we need to examine whether there is enough water in the pit for one day's pumping, and whether the soil can hold the irrigation water from the pit without exceeding the field capacity of both soil zones. If these two conditions are met, water will be pumped from the pit. Since these criteria allow the pumping of water not only during the growth stage but also during winter, more water can be utilized from the pit.

If water is not pumped from the pit, then ground water will be utilized during the growing season if the soil moisture content is below 50 percent of the available moisture from both zones. A flow chart of the schedule of irrigation management is shown in Figure 6.

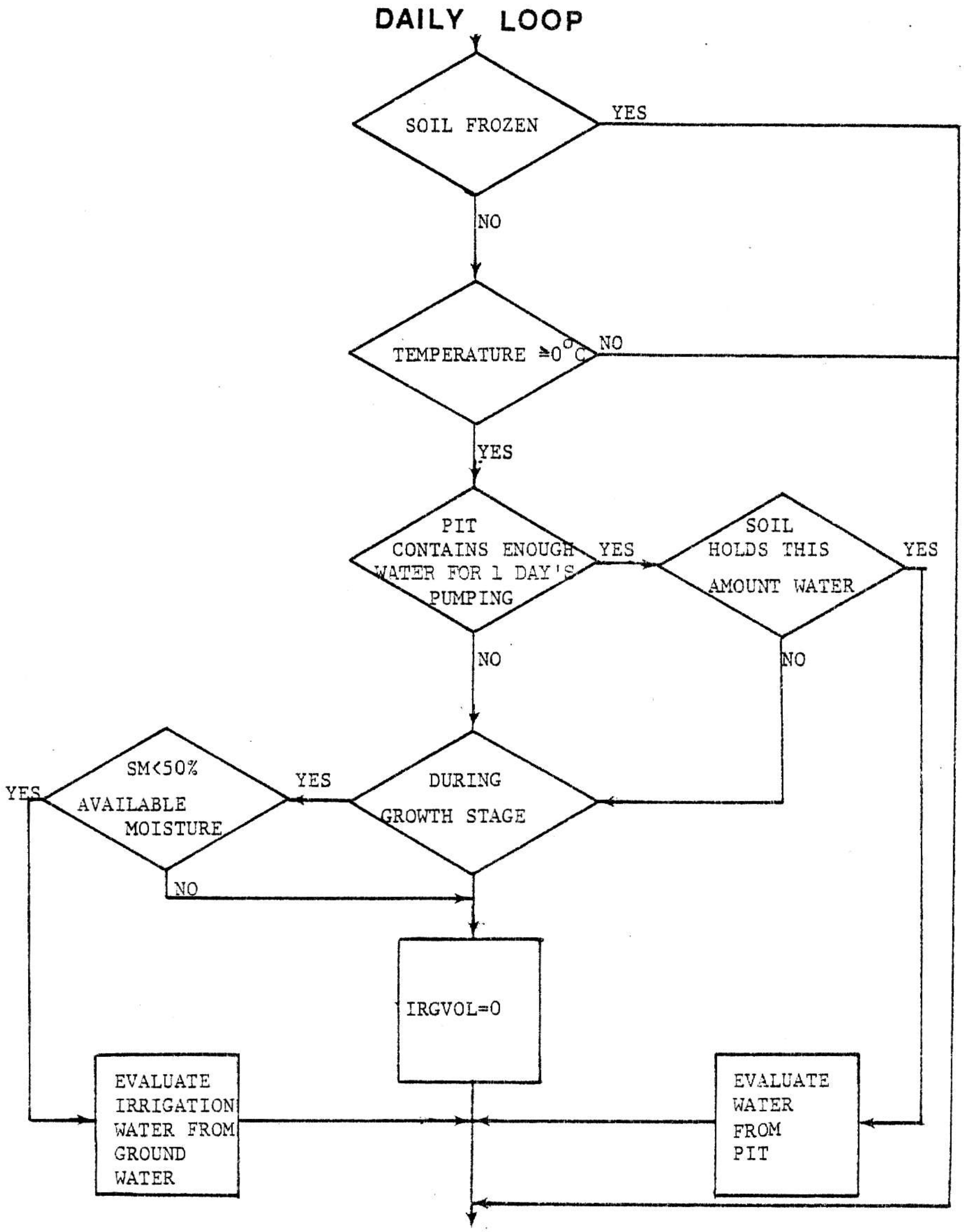

Figure 6. Flow Chart of Tailwater Management Procedure.

Testing of Model

The model was tested for two locations in Kansas, Garden City and Larned, which allowed the comparison of the effects from different climates. Soil Types 3 and 5 were tested. These represent soils with low intake rates and medium intake rates, respectively. The normal field-size irrigated area is 150 acres, excluding the ditches. In order to minimize the investment in irrigation equipment, longer irrigation frequency is desirable. For instance, for corn and Soil Type 5, the peak use rate for corn is approximately 0.3 inch per day. With 9.2 inches of available moisture in the top 4 feet of soil, irrigation when one-half the available moisture remains will give a frequency of 15 days. Assuming 85 percent irrigation efficiency, 5.4 inches of water must be applied to each plot (10 acres) for each irrigation. Therefore, the pump on the well should have a pumping rate of 1018 gallons per minute.

For Soil Type 5 (medium intake rate), it is predicted that 24 percent runoff will occur from irrigation. The storage volume of a normal tailwater recovery system has a holding capacity of one day's runoff. This volume is at least 12.96 acre-inch and is defined as 1V.

The program was run using various sizes of tailwater recovery systems. Considering the loss due to evaporation, slightly larger values were used such as 13.15 acre-inch for one day's runoff of 12.96 acre-inch. The shape of the tailwater recovery pit is as shown in Figure 7. The maximum depth of the pit is 8 feet and the slope of the pit sides is 3:1. The storage volume is determined by the length of the pit sides. The dike around the pit is designed to be 9 feet long at the top, 3:1 side slopes, and three feet above the maximum water level of the pit. For the sake of having a small surface area, a square shaped pit is adopted.

The general equation for the volume of the storage facility is:

$$x = \frac{1}{6} h \ (B_b + 4B_m + B_s) \tag{11}$$

where

x = volume of the storage pit

h = height of the storage pit

B_b = bottom surface area

B_s = top surface area

B_m = area of a plane at $\frac{h}{2}$ above the bottom

By substituting the specified design in this study, Equation (11) takes the following form:

$$x = \frac{8}{6} [L^2 + 4 \ (L + 24)^2 + (L + 48)^2] \tag{12}$$

where

L = length of the bottom, feet

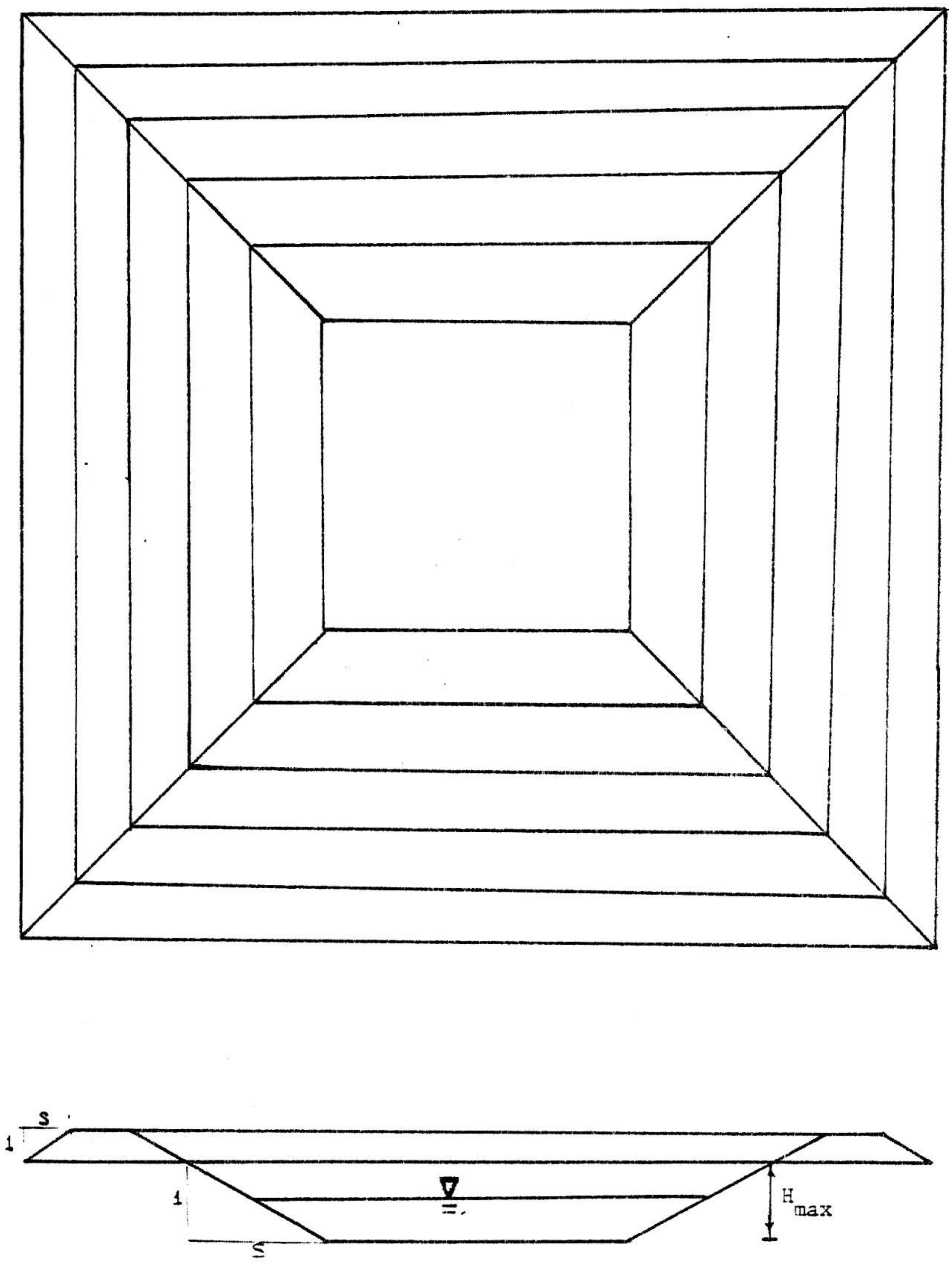

Figure 7. Configuration of Tailwater Recovery Pit.

Equation (12) can be expressed as:

$$L^2 + 48L + (768 - 453.75X) = 0 \quad (13)$$

where

X = volume of the storage pit, acre-inch

Solving Equation (13) for length L gives

$$L = -24 + \sqrt{453.75X - 192} \quad (14)$$

After adding the area of the dike, the total land area required for the pit, and adjacent dikes become:

$$A(X) = (L + 48 + 54)^2 \quad (15)$$

where

A(X) = total land area, square feet

Using Equation (14), the total area expressed as a function of X is:

$$A(X) = 5892 + 453.75X + 156\sqrt{453.75X - 192} \quad (16)$$

Results and Discussion

The model requires daily climatological data as input. Input for Garden City, Colby and Larned in Kansas, available from the Kansas Agricultural Experiment Station Weather Data Library, were used in the model. Initial computer runs indicated that the results for Colby and Garden City were essentially the same. Succeeding analyses were limited to Garden City and Larned.

Runoff Produced

The climatological data used in this study came from a 25-year period (1949-1973). The average annual precipitation at Garden City, Kansas, was 18.61 inches. The average annual runoff estimated from précipitation on irrigated land was 1.55 inches for Soil Type 5 and 2.7 inches for Soil Type 3. At Larned, Kansas, average annual precipitation was 24.35 inches. Runoff of 2.47 inches was produced from precipitation on Soil Type 5, and 4.13 inches of runoff was produced from Soil Type 3.

For Soil Type 5, about 8.3 percent of the precipitation was predicted to become runoff on irrigated land at Garden City, while about 10 percent of the precipitation was predicted to be runoff at Larned. Seven percent more precipitation was predicted to be runoff at both stations for Soil Type 3 than for Soil Type 5. A greater percentage of the precipitation is expected to become runoff as the precipitation increases, and also for the soil with the lower infiltration rate.

When the model was tested with the case of zero irrigation rate and only one irrigation plot, it was equivalent to a dry land area. Table 4 compares the runoff produced from irrigated

Table 4. Comparison of Total Annual Runoff Produced from Irrigated Areas and from Non-Irrigated Areas.

Station and Soil Type	Runoff Produced from Non-Irrigated Land (inches/year)	Runoff Produced from Irrigated Land (inches/year)	Percentage of Runoff Increase Due to Irrigation (%)
Garden City			
Soil Type 5	0.95	1.55	63.0
Garden City			
Soil Type 3	1.66	2.70	62.5
Larned			
Soil Type 5	1.69	2.47	46.2
Larned			
Soil Type 3	2.73	4.13	51.3

areas and non-irrigated areas. More runoff was produced from irrigated land than from non-irrigated land. Because irrigation increases the moisture content of the soil, a higher runoff curve number (N) will be selected.

Runoff Utilized

Table 5 lists the amount and percentage of runoff utilized for various sizes of tailwater recovery systems for different cases. Figures 8 and 9 show the major factor determining the percentage of runoff utilized is the size of the pit. The amount of runoff produced from precipitation is slightly affected by the pit size. A larger pit allows more chances to pump water as a kind of preirrigation during the non-growing season, which raises the soil moisture content and runoff curve number.

Generally speaking, when the pit size increases to 5V, the amount of runoff utilized increases from 25 to 70 percent, but the additional amount of runoff trapped by each succeeding increment of pit size is reduced. This characteristic is indicated by the curves in Figures 10 and 11.

The relationship between pit size and runoff utilized was sought through simple linear, polynomial linear, and non-linear regression models by the process of statistical analysis. It was found that the data fit best on a second-order regression model with a high multiple correlation

Table 5. Annual Runoff Produced and Utilized for Various Pit Sizes for Different Locations and Soil Types.

Pit Size		1V	2V	3V	4V	5V
				Garden City, Soil Type 5		
Pit Volume	acre-inches	13.15	26.61	40.00	53.37	67.15
Runoff Produced	inches	1.55	1.55	1.55	1.55	1.56
Runoff Utilized	inches	0.42	0.69	0.87	1.01	1.12
Runoff Utilized	%	27.00	44.50	56.10	65.20	71.80
				Larned, Soil Type 5		
Pit Volume	acre-inches	13.15	26.61	40.00	53.37	67.15
Runoff Produced	inches	2.46	2.46	2.47	2.48	2.50
Runoff Utilized	inches	0.60	0.98	1.23	1.44	1.60
Runoff Utilized	%	24.40	40.00	49.80	58.00	64.00
				Garden City, Soil Type 3		
Pit Volume	acre-inches	17.49	35.41	53.37	71.83	89.46
Runoff Produced	inches	2.67	2.68	2.70	2.72	2.72
Runoff Utilized	inches	0.70	1.17	1.48	1.70	1.88
Runoff Utilized	%	26.20	43.60	54.80	62.50	69.10
				Larned, Soil Type 3		
Pit Volume	acre-inches	17.49	35.41	53.37	71.83	89.46
Runoff Produced	inches	4.10	4.12	4.13	4.15	4.17
Runoff Utilized	inches	1.07	1.74	2.18	2.53	2.79
Runoff Utilized	%	26.10	42.20	52.80	61.00	66.90

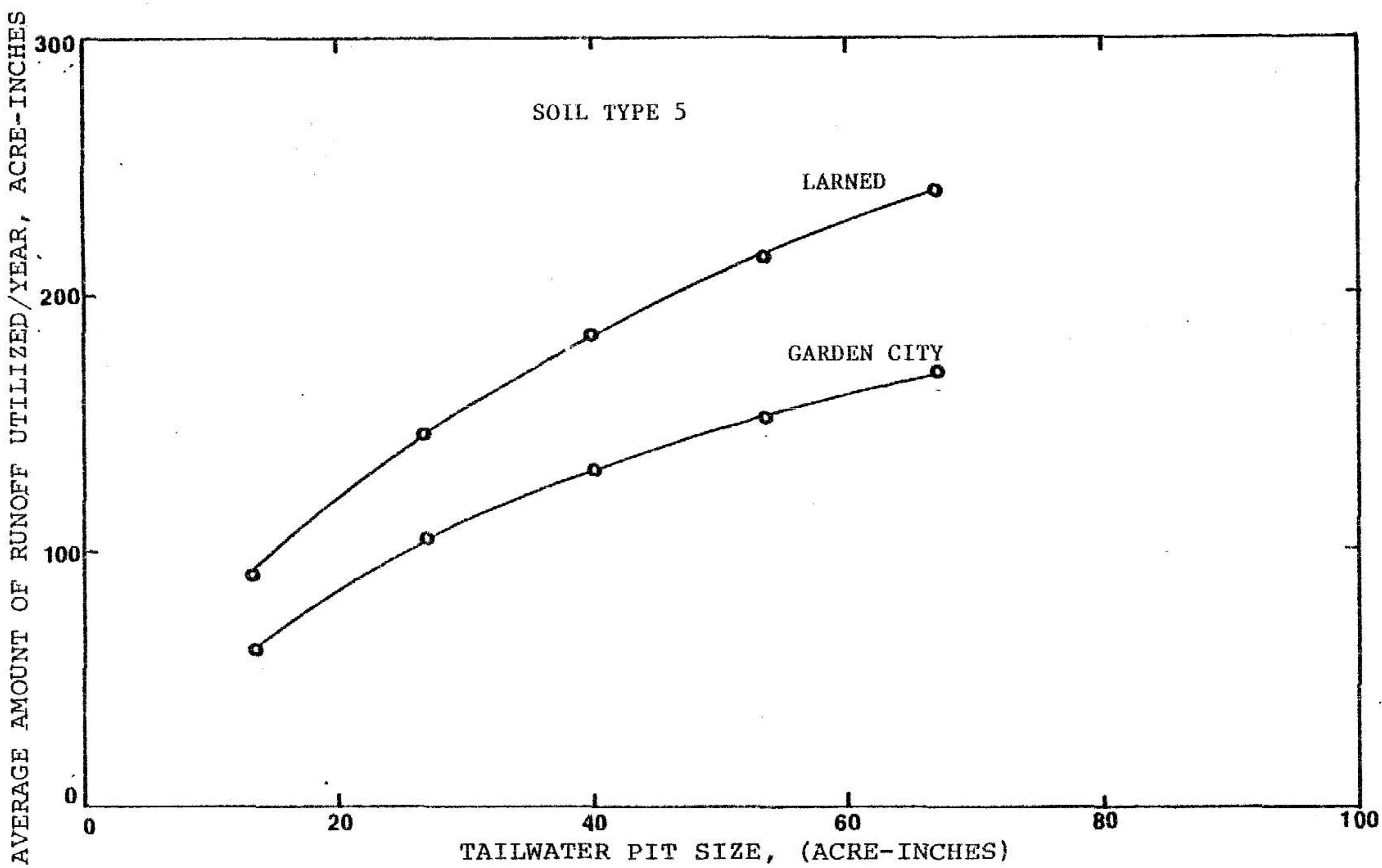

Figure 8. Estimated Amount of Runoff From Precipitation Utilized for Various Tailwater Pit Sizes (Soil Type 5).

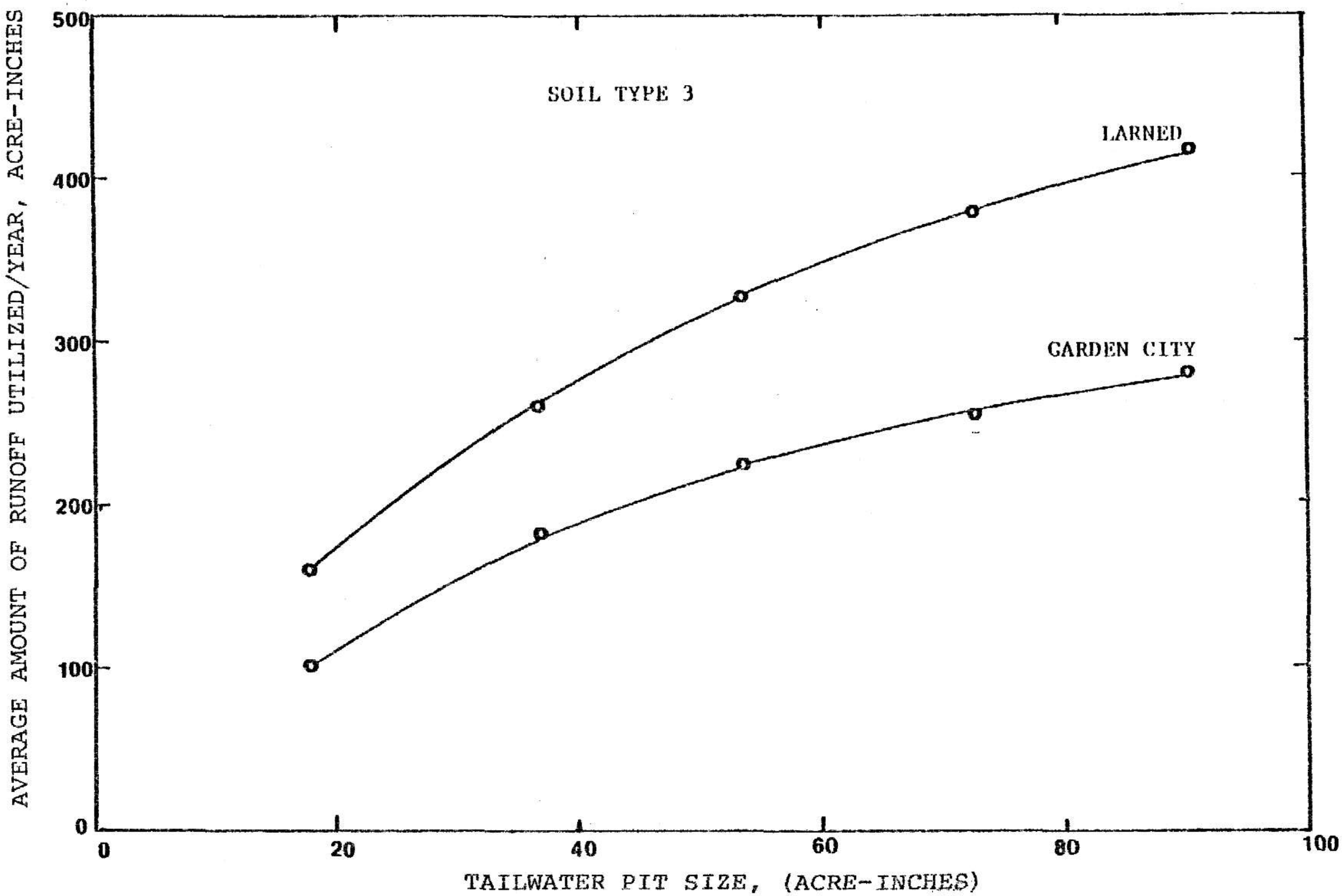

Figure 9. Estimated Amount of Runoff from Precipitation Utilized for Various Tailwater Pit Sizes (Soil Type 3).

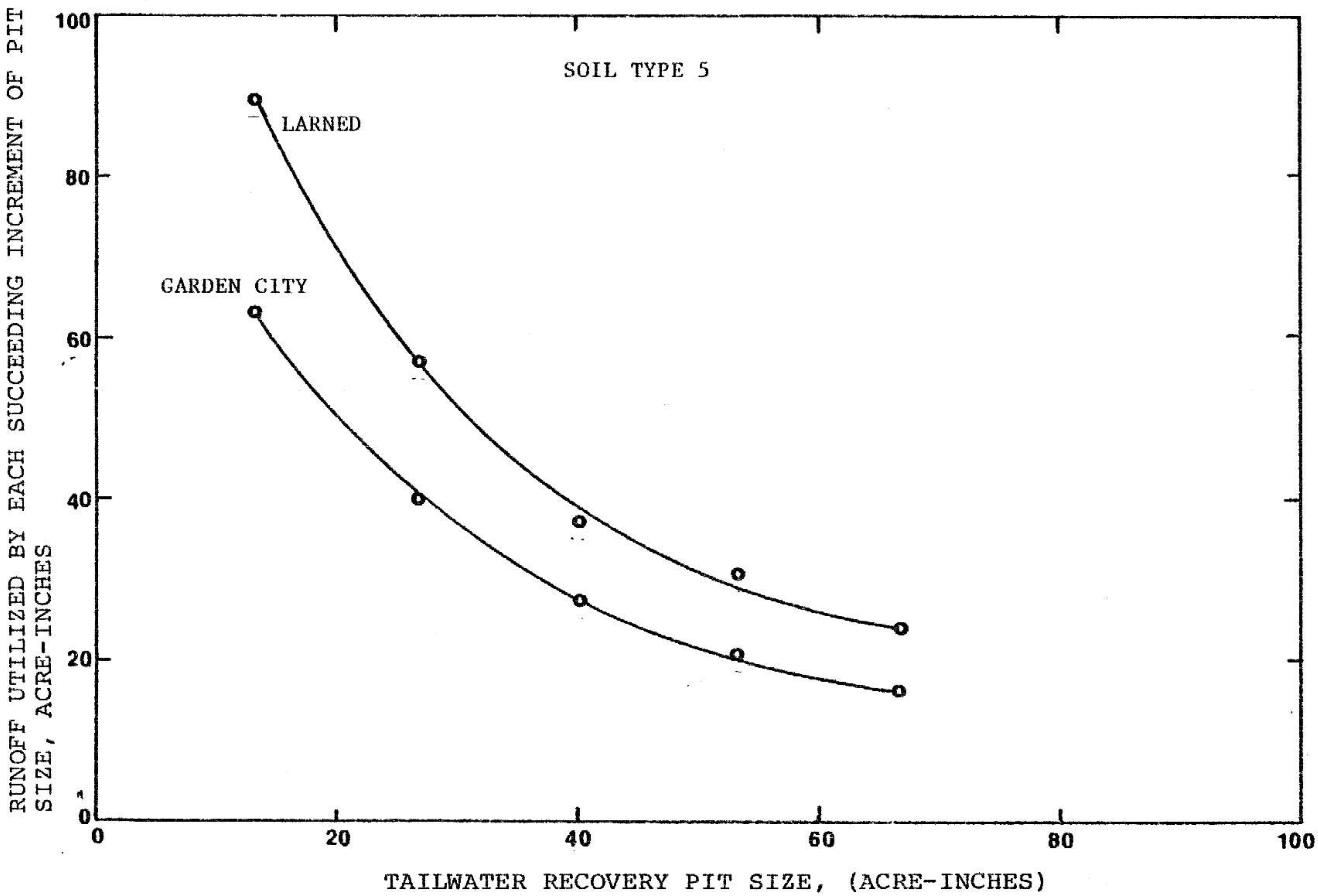

Figure 10. Average Annual Runoff Utilized by Each Succeeding Increment of Pit Size (Soil Type 5).

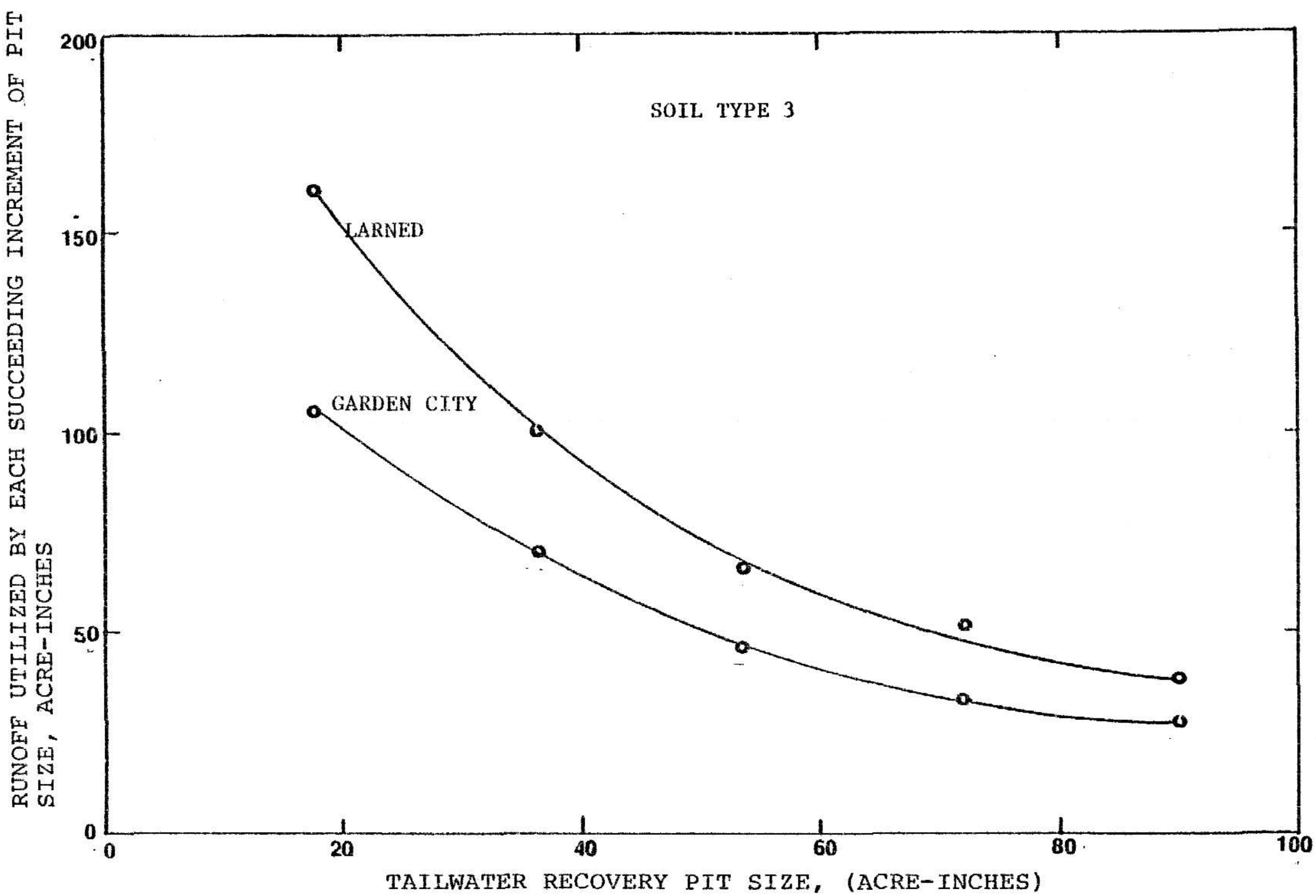

Figure 11. Average Annual Runoff Utilized by Each Succeeding Increment of Pit Size (Soil Type 3).

coefficient (R squared) value and the smallest mean square residual.

The runoff utilized equation was:

$$R_u = B_0 + B_1 X + B_2 X^2 \tag{17}$$

where

R_u = total annual runoff utilized, acre-inches

X = pit volume, acre-inches

B_0, B_1, B_2 = constants, depending upon the climate and soil type

Total Water Use

The total irrigation consists of the water pumped from the pit and from the well, as shown on Table 6. At Garden City, the average annual amount of irrigation water was 25.28 inches for Soil Type 5 and 27.07 inches for Soil Type 3. The amount of runoff utilized was up to 7 percent of the total amount of water used. At Larned, the total average annual water use was 23.16 inches for Soil Type 5 and 25.26 inches for Soil Type 3. The amount of runoff utilized was up to 11 percent of the amount of water needed for full irrigation. Soil Type 3 always produces more runoff than Soil Type 5 because of its lower permeability.

The irrigation requirement was less at Larned than at Garden City. The amount of rainfall at Larned was also higher than at Garden City, supplying more water for the needs of

Table 6. Total Annual Water Use for Various Pit Sizes for Different Locations and Soil Types.

Pit Size		1V	2V	3V	4V	5V
Garden City, Soil Type 5						
Runoff Utilized	inches	0.42	0.69	0.87	1.01	1.12
Ground Water Pumped	inches	24.81	24.59	24.44	24.26	24.23
Total Water Use	inches	25.23	25.28	25.31	25.27	25.35
Garden City, Soil Type 3						
Runoff Utilized	inches	0.70	1.17	1.48	1.70	1.88
Ground Water Pumped	inches	26.10	25.80	25.61	25.52	25.40
Total Water Use	inches	26.80	26.97	27.09	27.22	27.28
Larned, Soil Type 5						
Runoff Utilized	inches	0.60	0.98	1.23	1.44	1.60
Ground Water Pumped	inches	22.29	22.10	21.97	21.84	21.74
Total Water Use	inches	22.89	23.08	23.20	23.28	23.34
Larned, Soil Type 3						
Runoff Utilized	inches	1.07	1.74	2.18	2.53	2.79
Ground Water Pumped	inches	23.84	23.33	23.09	22.93	22.81
Total Water Use	inches	24.91	25.07	25.27	25.46	25.60

the crop. This is also the reason that, although the percentage of runoff from precipitation was greater at Larned than Garden City, the percentage of runoff utilized was less at Larned.

The amount of ground water pumped decreases when the amount of runoff utilized increases. The relationship between water pumped and pit size can be expressed best in a second-order linear regression model similar to Equation (17), expressed as:

$$G_p = B_0 + B_1X + B_2X^2 \tag{18}$$

where

G_p = total annual ground water pumped, acre-inches

The parameters are significant at 5 percent level. These equations are listed in Table 7.

Performance of Tailwater Recovery System

The average annual storage equation for the pit can be expressed as

$$I - 0 = \Delta S \tag{19}$$

where

I = inflow

0 = outflow

S = storage

Table 7. Annual Runoff Utilized and Ground Water Pumped as a Function* of Tail-water Recovery Pit Size (acre-inches).

Location and Soil Type	Runoff Utilized R_u	Ground Water Pumped G_p
Garden City Soil Type 5	$29.938 + 5.048X - 0.029X^2$	$3762.493 - 3.343X + 0.021X^2$
Garden City Soil Type 3	$30.118 + 4.738X - 0.022X^2$	$3961.465 - 3.033X + 0.015X^2$
Larned Soil Type 5	$19.748 + 3.643X - 0.022X^2$	$3372.447 - 2.390X + 0.011X^2$
Larned Soil Type 3	$54.303 + 6.747X - 0.030X^2$	$3652.627 - 5.102X + 0.029X^2$

*The equations only apply to values of X within the restricted range (1V to 5V).

The units are in volume. Inflow comprises the direct precipitation received at the pit surface and runoff produced from irrigated land. Outflow comprises runoff pumped, evaporation, and discharge. Δs is always smaller than one day's pumping capacity of the pit.

A comparison of the last columns in Tables 5 and 8 indicate that the percentage of runoff control was higher than the percentage of runoff utilized. Although the surface area of the pit increases as the size of the pit increases, the additional direct precipitation is smaller than the additional evaporation lost from the pit. Part of the profit is thereby lost when a larger pit is used, and this affect has a tendency to increase as the pit size increases.

Table 9, based on yearly averages, shows that precipitation occurs as a few single events with relatively high intensity, instead of an even distribution of occurrences. This is the reason why the increment of control percentage improves gradually.

Percolation

The percolation for various stations and soil types is shown on Table 10.

About 15 percent of the total water used becomes percolation. Note that the model is set so that the lower zone can hold only 90% of field capacity, but the irrigation rate selected can fill the soil moisture content of both zones to field capacity. The difference between this 10

Table 8. Average Annual Water Account for Tailwater Recovery Pit.

Pit Size	Inflow: Precipitation (acre-in)	Inflow: Runoff (acre-in)	Outflow: Runoff Pumped (acre in)	Outflow: Evaporation (acre-in)	Outflow: Discharge (acre-in)	Inflow Control Percent
Garden City, Soil Type 5						
1V	4.28	232.5	63.0	5.48	167.49	28.9
2V	7.63	232.5	103.5	10.72	125.14	47.6
3V	10.61	232.5	130.5	15.65	96.24	60.1
4V	13.77	232.5	151.5	20.64	74.22	69.1
5V	16.75	234.0	168.0	25.05	56.69	77.0
Garden City, Soil Type 3						
1V	5.40	400.5	105.0	7.60	293.0	27.73
2V	9.68	402.0	175.5	16.21	220.96	46.57
3V	13.77	405.0	222.0	23.52	173.62	58.63
4V	17.87	408.0	255.0	29.62	140.63	66.83
5V	21.59	408.0	282.0	34.94	112.91	73.78
Larned, Soil Type 3						
1V	7.06	615.0	160.5	8.19	453.0	27.40
2V	12.66	618.0	261.0	17.32	351.88	44.13
3V	18.02	619.5	327.0	26.14	284.78	55.40
4V	23.38	622.5	379.5	35.17	232.07	64.20
5V	28.30	625.5	418.5	43.49	192.62	70.67
Larned, Soil Type 5						
1V	5.60	369.0	90.0	6.27	277.13	25.70
2V	9.98	369.0	147.0	12.44	219.56	42.07
3V	13.87	370.5	184.5	19.10	179.51	52.97
4V	18.02	372.0	216.0	25.10	149.62	61.82
5V	21.91	375.0	240.0	30.73	126.02	68.21

Table 9. Yearly Average Performance of Runoff Control Facility.

Size	Yearly Average Inflow Controlled Percent	Years with Discharge	Average Number of Days with Discharge in Years when Discharge Occurred
Garden City, Soil Type 5			
1V	41.56	23	5.52
2V	61.38	21	3.81
3V	72.82	19	3.00
4V	80.43	17	2.71
5V	86.05	15	2.40
Garden City, Soil Type 3			
1V	38.84	23	7.35
2V	58.30	23	4.96
3V	69.59	21	4.00
4V	76.61	19	3.53
5V	82.61	17	3.29
Larned, Soil Type 5			
1V	34.85	25	7.24
2V	53.45	23	4.74
3V	64.10	21	3.52
4V	71.56	20	3.00
5V	76.55	19	2.63
Larned, Soil Type 3			
1V	33.96	25	10.20
2V	52.88	25	6.48
3V	63.91	23	5.26
4V	71.86	22	4.14
5V	77.50	20	3.45

Table 10. Average Annual Percolation for Various Locations and Soil Types (inches).

Pit Size	Garden City Soil Type 5	Garden City Soil Type 3	Larned Soil Type 5	Larned Soil Type 3
1V	3.36	3.73	3.02	3.25
2V	3.43	3.85	3.17	3.36
3V	3.43	3.92	3.25	3.49
4V	3.42	4.00	3.33	3.61
5V	3.47	4.02	3.34	3.70

percent of lower zone at field capacity and one day's actual evapotranspiration will be percolated. However, from the standpoint of leaching requirement, this amount of water is required to keep a favorable salt balance for a permanently irrigated field. This leaching requirement is defined as the fraction of the irrigation water that must be leached through the root zone to control soil salinity at a specified level. For soils where there is no salinity problem, the irrigation rate can be decreased so as to only fill the upper zone to field capacity and the lower zone to 90% of field capacity. Percolation will then be reduced.

Since the irrigation rate used can fill the soil moisture reservoir to field capacity, any rainfall occurring after irrigation is expected to have higher percolation. Also when the total water use increases with the increase of pit size, more percolation is expected to occur.

Other Types of Soils

Comparison of rainfall runoff generated for different soils showed that 70 percent more runoff is generated from Soil Type 3 than Soil Type 5.

Soils are classified into twelve types according to their characteristics as shown in Table 2. As the soil type number decreases the permeability decreases, due to the decrease in quantity of interconnected pores. Therefore, for locations with lower soil type numbers, the feasibility of making larger tailwater recovery pits is expected to improve.

Water Conservation

In Western Kansas, ground water aquifiers are being depleted faster than they are being replenished by local recharge. Proper management of the limited water resources must be made in order to maximize the value of the water and prolong the life of the ground water supply.

The results showed that, in addition to the increase of irrigation efficiency from 70 to 85 percent, a normal size tailwater recovery pit can reduce by 2 to 5 percent the volume of ground water needed for irrigation. For the best and wisest use of water, it might be necessary to enforce the construction of regular tailwater recovery systems in areas of limited water supplies.

The results also showed that, as a maximum estimate, 11 percent of the full irrigation water requirements could be supplied by rainfall runoff (Larned, Soil Type 3). Therefore, for locations with high precipitation and low soil intake rates, strict regulations regarding the sizes of tailwater recovery systems could prolong up to 10 percent of the possible ground water life.

Economic Analysis

Total Cost

In order to determine whether it is economically feasible to build a large tailwater recovery pit to catch and utilize runoff from precipitation, a study of the economic factors is presented.

Normally, annual irrigation costs are separated into fixed costs and operating costs. The total irrigation costs for this system, including the well and the pit, can be stated as:

$$T = (F_W + P_W) + (F_P + F_E + F_A + P_P) \qquad (20)$$

where

T = total costs of irrigation, \$/year

F_W = fixed costs of well, pump, and power unit, \$/year

P_W = operating costs of water pumped from well, \$/year

F_P = fixed costs of pump, power unit, and pipeline for tailwater recovery system, \$/year

F_A = fixed costs of land (surface area of pit), \$/year

F_E = fixed costs of pit excavation, \$/year

P_P = operating costs of water pumped from pit, \$/year

This analysis assumes that the tailwater recovery system is already in place or would be constructed anyway.

The fixed costs F_w for the well, pump, and power unit are independent of the volume of water pumped annually and was designated K_0. Likewise, the fixed costs F_p for the pump, power unit, and pipeline for the tailwater recovery system are independent of the volume of water pumped annually and was designated K_1.

The amount of water pumped from the pit and from the well can be expressed as a function of the storage volume of the pit R_u and G_p. For the consistency of the analysis, the relationship between land area and pit volume is also established in a second-order polynomial model similar to Equation (17) by the Method of Statistical Analysis. The equation obtained was:

$$A_L = 0.300425 + 0.019531X - 0.000033X^2 \qquad (21)$$

$$(\text{with } R^2 = 0.999871)$$

where

A_L = land area, acres

The operating costs for pumping water consist of costs for fuel, lubricating oil and grease, engine repairs, pump repairs and attendance. The fuel consumption costs depend upon the volume of water pumped, pumping lift, type of energy source used, and fuel price. Table 11 shows the unit fuel consumption required (F) for various energy sources.

Table 11. Fuel Consumption by Indicated Irrigation Energy Source. (Reproduced from Dickerson et. al., 1964)

Energy Source	Units Consumed per acre-foot per foot of lift
Diesel	0.12 to 0.16 gallon
LP gas	0.21 to 0.27 gallon
Natural gas	21 to 29 cubic feet
Gasoline	0.61 to 0.20 gallon
Electricity	1.55 to 1.92 kilowatt-hours

The total costs of lubricating oil and grease are assumed as a percentage N of the total fuel consumption costs. All the rest of the terms, including annual engine repairs and annual pump repairs and attendance, are approximated as M$ per acre-foot of water pumped per foot of pumping lift. Therefore, the operating costs of the pit are expressed as:

$$P_p = (R_u+G_p \cdot P) \cdot \frac{1}{12} \cdot H[(1+N)F \cdot C+M] \qquad (22)$$

where

H = total dynamic head of pit, feet

C = unit cost of fuel, \$/gallon or \$/kw-hr

P = percentage of irrigation water recovered, expressed as a decimal

R_u = total annual runoff utilized, acre-inches

G_p = total annual ground water pumped, acre-inches

F = unit fuel consumption required per gallon or ft^3 or kw-hr/acre-foot/foot lift

N = ratio of total costs of lubricating oil and grease to the total fuel consumption costs, expressed as a decimal

M = costs of annual engine repairs and annual pump repairs and attendance, \$/acre-foot of water pumped/foot of pumping lift

It should be kept in mind that the total amount of runoff pumped from the tailwater recovery pit is the sum of the runoff utilized from precipitation, and tailwater recovered from irrigation. The volume of tailwater recovered is one of the following perceptages (P): 17%, 24%, 31% of irrigation water, depending upon soil type.

The operating costs of the well can also be expressed as:

$$P_w = G_p \cdot \frac{1}{12} \cdot h \cdot [(1 + N)F \cdot C + M] \tag{23}$$

where

h = total dynamic head of well, feet

The fixed costs of land and excavation are represented as:

$$F_A = A_L \cdot C_A \cdot I \tag{24}$$

$$F_E = X \cdot 134.4 \cdot C_E \cdot CRF \tag{25}$$

where

C_A = land cost per unit area, $/acre

I = interest, expressed as a decimal

C_E = excavation cost per unit volume, $/yard

CRF = capital recovery factor, expressed as a decimal

134.4 = coefficient for converting acre-inch to cubic yard

By substituting Equations (22), (23), (24), and (25) into Equation (20), we obtain:

$$T = K_0 + K_1 + (R_u + G_p \cdot P) \cdot \frac{1}{12} \cdot H \cdot [(1+N)F \cdot C + M]$$

$$+ G_p \cdot \frac{1}{12} \cdot h \cdot [(1+N)F \cdot C + M] + A_L \cdot C_A \cdot I$$

$$+ X \cdot 134.4 \cdot C_E \cdot CRF$$

$$= \frac{1}{12} \cdot [(1+N)F \cdot C + M] \; [(R_u + G_p \cdot P) \cdot H + G_p \cdot h]$$

$$+ A_L \cdot C_A \cdot I + X \cdot 134.4 \cdot C_E \cdot CRF \qquad (26)$$

Equation (26) is a general form which is applicable to any case occurring in the foreseeable future.

Optimum Tailwater Recovery Pit Size

In order to minimize the irrigation costs, the optimum size of the tailwater recovery system should be determined.

Substituting the general forms $F(X) = B_0 + B_1X + B_2X^2$ of R_u, G_p, A_L into Equation (26), we obtain

$$T = K_0 + K_1 + \frac{1}{12} \cdot [(1+N)F \cdot C + M] [(B_{0R} + B_{1R}X$$

$$+ B_{2R}X^2 + (B_{0G} + B_{1G}X + B_{2G}X^2)P] \cdot H$$

$$+ (B_{0G} + B_{1G}X + B_{2G}X^2) \cdot h + (B_{0A} + B_{1A}X + B_{2A}X^2) \cdot C_A \cdot I$$

$$+ X \cdot 134.4 \cdot C_E \cdot CRF \qquad (27)$$

Differentiating with respect to X and equating to zero:

$$\frac{1}{12} \cdot [(1+N)F \cdot C + M][(B_{1R} + 2B_{2R}X + (B_{1G} + 2B_{2G}X)P] \cdot H$$

$$+ (B_{1G} + 2B_{2G}X) \cdot h + (B_{1A} + 2B_{2A}X) \cdot C_A \cdot I$$

$$+ 134.4 \cdot C_E \cdot CRF = 0 \qquad (28)$$

from which

$$X = -\frac{\frac{1}{12}[(1+N)F \cdot C + M][(B_{1R} + B_{1G}P) \cdot H + B_{1G} \cdot h] + B_{1A} \cdot C_A \cdot I + 134.4 \cdot C_E \cdot CRF}{\frac{1}{12}[(1+N)F \cdot C + M][(2B_{2R} + 2B_{2G}P) \cdot H + 2B_{2G} \cdot h] + 2B_{2A} \cdot C_A \cdot I} \qquad (29)$$

X is the critical point for minimizing total costs, under the condition

$$\frac{d^2T}{dX^2} = \frac{1}{12}[(1+N)F \cdot C + M][(2B_{2R} + 2B_{2G} \cdot P) \cdot H + 2B_{2G} \cdot h] + 2B_{2A} \cdot C_A \cdot I > 0 \qquad (30)$$

The optimum size for any situation can be determined by the above equation. If the optimum size X obtained is smaller than 1V, we still choose 1V because it is the basic size of the tailwater recovery system required to accomplish the reuse of irrigation runoff. If the optimum size obtained is larger than 5V, it needs further verification since these equations were derived within the 5V range. If the optimum size obtained is not an integer, the management of the pump at the pit should be modified by reducing the pumping rate so that the time needed to empty the pit is one or more full days.

For instance, if the optimum size is 1.5V, then a pumping rate of 0.75V per day is chosen in order to use the full design capacity.

The optimum tailwater recovery pit sizes for various fuel types are summarized in Table 12. The construction cost is $0.50 per cubic yard. Land cost is $800 per acre at Garden City and $900 per acre at Larned. The capital recovery factor is based on 8 percent interest and 25 year expected equipment life. We assume that N is 15% of the total fuel, and M is 0.75¢ per acre-foot of water pumped per foot of total dynamic head. Only when fuel type is electricity; N and M are assumed to be 0 and 0.5¢ per acre-foot per foot of total dynamic head respectively.

Table 12 shows that at current fuel prices with the wells up to 275 feet of total dynamic head, it is not economical to use a larger pit to utilize runoff from precipitation. The amount of runoff available to be utilized is limited by the nature of runoff. Even though the energy requirement of pumping runoff from a pit is much less than pumping from a well, the reduction of energy costs is not enough to compensate for the extra costs of excavation and increased land area.

As the price of fuel rises in the future, it might become economical to have a larger pit to utilize rainfall runoff

Table 12. Optimum Pit Sizes (acre-inches) for Various Well Depths, Fuel Types, and Prices.

TDH of Pit = 25 feet

Garden City, Soil Type 5						
Total Dynamic Head of Well	Fuel Price LP Gas $/gallon					
	0.35	0.70	1.05	1.40	1.75	2.10
75 feet	13.15*	13.15*	13.15*	13.15*	13.15*	13.15*
175 feet	13.15*	13.15*	29.45	41.79	49.19	54.12
275 feet	13.15*	34.77	49.40	56.77	61.21	64.18
Total Dynamic Head of Well	Diesel $/gallon					
	0.50	1.00	1.50	2.00	2.50	3.00
75 feet	13.15*	13.15*	13.15*	13.15*	13.15*	13.15*
175 feet	13.15*	13.15*	19.57	34.38	43.27	49.19
275 feet	13.15*	26.05	43.53	52.35	57.66	61.21
Total Dynamic Head of Well	Electricity $/kw-hr					
	0.03	0.06	0.09	0.12	0.15	0.18
75 feet	13.15*	13.15*	13.15*	13.15*	13.15*	13.15*
175 feet	13.15*	13.15*	13.15*	13.15*	23.31	32.64
275 feet	13.15*	13.15*	23.56	37.42	45.75	51.30
Total Dynamic Head of Well	Natural Gas $/MCF					
	1.00	2.00	3.00	4.00	5.00	6.00
75 feet	13.15*	13.15*	13.15*	13.15*	13.15*	13.15*
175 feet	13.15*	13.15*	13.15*	13.15*	13.15*	13.15*
275 feet	13.15*	13.15*	13.15*	13.15*	19.81	29.53

Garden City, Soil Type 3						
Total Dynamic Head of Well	LP Gas $/gallon					
	0.35	0.70	1.05	1.40	1.75	2.10
75 feet	17.49*	17.49*	17.49*	17.49*	17.49*	17.49*
175 feet	17.49*	17.49*	25.04	43.23	54.08	61.30
275 feet	17.49*	34.84	55.81	66.32	72.63	76.84
Total Dynamic Head of Well	Diesel $/gallon					
	0.50	1.00	1.50	2.00	2.50	3.00
75 feet	17.49*	17.49*	17.49*	17.49*	17.49*	17.49*
175 feet	17.49*	17.49*	17.49*	32.33	45.40	54.08
275 feet	17.49*	22.29	47.42	60.01	67.58	72.63
Total Dynamic Head of Well	Electricity $/kw-hr					
	0.03	0.06	0.09	0.12	0.15	0.18
75 feet	17.49*	17.49*	17.49*	17.49*	17.49*	17.49*
175 feet	17.49*	17.49*	17.49*	17.49*	17.49*	29.75
275 feet	17.49*	17.49*	18.69	38.66	50.59	58.53
Total Dynamic Head of Well	Natural Gas $/MCF					
	1.00	2.00	3.00	4.00	5.00	6.00
75 feet	17.49*	17.49*	17.49*	17.49*	17.49*	17.49
175 feet	17.49*	17.49*	17.49*	17.49*	17.49*	17.49
275 feet	17.49*	17.49*	17.49*	17.49*	17.49*	27.31

Table 12 (Continued)

Larned, Soil Type 5						
Total Dynamic	Fuel Price					
Head of		LP Gas	$/gallon			
Well	0.35	0.70	1.05	1.40	1.75	2.10
75 feet	13.15*	13.15*	13.15*	13.15*	13.15*	13.15*
175 feet	13.15*	13.15*	13.15*	23.17	43.56	56.97
275 feet	13.15*	13.15*	47.10	64.56	74.97	81.88
Total Dynamic		Diesel	$/gallon			
Head of Well	0.50	1.00	1.50	2.00	2.50	3.00
75 feet	13.15*	13.15*	13.15*	13.15*	13.15*	13.15*
175 feet	13.15*	13.15*	13.15*	13.15*	27.28	43.56
275 feet	13.15*	13.15*	33.02	54.10	66.65	74.97
Total Dynamic		Electricity	$/kw-hr			
Head of Well	0.03	0.06	0.09	0.12	0.15	0.18
75 feet	13.15*	13.15*	13.15*	13.15*	13.15*	13.15*
175 feet	13.15*	13.15*	13.15*	13.15*	13.15*	13.15*
275 feet	13.15*	13.15*	13.15*	18.22	38.36	51.62
Total Dynamic		Natural	Gas	$/MCF		
Head of Well	1.00	2.00	3.00	4.00	5.00	6.00
75 feet	13.15*	13.15*	13.15*	13.15*	13.15*	13.15*
175 feet	13.15*	13.15*	13.15*	13.15*	13.15*	13.15*
275 feet	13.15*	13.15*	13.15*	13.15*	13.15*	13.15*
Larned, Soil Type 3						
Total Dynamic		LP Gas	$/gallon			
Head of Well	0.35	0.70	1.05	1.40	1.75	2.10
75 feet	17.49*	17.49*	17.49*	17.49*	17.49*	27.16
175 feet	17.49*	31.32	49.26	58.29	63.72	67.35
275 feet	22.86	54.34	65.09	70.51	73.78	75.97
Total Dynamic		Diesel	$/gallon			
Head of Well	0.50	1.00	1.50	2.00	2.50	3.00
75 feet	17.49*	17.49*	17.49*	17.49*	17.49*	17.49*
175 feet	17.49*	20.45	42.04	52.87	59.38	63.72
275 feet	17.49*	47.95	60.77	67.25	71.17	73.78
Total Dynamic		Electricity	$/kw-hr			
Head of Well	0.03	0.06	0.09	0.12	0.15	0.18
75 feet	17.49*	17.49*	17.49*	17.49*	17.49*	17.49*
175 feet	17.49*	17.49*	17.49*	34.52	44.77	51.59
275 feet	17.49*	25.91	46.13	56.29	62.40	66.49
Total Dynamic		Natural	Gas	$/MCF		
Head of Well	1.00	2.00	3.00	4.00	5.00	6.00
75 feet	17.49*	17.49*	17.49*	17.49*	17.49*	17.49*
175 feet	17.49*	17.49*	17.49*	17.49*	17.49*	24.76
275 feet	17.49*	17.49*	17.49*	32.81	43.38	50.50

* Shows that the optimum size is smaller than 1V. 13.15 acre-inches or 17.49 acre-inches, depending on soil type.

(for a given depth of well). The higher the price of fuel, the greater the possibility that it will be economical to construct a pit larger than the normal size.

CONCLUSIONS

The following conclusions are presented from the results of this investigation:

1. The amount of runoff produced from furrow irrigated land is affected by the quantities of precipitation and by the soil type. Due to the higher soil moisture content of irrigated land, about 50 to 60 percent more runoff is predicted for irrigated land than for non-irrigated land.
2. The amount of runoff utilized mainly depends upon the size of the pit. The runoff can be expressed by a second-order polynomial equation for values within the test range. When the volume of the tailwater pit increases to five times the normal pit volume, about 70 percent of the runoff from precipitation can be utilized.
3. Runoff from rainfall usually occurs as an event with a relatively high volume of short duration, rather than one that is evenly distributed in Western Kansas. Therefore, the additional amount of runoff utilized by each succeeding increment of size is reduced.
4. The quantity of ground water supplied decreases when the quantity of runoff pumped from the pit increases. Nevertheless, total water use also increases when

water is pumped from the pit during a non-growing season.

5. According to the irrigation management scheme, percolation accounts for about 15 percent of the total irrigation water used. For a location without a salinity problem, a smaller irrigation application should be used to reduce the amount of percolation.
6. By proper management of normal size tailwater recovery systems, about 25 percent of the runoff from precipitation can be utilized. This additional benefit makes the construction of typical recovery systems attractive.
7. At present, it is not economical to build a larger size pit to utilize runoff from precipitation. If in the future, the price of fuel used, and the total dynamic head of the well rise above a certain level, it might become economical to construct a larger pit to use runoff from precipitation.
8. From the standpoint of conserving water resources and prolonging the life of ground water supplies, strict regulations regarding the size of tailwater recovery systems can be instigated without considering the economic feasibility of a particular system. This depends upon the decisions of the State Legislature and the Division of Water Resources.

SUMMARY

Runoff from precipitation on furrow-irrigated land in Western Kansas is considered as an alternative source of irrigation water, in order to prolong the life of ground water supplies.

A modified watershed simulation model was used to estimate the amount of runoff generated from field-size furrow irrigated areas. The runoff was then routed through various sizes of tailwater recovery pits to determine the amounts of runoff utilized, based on continuous pumping systems. Twenty-five years of continuous records of climatological data were used to simulate the long-time performance of the management and use of this water resource.

The tailwater management model was tested for two locations in Kansas, Garden City and Larned, for both Soil Type 3 and Soil Type 5. The particular crop that was tested was corn. About 10 percent of the annual precipitation is estimated to become runoff from Soil Type 3, and 15 percent is expected to become runoff from Soil Type 5. A greater percentage of precipitation is estimated to become runoff at Larned than at Garden City.

Pit size is the main factor affecting the percentage of runoff utilized. When the storage volume of the pit increases to 5 times the normal tailwater pit size, about 70 percent of

the runoff was utilized. This is up to 10 percent of the total amount needed for full irrigation. However, the additional amount of runoff trapped by each succeeding increment of pit size is reduced, due to the nature of runoff.

The quantity of ground water used decreases as the quantity of runoff utilized increases. Both of these terms can be expressed in a second-order polynomial equation of pit size (within the test range).

The sum of all the costs affecting the use of runoff from precipitation were expressed as a function of pit size. By differentiating this equation, the optimum pit size can be obtained for various conditions. The factors that determine the optimum pit size are the quantity of runoff available to be utilized, pumping lifts of the well and the pit, type of energy used, and energy price.

The results of this study show that it is not economical to build a larger pit to utilize runoff from precipitation on irrigated land at present. If the fuel price and well pumping lift continue to rise in the future it might become economically feasible to construct a larger pit to utilize runoff from precipitation.

SUGGESTIONS FOR FUTURE RESEARCH

The climate of Kansas varies widely from the semi-arid west to the humid east. The amount and percentage of runoff produced from precipitation, which is available for irrigation, is expected to increase from west to east. A similar model is recommended to test the possibility of sizing a larger storage facility to utilize the runoff from precipitation in Eastern and Central Kansas.

It is also suggested to study the effects of various irrigation managements on the tailwater management model. For instance, the application of irrigation water when the root zone soil moisture is greater than 50 percentage of field capacity might be tested. The application of a small irrigation to fill the soil moisture content to a moisture content less than field capacity might also be tried. They are expected to increase the amount of runoff and reduce the amount of percolation.

A study to directly measure the quantity of runoff generated from irrigated land is recommended. Then the results of this model can be verified.

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APPENDIX I

Computer Program Input/Output

Input Data

CROP	number corresponding to a specified crop
HMAX	maximum pit height, feet
INDST	number corresponding to a specified station
IRRATE	depth of irrigation water applied, inches/time
L	pit length, feet
MONEND	month growing season ends
MONST	month growing season starts
NPLOTS	number of separate plots
PSMN	irrigation management level, percentage of field capacity
PSUNS	percentage of sunshine, %
PTLV	percentage of runoff generated from irrigation, %
RA	extra-terretrial solar radiation on a horizontal surface, millimeters of water evaporated/day
RHD	mean relative humidity, %
S	side slope of pit, feet/foot
SOIL	number corresponding to a specified soil
TPAREA	total irrigated area, acres
W	pit width, feet
WIND	mean wind speed at 2 meters above the ground, miles/day
YEND	year the data is ended for the computer test run
YSTART	year the data is started for the computer test run

Output Form

The computer output consists of annual summaries for each simulation year and a final summary for the total period.

An annual summary includes water accounts for both the storage facility and the irrigated area. The water account for runoff storage facility lists the monthly values of precipitation, runoff, amount of runoff pumped, and amount of runoff discharged. Following is a list of water balance for the irrigated area which includes the yearly sum of ground water pumped, interception, deep percolation and actual evapotranspiration. At last, a final summary gives the long term average of the meterologic data, pit operation and irrigated land performance. These provide information on average annual runoff produced, average percentages of runoff utilized and runoff controlled for each size of systems, . . . etc.

APPENDIX II

Computer Printouts for Tailwater Management Model

```
      C       FRCMKSU - TAILWATER RECOVERY SYSTEMS
      C       DEPARTMENT OF AGRICULTURAL ENGINEERING
      C                KANSAS STATE UNIVERSITY
      C                   DECEMBER 1976
      C
0001          INTEGER CROP,FROZE,SOIL,STIND,T,YEAR,YEARS,YEND,YSTART
0002          REAL IA,IAACD,IAET,KCROP,KS,LAKEVP,LKEVPT,L,M,PA,MINVOL
0003          REAL MAXVOL,MR,IRRAFP
0004          INTEGER PREVYR
0005          REAL IRGVOL,IRRATE,IRPERC,IRRNEF,IRAREA,IREPIT
0006          REAL NIA,NOPERC,NRNOF,LZSP,NRNOFT,IPIESS
0007          INTEGER PLOT
0008          DIMENSION T(24),Z(24),AREA(24),IAREA(24,2),EO(24),OE(24)
0009          DIMENSION AETU(24),AETL(24),IAADD(24),IAET(24),ADDIA(24),ETIA(24)
0010          DIMENSION SM(24),SMUZ(24),SMLZ(24),UZSM(24),LZSM(24),ETA2(24),NIA(
             124),NRNOF(24),NOPERC(24),NAMES(8),SMPC(24)
0011          DIMENSION DPERC1(24),DPERC2(24),IA1(24),IA2(24),RNOF1(24),RNOF2(24
             1),ETA1(24)
0012          DIMENSION AMONTH(13),AVLFCL(12),AVLFCU(12),C(12),FCL(12),FCU(12)
0013          DIMENSION KCROP(7,12),NDIM(12),PDACCT(13,8),PREC(31),PSUMS(12)
0014          DIMENSION PWPLZ(12),PWPUZ(12),PA(12),RCM(12,7),RCN(12,7),RIND(12)
0015          DIMENSION SMACCT(13,10,24),SMSATL(12),SMSATU(12),TAVG(31),TMAX(31)
0016          DIMENSION TMIN(31),U(12),WIND(12)
0017          COMPLEX*16 KROP*16(7)/'WHEAT','SORGHUM','CORN','SOY BEANS',
             1      'PASTURE','ALFALFA','FALLOW'/
0018          DATA NAMES/'IRR.','INT.','GW. ','TW. ','RNFF','PERC','AET ','SM  '
             1/
0019          DATA AMONTH/'JAN.','FEB.','MAR.','APR.','MAY ','JUNE','JULY',
             1      'AUG.','SEPT','OCT.','NOV.','DEC.','TOT.'/
0020          DATA AVLFCL/2.6,1.5,2.5,2.4,2.5,2.6,2.4,2.4,2.4,2.2,1.5,1.0/
0021          DATA AVLFCU/2.1,2.9,5.7,2.5,6.7,4.2,6.6,3.3,5.2,4.1,4.1,2.5/
0022          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/
0023          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/
0024          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/
0025          DATA NDIM/31,28,31,30,31,30,31,31,30,31,30,31/
0026          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/
0027          DATA PWPLZ/6.7,6.5,8.5,4.5,7.2,4.9,7.1,3.5,4.0,2.9,2.9,1.8/
0028          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/
0029          DATA SMSATL/11.8,11.5,16.3,8.2,15.8,10.4,15.4,7.7,13.9,13.7,13.2,
             1      12.9/
0030          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/
0031          DATA AET,AETLZ,AETUZ,B2,IRGVOL,DPERC,EXCESS,IA,M,MA,
             1      MR,PACK,PACKPY,PDVOL,PERC,PITVOL,P1,P2,P3,SNCMLT,TDPERC,
             2      TRNOF,I1,I2/24*0.0/
0032          DATA CROP,SOIL/2*0/
0033          DATA POT,SMMAXL,SMUZPR,SMPREV/37.5,2.2,3.25,12.60/
0034          NAMELIST/ALPHA/CORM,E,GROW,PSMN,RCROP,NPLOTS
0035          NAMELIST/BETA/IRRATE,MMAX,IADST,L,NSTART,S,W,YSTART,
             *YEND,PITLV,PCNST,MONCHD
0036          AVAILL=0.0
0037          AVAILU=0.0
0038          UZSMCP=0.0
0039          MM=0
0040          CM=0.0
0041          DSCVOL=0.0
0042          H=0.0
```

```
      IPIDAS=0
      IPPEPC=0.0
      IRRNCI=0.0
      TAILWW=0.0
      PVSUM=0.0
      GWSUM=0.0
      SNOW=0.0
      EVAPLK=0.0
      PREVOS=0.0
      PEAK=0.0
      TPREC=0.0
      WET=0.0
      PRCEFF=0.85
C
C          ***** INPUTS *****
C
C
      READ(5,20) NAME,OF,CITY,AND,STATE
   20 FORMAT(20X,5A4)
      READ(5,40) ((KCROP(I,J),J=1,12),I=1,7)
   40 FORMAT(12F4.2)
      READ(5,60) ((RCN(I,K),K=1,7),I=1,12)
   60 FORMAT(7(F2.0,1X))
C*** READ THE PIT AND IRRIGATION PARAMETERS
      READ(5,ALPHA)
      READ(5,BETA)
      WRITE(6,ALPHA)
      WRITE(6,BETA)
      PREVYR=YSTART
C*** READ THE MONTHLY AVERAGE METEOROLOGICAL DATA
      READ(5,80) (PSUNS(I),RHD(I),RA(I),WIND(I),I=1,12)
   80 FORMAT(2X,F2.2,F7.0,F4.2,F3.1)
      DO 83 I=1,NPLOTS
      READ(5,81) (IAREA(I,J),J=1,2)
   81 FORMAT(2X,I1,2X,I2)
   83 CONTINUE
      READ(5,82) TPAREA
   82 FORMAT(1X,F6.0)
      SHAREA=TPAREA/NPLOTS
      DO 401 I=1,NPLOTS
      AREA(I)=SHAREA
      SOIL=IAREA(I,2)
      CROP=IAREA(I,1)
      IRAREA=AREA(I)
  401 CONTINUE
C
C*** A1,A2,A3,A4,AND A5 ARE COEFFICIENTS USED IN 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)/43560.
C*** PSAREA IS THE DIRECT RECEIVING AREA OF THE FACILITY
      PSAREA=((W+2.*S*HMAX)*(L+2.*S*HMAX))/43560.
      FCTOT=FC(SOIL)+FCL(SOIL)
      IRRAPP=PILV*IRRATE
```

```
0091            SMSTAN=PSMN+(AVLFCU(SOIL)+AVLFCL(SOIL))+PWPUZ(SOIL)+PWPLZ(SOIL)
0092            IWPURA=IRRATE*IRAREA*18.86
          C     18.86 IS THE COEFFICIENT CONVERTS ACRE-IN INTO GALLON PER MINUTE
          C     DURING THE TIME 24 HOURS
0093            DO 85 II=1,NPLOTS
0094            Z(II)=0.0
0095            T(II)=0.0
0096            EC(II)=0.0
0097            OE(II)=0.0
0098            IALT(II)=0.0
0099            IAADD(II)=0.0
0100            SMLZ(II)=9.35
0101            SMUZ(II)=3.25
0102         85 SMPD(II)=SMLZ(II)+SMUZ(II)
0103            YEARS=YEND-YSTART+1
0104            WRITE(6,100) NAME,OF,CITY,AND,STATE,YSTART,YEND,TPAREA,L,W,S,
               1DMAX,VOLMAX,PSAREA,IRAREA,KRCP(CROP),SOIL,IRRATE,PSMN,IWPURA
0105        100 FORMAT('1',10X///////////10X,'STATION:',3X,5A4,10X,I4,'  TO  ',I4,
               1///10X,'TOTAL IRRIGATION AREA',2X,
               2F6.2,'ACRES'////10X,'PIT VARIABLES:'//25X,'(A) BASE DIMENSION- ',
               3F7.2,'  FEET BY ',F7.2,'  FEET'//25X,'(B) SIDE SLOPE--   RUN: RISE
               4 = ',F3.1,' : 1'//25X,'(C) MAXIMUM DEPTH--  ',F5.2,'  FEET'//25X,
               5'(D) MAXIMUM PIT VOLUME-- ',F9.2,' ACRE-INCHES'//25X,'(E) DIRECT R
               6ECEIVING AREA (FOR PRECIPITATION) --  ',F8.2,' ACRES'////10X,
               7'IRRIGATION AREA VARIABLES:'//25X,'(A) IRRIGATION AREA--  ',F6.2,
               8'  ACRES'//25X,'(B) CROP--  ',2A8//25X,'(C) SOIL TYPE--  ',I3,
               9'   (SCS) SOIL TYPES)'//25X,'(D) IRRIGATION RATE-- ',F5.2,
               1' INCHES/DAY ON IRRIGATION DAYS'//25X,'(E) IRRIGATION MANAGEMENT--
               2  IRRIGATION BELOW  ',F5.2,'  AVAILABLE SOIL MOISTURE'//25X,
               3'(F) IRRIGATION WELL PUMPING RATE-- ',I6,' GPM')
          C
          C          ***** ENTER YEARLY LOOP *****
          C
0106            DO 1500 NY=1,YEARS
0107            DO 140 I=1,13
0108            DO 120 J=1,8
0109        120 PDACCT(I,J)=0.0
0110        140 CONTINUE
0111            DO 145 I=1,13
0112            DO 148 J=1,10
0113            DO 149 K=1,NPLOTS
0114        149 SMACCT(I,J,K)=0.0
0115        148 CONTINUE
0116        145 CONTINUE
0117            ANUPRE=0.0
0118            ANUINT=0.0
0119            ANURUN=0.0
0120            ANUPER=0.0
0121            ANLAET=0.0
0122            MAXVOL=0.0
0123            LKEVPT=0.0
0124            PVUSDT=0.0
0125            GWVLTT=0.0
0126            IF(NY.GT.1) MSTART=1
0127            WRITE(6,160)
0128        160 FORMAT('1',46X,'****** ANNUAL SUMMARY ******')
          C
          C          ***** ENTER MONTHLY LOOP *****
```

```
                C
0129                  DO 1200 NM=MSTART,12
                C
                C
0130              180 READ(1,200,END=1520) KAN,STIND,YEAR,MONTH,(PREC(I),I=1,31),
                     1(TMAX(I),I=1,31),(TMIN(I),I=1,31)
0131              200 FORMAT(I2,I4,2I2,31F4.2,62F3.0)
0132                  IF(STIND.NE.INDST) GO TO 180
0133                  IF(YEAR.LT.YSTART-1900) GO TO 180
0134                  IF(YEAR.GT.YEND-1900) GO TO 1520
0135                  IF(MONTH.LT.MSTART.AND.YEAR.EQ.YSTART-1900) GO TO 180
0136                  PVUSD=0.0
0137                  GWVOLT=0.0
0138                  IPITCA=0.0
0139                  NDIM(2)=28
0140                  IF(NM.EQ.2.AND.TMAX(29).LT.900) NDIM(2)=29
0141                  NDAYS=NDIM(NM)
                C
                C        ***** ENTER DAILY LOOP *****
                C
0142                  DO 1240 ND=1,NDAYS
                C
                C***  TAVG IS THE AVERAGE DAILY AIR TEMPERATURE, DEGREE FAHRENHEIT
0143                  TAVG(ND)=(TMAX(ND)+TMIN(ND))/2.0-100.0
                C***  THE FOLLOWING STATEMENTS CORRECT  FOR MISSING DATA ON INPUT TAPE
0144                  IF(TAVG(ND).GT.120) TAVG(ND)=PDT
0145                  IF(PREC(ND).GT.99.97) PREC(ND)=0.0
                C
                C *** CALCULATION OF POTENTIAL EVAPOTRANSPIRATION BY MEANS OF PENMAN COM
                C                                               EQUATION ***
                C
0146                  R=RCROP
                C***  THE FOLLOWING CARD CHECKS FOR SNOW COVER
0147                  IF(PACK.GT.0.1) R=0.70
                C***  THE NEXT TWO CARDS CONVERT TAVG TO ABSOLUTE, DEGREE KELVIN
0148                  CENT=(TAVG(ND)-32.0)*100.0/180.0
0149                  ABST=CENT+273.16
                C***  ES IS THE DAILY CALCULATED SATURATED VAPOR PRESSURE, IN MILLIBARS
0150                  ES=33.9*((0.00738*CENT+0.8072)**8-0.000019*ABS(1.8*CENT+48)
                     1  +0.001368)
0151                  IF(ES.LE.0.0) ES=0.0
                C***  ESA IS THE DAILY CALCULATED ACTUAL VAPOR PRESSURE, IN MILLIBARS
0152                  ESA=ES*RHD(NM)/100.0
                C***  RN IS THE CALCULATED DAILY NET RADIATION, IN MM OF WATER
0153                  RN=(1-R)*RA(NM)*(0.22+0.54*PSUNS(NM))-2.010E-09*ABST**4*
                     1(0.98-0.68-0.036*SQRT(ESA))*(0.1+0.9*PSUNS(NM))
                C***  WINDD IS THE MONTHLY AVERAGE WINDRUN, MILES/DAY AT 2 METERS HEIGHT
0154                  WINDD=(WIND(NM)*24)*0.555
                C***  EA IS THE CONVECTIVE LOSSES, MM WATER
0155                  EA=0.26*(E+0.01*WINDD)*(ES-ESA)
0156                  IF(TAVG(ND)) 240,240,260
0157              240 DELTA=0.0
0158                  GO TO 280
0159              260 DELTA=0.039*TAVG(ND)**0.673
0160              280 GAMMA=1-DELTA
                C***  PET IS THE CALCULATED DAILY POTENTIAL EVAPOTRANSPIRATION, INCHES
0161                  PET=((DELTA*RN)+(GAMMA*EA))/25.4
                C***  CALCULATE LAKE AND BARE SOIL EVAPORATION
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          RNSOIL=RN*((1.0-0.20)/(1.0-R))
          RNLAKE=RN*((1.0-0.05)/(1.0-R))
          PETBS=((DELTA*RNSOIL)+(GAMMA*EA))/25.4
          LAKEVP=((DELTA*RNLAKE)+(GAMMA*EA))/25.4
          PDT=TAVG(ND)
          IF(TAVG(ND).LT.20.0) PET=0.0
          IF(TAVG(ND).LT.20.0) PETBS=0.0
          IF(TAVG(ND).LT.20.0) LAKEVP=0.0
          DO 290 MQ=1,NPLOTS
          IAADD(MQ)=IAET(MQ)-PET
          IF(KCROP(CROP,NM).EQ.0.0)  IAADD(MQ)=IAET(MQ)-PETBS
          IF(IAADD(MQ).GT.0.1) IAADD(MQ)=0.1
          IF(IAADD(MQ).LT.0.0) IAADD(MQ)=0.0
  290 CONTINUE
C
C              ***  CALCULATION OF MOISTURE ADDED TO IRRICATION AREA
C                             DUE TO SNOWMELT ON THE AREA  ***
C
C
          SNOVAP=0.0
          M=0.0
          PRECIP=PREC(ND)
          WATER=PRECIP
          IF(PACK.GT.0.1) SNOVAP=PET
          PACK=PACK-SNOVAP
          IF(TAVG(ND)-32) 300,300,320
  300 IF(PRECIP) 420,420,340
  320 IF(PACK) 460,460,360
  340 PACK=PACK+PRECIP
          WATER=0.0
          GO TO 460
C***  MA IS SNOWMELT DUE TO ATMOSPHERIC CONDITIONS
  360 MA=0.05*(TAVG(ND)-34)
          IF(MA.LT.0.0) MA=0.0
          IF(PACK-MA) 400,400,380
C***  MR IS SNOWMELT DUE TO RAIN
  380 MR=(PRECIP*(TAVG(ND)-32))/144
          M=MR+MA
          IF(PACK-M) 400,420,420
  400 M=PACK
          PACK=0.0
          GO TO 440
  420 PACK=PACK-M
  440 WATER=M+PRECIP
C
C
C          *** EVALUATION OF SOIL MOISTURE AND CALCULATION OF ACTUAL
C                            EVAPOTRANSPIRATION FROM IRRIGATION AREA
C
C
  460 FLOW=IRGVOL
          DO 445 LK=1,NPLOTS
          Z(LK)=T(LK)
          QE(LK)=EC(LK)
          ADDIA(LK)=IAADD(LK)
          ETIA(LK)=IAET(LK)
          UZSM(LK)=SPUZ(LK)
  445 LZSM(LK)=SPLZ(LK)
          LL=0
```

```
      JJ=0
      KKK=0
      RAIN=WATER
      NRNOFI=0.0
  455 NNN=NNN+1
      IF(NNN.GT.NPLCTS) GO TO 961
      IRGVCL=0.0
      JJ=JJ+1
  457 CROP=IAREA(JJ,1)
      SOIL=IAREA(JJ,2)
      IRAREA=AREA(JJ)
      IF(IL.EQ.1) GO TO 640
      IF(RAIN.LE.0.0) GO TC 580
C***  CALCULATE SURFACE RUNOFF VOLUME BY SCS METHOD
      IF(KCROP(CROP,NM).LE.0.0) GC TO 520
      IF(SMUZ(JJ).LT.0.5*AVLFCU(SOIL)+PWPUZ(SOIL)) GC TO 480
      IF(SMUZ(JJ).GT.0.8*AVLFCU(SOIL)+PWPUZ(SOIL)) GC TO 500
      GO TO 540
C***  MODIFY RUNOFF CURVE NUMBER TC CONDITION I ANTECEDENT MOISTURE
  480 RCM(SOIL,CROP)=RCN(SOIL,CROP)*0.39*EXP(0.009*RCN(SOIL,CROP))
      GO TO 560
C***  MODIFY RUNOFF CURVE NUMBER TO CONDITION III ANTECEDENT MOISTURE
  500 RCM(SOIL,CROP)=RCN(SOIL,CROP)*1.95*EXP(-0.00663*RCN(SOIL,CROP))
      GO TO 560
  520 IF(SMUZ(JJ).LT.0.6*AVLFCU(SOIL)+PWPUZ(SOIL)) GC TO 480
      IF(SMUZ(JJ).GT.0.9*AVLFCU(SOIL)+PWPUZ(SOIL)) GC TO 500
  540 RCM(SOIL,CROP)=RCN(SOIL,CROP)
  560 SI=1000.0/RCM(SOIL,CROP)-10.0
      ER=RAIN-0.2*SI
      IF(ER.LT.0.0) GO TO 600
      RNOF=ER**2/(RAIN+0.8*SI)
      GO TO 620
C***  EVALUATE INTERCEPTION STORAGE
  580 RNOF=0.0
      IA=0.0
      GO TO 640
  600 RNOF=0.0
  620 IA=0.1
      IF(IA.GT.RAIN) IA=RAIN
      IF((IA+IAADD(JJ).GE.0.1)) IA=0.1-IAADD(JJ)
C***  EVALUATE PERCOLATION INTO UPPER ZONE
  640 PERC=RAIN-RNOF-IA
      UZEVAP=0.0
C***  CALCULATE PRESENT STORAGE AVAILABLE IN UPPER ZONE
      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 660
      EXCESS=0.0
      GO TO 680
C***  EVALUATE GRAVITATIONAL WATER IN UPPER ZONE
  660 EXCESS=SMUZ(JJ)-FCU(SOIL)
C***  IF THE CROP IS DORMANT OR THE SOIL LIES FALLOW, SOIL
C***  EVAPORATION IS EVALUATED
  680 IF(KCROP(CROP,NM).LE.0.0) GO TO 860
      T(JJ)=0.0
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C***   MODIFY PET BY THE PLANT CONSUMPTIVE USE COEFFICIENT
       AET=KCROP(CROP,NM)*PET
       IF(PET.LE.IAET(JJ)) AET=0.0
C***   CHECK WHETHER SOIL MOISTURE LIMITS AET FROM THE UPPER ZONE
       IF(SMUZ(JJ)-(0.3*(AVLFCU(SOIL))+PWPUZ(SOIL)))700,700,760
C***   CALCUATE AET FROM THE UPPER ZONE WHEN LIMITED BY SOIL MOISTURE
   700 AVAILU=SMUZ(JJ)-PWPUZ(SOIL)
       IF(AVAILU.LE.0.0) AVAILU=0.0
       AETUZ=0.7*AET*(AVAILU/(0.3*AVLFCU(SOIL)))
C***   EVALUATE AVAILABLE WATER IN THE LOWER ZONE
       AVAILL=SMLZ(JJ)-PWPLZ(SOIL)
       IF(AVAILL.LE.0.0) AVAILL=0.0
C***   CHECK WHETHER SOIL MOISTURE LIMITS AET FROM THE LOWER ZONE
       IF(SMLZ(JJ)-(0.3*(AVLFCL(SOIL))+PWPLZ(SOIL))) 720,720,740
C***   CALCUATE AET FROM THE LOWER ZONE WHEN LIMITED BY SOIL MOISTURE
   720 AETLZ=0.3*AET*(AVAILL/(0.3*AVLFCL(SOIL)))
       GO TO 780
   740 AETLZ=AET-AETUZ
       GO TO 780
C***   EVALUATE AET FROM BOTH ZONES UNDER WET CONDITIONS
   760 AETUZ=0.7*AET
       AETLZ=0.3*AET
       AVAILL=SMLZ(JJ)-PWPLZ(SOIL)
       IF(SMLZ(JJ).LE.0.3*(AVLFCL(SOIL))+PWPLZ(SOIL)) GO TO 720
   780 IF(PERC-SMMAXU) 800,820,820
C***   EVALUATE SOIL MOISTURE
   800 SMUZ(JJ)=SMUZ(JJ)+PERC-AETUZ-EXCESS
       SMLZ(JJ)=SMLZ(JJ)-AETLZ+EXCESS
       GO TO 960
   820 SMUZ(JJ)=SMUZ(JJ)+SMMAXU-EXCESS-AETUZ
   830 SMMAXL=0.9*FCL(SOIL)-SMLZ(JJ)
       IF(PERCL+EXCESS-SMMAXL) 840,840,850
   840 SMLZ(JJ)=SMLZ(JJ)+PERCL-AETLZ+EXCESS
       GO TO 960
   850 SMLZ(JJ)=SMLZ(JJ)+SMMAXL-AETLZ
       DPERC=PERCL+EXCESS-SMMAXL
       GO TO 970
C***   CALCULATE EVAPORATION FROM BARE SOIL SURFACE(SEVAP) FOR MONTHS OCT
C***   THROUGH MARCH OR WHEN THE DISPOSAL AREA IS FALLOW
   860 AETUZ=0.0
       AETLZ=0.0
       IF(PACK.GT.0.0) GO TO 920
       IF(SMUZ(JJ).LT.(FCU(SOIL)-U(SOIL))) GO TO 880
       EO(JJ)=FCU(SOIL)-SMUZ(JJ)
       IF(SMUZ(JJ).GE.FCU(SOIL)) EO(JJ)=0.0
C***   CALCULATE STAGE 1 SOIL EVAPORATION
       UZEVAP=PETBS
       EO(JJ)=EO(JJ)+UZEVAP
       IF(EO(JJ).GT.U(SOIL)) UZEVAP=EO(JJ)-U(SOIL)
       T(JJ)=0.0
       GO TO 900
C***   CALCULATE STAGE 2 SOIL EVAPORATION
   880 T(JJ)=T(JJ)+1
       UZEVAP=C(SOIL)*(T(JJ)**0.5)-C(SOIL)*((T(JJ)-1)**0.5)
   900 IF(UZEVAP.GT.(PETBS-IAET(JJ))) UZEVAP=PETBS-IAET(JJ)
       IF(UZEVAP.LT.0.0) UZEVAP=0.0
       IF(SMUZ(JJ)-PWPUZ(SOIL).LT.UZEVAP) UZEVAP=SMUZ(JJ)-PWPUZ(SOIL)
       GO TO 940
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0302         920 UZEVAP=0.0
0303         940 SMUZ(JJ)=SMUZ(JJ)-UZEVAP+PERC-EXCESS
0304             IF(SMUZ(JJ).LE.PWPUZ(SOIL)) SMUZ(JJ)=PWPUZ(SOIL)
0305             GO TO 030
0306         960 IF(SMLZ(JJ).LT.PWPLZ(SOIL)) AETLZ=AETLZ-(PWPLZ(SOIL)-SMLZ(JJ))
0307             IF(SMLZ(JJ).LE.PWPLZ(SOIL)) SMLZ(JJ)=PWPLZ(SOIL)
0308             DPERC=SMLZ(JJ)-0.9*FCL(SOIL)
0309             IF(DPERC.LT.0.0) DPERC=0.0
0310             IF(SMLZ(JJ).GT.0.9*FCL(SOIL)) SMLZ(JJ)=0.9*FCL(SOIL)
0311         970 AETUZ=AETUZ+UZEVAP
            C*** SM IS SOIL THE MOISTURE IN THE GROWING ZONE, IN INCHES
0312             SM(JJ)=SMUZ(JJ)+SMLZ(JJ)
0313             IAET(JJ)=IA+IAACC(JJ)
0314             AETU(JJ)=AETUZ
0315             AETL(JJ)=AETLZ
0316             NOPERC(JJ)=DPERC
0317             NIA(JJ)=IA
0318             NRNOF(JJ)=RNOF
0319             IF(NNN.GT.(NPLOTS+1)) GO TO 998
0320             GO TO 455
0321         981 IRGVOL=FLOW
0322             RAIN=WATER+IRGVOL/IRAREA*PRCEFF
0323             IF(IRGVOL.LE.0.0) GO TO 958
0324             LL=1
0325             JJ=PLOT
0326             RNOF=NRNOF(JJ)
0327             EC(JJ)=OE(JJ)
0328             T(JJ)=Z(JJ)
0329             IAET(JJ)=ET(IA(JJ)
0330             IAADD(JJ)=ACDIA(JJ)
0331             SMUZ(JJ)=UZSM(JJ)
0332             SMLZ(JJ)=LZSM(JJ)
0333             GO TO 457
0334         998 CONTINUE
0335             SMPREV=SMUZ(1)+SMLZ(1)
0336             DO 1253 MT=1,NPLOTS
0337             NRNOFT=NRNOFT+NRNOF(MT)
0338             IF(SM(MT).LE.SMPREV) PLOT=MT
0339             IF(SM(MT).LE.SMPREV) SMPREV=SM(MT)
0340        1253 CONTINUE
            C
            C
            C                              *** EVALUATION OF VOLUME IRRIGATED
            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
0341             GWVOL=0.0
0342             IRFPIT=0.0
0343             THAWED=TAVG(ND)+T1+T2
0344             FREEZE=TAVG(ND)+T1
0345             T2=T1
0346             T1=TAVG(ND)
0347             IF(FREEZE.LT.64.0) FROZE=1
0348             IF(THAWED.GT.114.0) FROZE=0
            C*** WHEN FROZE EQUALS 1 THE SOIL IS CONSIDERED TO BE FROZEN IT IS THAW
            C*** WHEN FROZE EQUALS 0
0349             IF(FROZE.EQ.1) GO TO 2500
            C*** SMUZ IS THE SOIL MOISTURE IN THE TOP 12 INCHES OVER THE DISPOSAL
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      C***  AREA, FC(ISOIL) IS THE FIELD CAPACITY TO UTILIZE PRECIPITATION ON
      C***  THE DISPOSAL AREA.  WE WILL NOT IRRIGATE SHOULD THE SOIL MOISTURE
      C***  BE GREATER THAN THE PERCENTAGE OF FIELD CAPACITY SPECIFIED BY THE
      C***  VARIABLE PSMN.
            IRGVOL=IRRATE*IRAREA
            MINVOL=PITV*IRGVOL
            IF(PITVOL.LE.MINVOL) GO TO 2620
            IF((FCTOT-SMPREV).LE.IRRAFP) GO TO 2500
            IPITCA=IPITCA+1
            IRGVOL=MINVOL
            IRFPIT=IRGVOL
            PITVOL=PITVOL-IRFPIT
            PVUSD=PVUSD+IRFPIT
            GO TO 1120
       2620 IF(MONTH.LT.MONST.OR.MONTH.GT.MONEND) GO TO 2500
            IF(SMPREV.GT.SMSTAN) GO TO 2500
            GWVOL=IRGVOL
            GWVOLT=GWVOLT+GWVOL
            GO TO 1120
       2500 IRGVOL=0.0
            GO TO 1120
      C
      C
      C
      C              *** CALCULATION OF SURFACE AREA AND DETERMINATION OF
      C                                  SURFACE EVAPORATION FROM STORAGE FACIL
      C
      C***  THE FOLLOWING CALCULATION EXPRESSES THE VOLUME OF WATER IN THE
      C***  STORAGE FACILITY IN CUBIC FEET.
       1120 IF(PITVOL.LE.0.0) GO TO 1160
      C
            V=PITVOL*3630
      C*** THE FOLLOWING CALCULATIONS DETERMINE THE SURFACE AREA OF THE STORAG
      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 I
      C***  FRUSTRUM OF A PYRAMID.  INPUT PARAMETERS TO SIZE THE FACILITY ARE
      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 ASSU
      C***  THE POND DOES NOT LEAK.  INPUTS TO THE STORAGE WILL BE RUNOFF AND
      C***  PRECIPITATION.  LOSSES FROM IT INCLUDE EVAPORATION AND DISPOSAL
      C***  VOLUME.  B2 IS THE AREA OF THE SURFACE LIQUID IN SQUARE FEET.
            HAPRX=(PITVOL/VOLMAX)*HMAX
       1140 VC=A1*HAPRX+A2*HAPRX**2+A3*HAPRX**3
            DV=V-VC
            DVDH=A1+A4*HAPRX+A5*HAPRX**2
            H=HAPRX+DV/DVDH
            IF(ABS(H-HAPRX).LT.0.1) GO TO 1160
            HAPRX=H
            GO TO 1140
       1160 IF (H.GT.HMAX) H=HMAX
            B2=(W+2.*S*H)*(L+2.*S*H)
            IF(FROZE.EQ.1) LAKEVP=0.0
            LKEVPT=LKEVPT+LAKEVP
            SEVAP=B2*(LAKEVP/12)
      C***  SEVAP IS THE VOLUME OF WATER EXTRACTED FROM THE STORAGE FACILITY B
      C***  FREE SURFACE EVAPORATION.
            IF((SEVAP/3630).GT.PITVOL) SEVAP=PITVOL*3630
            PITVOL=PITVOL-(SEVAP/3630)
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0384          IF(PITVOL.LE.0.0) PITVOL=0.0
         C
         C*** THE VOLUMES OF CALCULATED RUNOFF FROM THE IRRIGATION AREA AND PRECI
         C***  FALLING ON THE FACILITY ARE ADDED TO THE VOLUME OF WATER IN THE ST
         C***  FACILITY(ACRE-IN).
0385          PITVOL=PITVOL+(PRECIP*PSAREA)+(IRRNUFT*IPAREA/NPLOTS)
         C
         C***  THE VOLUME OF WATER REMAINING AT THE END OF THE DAY IS EXPRESSED
         C***  IN ACRE-IN.
         C
         C
         C***  THE FOLLOWING STATEMENTS DETERMINE WHETHER THE STORAGE FACILITY H
         C***  OVERFLOWED AND IF SO, THE QUANTITY DISCHARGED
0386          DSCHRG=0.0
0387          IF(PITVOL-VOLMAX) 1220,1220,1180
0388     1180 DSCHRG=PITVOL-VOLMAX
0389          DSCVOL=DSCVOL+DSCHRG
0390          PITVOL=VOLMAX
0391          WRITE(6,1200) MM,MD,YEAR,DSCHRG
0392     1200 FORMAT(20X,I2,'/',I2,'/',I2,'  -  DISCHARGE OF',F10.2,' ACRE-IN')
0393          IF(DSCHRG.GE.PEAK) PEAK=DSCHRG
0394          IF(YEAR.GT.PREVYR.OR.CM.LT.1.0) MM=MM+1
0395          PREVYR=YEAR
0396          CM=CM+1.0
         C
         C
0397     1220 CONTINUE
0398          DO 1230 KI=1,NPLOTS
0399          SMACCT(NM,2,KI)=SMACCT(NM,2,KI)+PRECIP
0400          IF(KI.EQ.PLOT) SMACCT(NM,3,KI)=SMACCT(NM,3,KI)+IRGVOL/AREA(KI)
             1*PRCEFF
0401          IF(KI.NE.PLOT) SMACCT(NM,3,KI)=SMACCT(NM,3,KI)+0.0
0402          IF(KI.EQ.PLOT) SMACCT(NM,4,KI)=SMACCT(NM,4,KI)+GWVOL/AREA(KI)
             1*PRCEFF
0403          IF(KI.NE.PLOT) SMACCT(NM,4,KI)=SMACCT(NM,4,KI)+0.0
0404          IF(KI.EQ.PLOT) SMACCT(NM,5,KI)=SMACCT(NM,5,KI)+IRFPIT/AREA(KI)*PRC
             1EFF
0405          IF(KI.NE.PLOT) SMACCT(NM,5,KI)=SMACCT(NM,5,KI)+0.0
0406          SMACCT(NM,6,KI)=SMACCT(NM,6,KI)+NIA(KI)
0407          SMACCT(NM,7,KI)=SMACCT(NM,7,KI)+NRNUF(KI)
0408          SMACCT(NM,8,KI)=SMACCT(NM,8,KI)+NDPERC(KI)
0409          SMACCT(NM,9,KI)=SMACCT(NM,9,KI)+AETU(KI)+AETL(KI)+SNOVAP
0410          SMACCT(NM,10,KI)=SMACCT(NM,10,KI)+SM(KI)-SMPD(KI)
0411     1230 SMPD(KI)=SM(KI)
0412          PDACCT(NM,3)=PDACCT(NM,3)+NRNGFT/NPLOTS*IPAREA
0413          PDACCT(NM,6)=PDACCT(NM,6)+SEVAP/3630
0414          PDACCT(NM,7)=PDACCT(NM,7)+DSCHRG
0415          PDACCT(NM,8)=PDACCT(NM,8)+PITVOL-PDVOL
0416          PDVOL=PITVOL
0417          IF(PITVOL.GT.MAXVOL) MAXVOL=PITVOL
         C
0418     1240 CONTINUE
         C
         C
         C        ***** EXIT DAILY LOOP *****
         C
0419          PDACCT(NM,1)=AMCNTH(NM)
0420          PDACCT(NM,2)=SMACCT(NM,2,1)*PSAREA
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0421              PCACCT(NM,4)=IPTICA
0422              PCACCT(NM,5)=PVUSD
0423              DO 1260 J=2,8
0424         1260 PDACCT(13,J)=PDACCT(13,J)+PDACCT(NM,J)
0425              DO 1270 MP=1,NPLOTS
0426              DO 1265 J=2,10
0427         1265 SMACCT(13,J,MP)=SMACCT(13,J,MP)+SMACCT(NM,J,MP)
0428              SMACCT(NM,1,MP)=AMONTH(NM)
0429         1270 SMACCT(13,1,MP)=AMONTH(13)
0430              PDACCT(13,1)=AMONTH(13)
0431              GWVLTT=GWVLTT+GWVOLT
0432              PVUSDT=PVUSDT+PVUSD
       C
0433         1280 CONTINUE
       C
       C              ***** EXIT MONTHLY LOOP *****
       C
0434              DSNOW=PACK-PACKPY
0435              PACKPY=PACK
0436              PCTW=((PDACCT(13,2)+PDACCT(13,3)-PDACCT(13,7))/
                 1     (PDACCT(13,2)+PDACCT(13,3)))*100.
0437              TAILWW=TAILWW+PCTW
0438              DO 1290 KT=1,NPLOTS
0439              IRRNFF=IRRNFF+SMACCT(13,7,KT)
0440         1290 IRPERC=IRPERC+SMACCT(13,8,KT)
0441              GWSUM=GWSUM+GWVLTT
0442              PVSUM=PVSUM+PVUSDT
0443              IPTDAS=IPTDAS+PDACCT(13,4)
0444              TPREC=TPREC+SMACCT(13,2,1)
0445              IF((YEAR+1900).EQ.VSTART) DRY=SMACCT(13,2,1)
0446              IF(SMACCT(13,2,1).GE.WET) WET=SMACCT(13,2,1)
0447              IF(SMACCT(13,2,1).LE.DRY) DRY=SMACCT(13,2,1)
0448              WRITE(6,1300) YEAR
0449         1300 FORMAT('0',27X,'WATER ACCOUNT FOR RUNOFF STORAGE FACILITY (',
                 1'VOLUME IN ACRE-INCHES)-19',I2//9X,'-----------------------------------
                 2-----------------------------------------------------------------------
                 3---------------'/29X,'INFLOWS',50X,'OUTFLOWS'/17X,'---------------',
                 4---------------',23X,'-----------------------------------------'/
                 59X,'MONTH',3X,'PRECIPITATION',2X,'SURFACE RUNOFF',3X,'NO. PUMPING
                 6 DAYS',3X,'  PUMPED    VOL.',2X,'SURFACE EVAP.',2X,'DISCHARGE',4X,
                 7'CHANGE IN VOL.')
0450              WRITE(6,1320) ((PCACCT(I,K),K=1,8),I=1,13)
0451         1320 FORMAT(10X,A4,4X,F9.2,5X,F9.2,15X,F3.0,9X,F9.2,7X,F9.2,4X,F9.2,6X,
                 1F9.2)
0452              ANUPRE=SMACCT(13,2,1)
0453              DO 1370 JM=1,NPLOTS
0454              ANUINT=ANUINT+SMACCT(13,6,JM)*IRAREA
0455              ANURUN=ANURUN+SMACCT(13,7,JM)*IRAREA
0456              ANUPER=ANUPER+SMACCT(13,8,JM)*IRAREA
0457              ANUAET=ANUAET+SMACCT(13,9,JM)*IRAREA
0458         1370 CONTINUE
0459              WRITE(6,1380) PCTW
0460         1380 FORMAT('0',10X,'PERCENT OF SURFACE RUNOFF CONTROLLED=',F10.2)
0461              WRITE(6,1420) PACK,DSNOW
0462         1420 FORMAT('0',10X,'PACK ON DECEMBER 31 =',F5.2,15X,
                 1'CHANGE IN SNOW STORAGE=',F5.2)
0463              MAXVOL=MAXVOL*100.0/VOLMAX
0464              WRITE(6,1460) MAXVOL
```

```
0465       1460 FORMAT('0',10X,'PERCENT OF MAXIMUM POND VOLUME REQUIRED =',F7.2)
0466            EVAPLK=EVAPLK+LKEVPT
0467            WRITE(6,1480) LKEVPT
0468       1480 FORMAT('0',10X,'ESTIMATED LAKE EVAPORATION, INCHES =',F6.2)
0469            WRITE(6,1485)
0470       1485 FORMAT('0',10X,'ANNUAL ACCOUNT FOR IRRIGATED LAND')
0471            WRITE(6,1515) ANUPRE
0472       1515 FORMAT('0',10X,'PRECIPITATION, INCHES =',F10.2)
0473       1565 FORMAT('0',10X,'GROUND WATER PUMPED, ACRE-INCHES =',F10.2)
0474            WRITE(6,1565) GWVLTT
0475            WRITE(6,1525) ANUINT
0476       1525 FORMAT('0',10X,'INTERCEPTION, ACRE-INCHES =',F10.2)
0477            WRITE(6,1535) ANURUN
0478       1535 FORMAT('0',10X,'SURFACE RUNOFF, ACRE-INCHES =',F10.2)
0479            WRITE(6,1545) ANUPER
0480       1545 FORMAT('0',10X,'DEEP PERCOLATION, ACRE-INCHES =',F10.2)
0481            WRITE(6,1555) ANUAET
0482       1555 FORMAT('0',10X,'ACTUAL EVAPOTRANSPIRATION, ACRE-INCHES =',F10.2)
0483       1500 CONTINUE
          C
          C        ***** EXIT YEARLY LOOP *****
          C
0484       1520 CONTINUE
0485            EVAP=EVAPLK/YEARS
0486            CMNEW=CM
0487            IF(MM.EQ.0)  MM=1
0488            COUNT=CM/MM
0489            IF(COUNT.EQ.0.0) MM=0
0490            IF(CM.EQ.0.0) CM=YEARS
0491            DSCRG=DSCVOL/CM
0492            CM=CMNEW
0493            CONTRL=TAILWW/YEARS
0494            AVGPVL=PVSUM/(YEARS*IPAREA)
0495            AVGGWV=GWSUM/(YEARS*IPAREA)
0496            PERCIR=IPPERL/(YEARS*NPLOTS)
0497            RNFFIR=IRRNFF/(YEARS*NPLOTS)
0498            IPTOSS=IPTEAS/YEARS
0499            APREC=IPREC/YEARS
0500            RANGE=WET-DRY
0501            WRITE(6,1540)
0502       1540 FORMAT('1',47X,'***** FINAL SUMMARY *****')
0503            WRITE(6,1550)
0504       1550 FORMAT('0',10X,'METEOROLOGICAL SUMMARY')
0505            WRITE(6,1560) EVAP
0506       1560 FORMAT('0',25X,'AVERAGE ANNUAL LAKE EVAPORATION=',F6.2,' INCHES')
0507            WRITE(6,1624) APREC
0508       1624 FORMAT('0',25X,'AVERAGE ANNUAL PRECIPITATION=',F6.2,' INCHES')
0509            WRITE(6,1626) RANGE,DRY,WET
0510       1626 FORMAT('0',25X,'PRECIPITATION RANGE=',F6.2,' INCHES   (FROM A LOW
               1OF',F6.2,' INCHES  TO A HIGH OF ',F6.2,' INCHES)')
0511            WRITE(6,1610)
0512       1610 FORMAT('0',10X,'SUMMARY OF PIT OPERATIONS')
0513            WRITE(6,1580) MM
0514       1580 FORMAT('0',25X,'NO. OF YEARS HAVING A DISCHARGE=',I6)
0515            WRITE(6,1600) COUNT
0516       1600 FORMAT('0',25X,'AVERAGE AC. OF DISCHARGES / YEAR HAVING A DISCHARG
               1E=',F6.2)
0517            WRITE(6,1620) DSCRG
```

```
0518      1620 FORMAT('0',25X,'AVERAGE DISCHARGE=',F6.2,1X,'ACRE-INCHES')
0519           WRITE(6,1640) CONTRL
0520      1640 FORMAT('0',25X,'AVERAGE PERCENT OF RAINFALL RUNOFF CONTROLLED=',
              1F6.2)
0521           WRITE(6,1621) CSCVUL
0522      1621 FORMAT('0',25X,'TOTAL DISCHARGE VOLUME=',F9.2,' ACRE-INCHES')
0523           WRITE(6,1622) CM
0524      1622 FORMAT('0',25X,'TOTAL NO. OF DISCHARGES=',F4.0)
0525           WRITE(6,1623) PEAK
0526      1623 FORMAT('0',25X,'MAXIMUM DISCHARGE=',F6.2,' ACRE-INCHES')
0527           WRITE(6,1660) AVGPVL
0528      1660 FORMAT('0',25X,'AVERAGE ANNUAL DEPTH OF RAINFALL RUNOFF APPLIED=',
              1F6.2,' INCHES OVER ENTIRE IRRIGATION AREA')
0529           WRITE(6,1619)
0530      1619 FORMAT('0',10X,'SUMMARY OF IRRIGARION PLOTS')
0531           WRITE(6,1680) RNFFIR
0532      1680 FORMAT('0',25X,'AVERAGE ANNUAL IRRIGATION AREA RUNOFF=',F6.2,2X,'I
              1NCHES')
0533           WRITE(6,1700) PERCIR
0534      1700 FORMAT('0',25X,'AVERAGE ANNUAL IRRIGATION AREA PERCOLATION=',F6.2,
              1' INCHES')
0535           WRITE(6,1720) IPIDSS
0536      1720 FORMAT('0',25X,'AVERAGE ANNUAL NO. OF IRRIGATION DAYS PUMPING FROM
              1 PIT=',F6.1)
0537           WRITE(6,1740) AVGGWV
0538      1740 FORMAT('0',25X,'AVERAGE ANNUAL DEPTH OF GROUNDWATER APPLIED=',F6.2
              1,' INCHES OVER ENTIRE IRRIGATION AREA')
0539           STOP
0540           END
```

STATION: GARDEN CITY,KANSAS 1949 TO 1973

TOTAL IRRIGATION AREA 150.00ACRES

PIT VARIABLES:

(A) BASE DIMENSION- 52.00 FEET BY 52.00 FEET

(B) SIDE SLOPE-- RUN: RISE = 3.0 : 1

(C) MAXIMUM DEPTH-- 8.00 FEET

(D) MAXIMUM PIT VOLUME-- 13.15 ACRE-INCHES

(E) DIRECT RECEIVING AREA (FOR PRECIPITATION) -- 0.23 ACRES

IRRIGATION AREA VARIABLES:

(A) IRRIGATION AREA-- 10.00 ACRES

(B) CROP-- CORN

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

(D) IRRIGATION RATE-- 5.40 INCHES/DAY ON IRRIGATION DAYS

(E) IRRIGATION MANAGEMENT-- IRRIGATION BELOW 0.50 AVAILABLE SOIL MOISTURE

(F) IRRIGATION WELL PUMPING RATE-- 1019 GPM

***** ANNUAL SUMMARY *****

5/23/49	-	DISCHARGE OF	23.38 ACRE-IN
6/ 2/49	-	DISCHARGE OF	41.03 ACRE-IN
6/ 3/49	-	DISCHARGE OF	49.24 ACRE-IN
6/ 4/49	-	DISCHARGE OF	212.91 ACRE-IN
6/ 8/49	-	DISCHARGE OF	3.18 ACRE-IN
6/12/49	-	DISCHARGE OF	57.45 ACRE-IN
7/11/49	-	DISCHARGE OF	3.41 ACRE-IN
8/30/49	-	DISCHARGE OF	33.95 ACRE-IN

WATER ACCOUNT FOR RUNOFF STORAGE FACILITY (VOLUME IN ACRE-INCHES)-1949

	INFLOWS			OUTFLOWS			
MONTH	PRECIPITATION	SURFACE RUNOFF	NO. PUMPING DAYS	PUMPED VOL.	SURFACE EVAP.	DISCHARGE	CHANGE IN VOL.
JAN.	0.20	0.0	0.	0.0	0.0	0.0	0.20
FEB.	0.19	0.0	0.	0.0	0.04	0.0	0.15
MAR.	0.37	0.0	0.	0.0	0.26	0.0	0.11
APR.	0.22	0.0	0.	0.0	0.42	0.0	-0.20
MAY	0.67	36.17	1.	12.96	0.70	23.38	-0.20
JUNE	1.66	403.74	3.	38.88	0.82	363.80	1.90
JULY	0.74	14.38	1.	12.96	0.71	3.41	-1.96
AUG.	0.88	46.88	1.	12.96	0.67	33.95	0.18
SEPT	0.06	0.0	0.	0.0	0.24	0.0	-0.18
OCT.	0.23	0.0	0.	0.0	0.20	0.0	0.03
NOV.	0.0	0.0	0.	0.0	0.03	0.0	-0.03
DEC.	0.01	0.0	0.	0.0	0.01	0.0	0.01
TOT.	5.23	501.17	6.	77.76	4.09	424.55	0.01

PERCENT OF SURFACE RUNOFF CONTROLLED= 16.16

PACK ON DECEMBER 31 = 0.0 CHANGE IN SNOW STORAGE= 0.0

PERCENT OF MAXIMUM POND VOLUME REQUIRED = 100.00

ESTIMATED LAKE EVAPORATION, INCHES = 61.46

ANNUAL ACCOUNT FOR IRRIGATED LAND

PRECIPITATION, INCHES = 22.80

GROUND WATER PUMPED, ACRE-INCHES = 3347.99

INTERCEPTION, ACRE-INCHES = 151.54

SURFACE RUNOFF, ACRE-INCHES = 501.17

DEEP PERCOLATION, ACRE-INCHES = 747.28

ACTUAL EVAPOTRANSPIRATION, ACRE-INCHES = 4645.05

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

METEOROLOGICAL SUMMARY

AVERAGE ANNUAL LAKE EVAPCRATION= 60.83 INCHES

AVERAGE ANNUAL PRECIPITATION= 18.61 INCHES

PRECIPITATION RANGE= 23.93 INCHES (FRCM A LOW OF 5.68 INCHES TO A HIGH OF 29.61 INCHES)

SUMMARY OF PIT OPERATICNS

NO. OF YEARS HAVING A CISCHARGE= 23

AVERAGE NO. OF DISCHARGES / YEAR HAVING A DISCHARGE= 5.52

AVERAGE DISCHARGE= 32.97 ACRE-INCHES

AVERAGE PERCENT CF RAINFALL RUNOFF CCNTRCLLED= 41.56

TOTAL CISCHARGE VOLUME= 4187.41 ACRE-INCHES

TCTAL NC. CF DISCHARGES=127.

MAXIMUM DISCHARGE=212.91 ACRE-INCHES

AVERAGE ANNUAL DEPTH OF RAINFALL RUNOFF APPLIED= 0.42 INCHES OVER ENTIRE IRRIGATICN AREA

SUMMARY OF IRRIGARICN FLCTS

AVERAGE ANNUAL IRRIGATICN AREA RUNOFF= 1.55 INCHES

AVERAGE ANNUAL IRRIGATICN AREA PERCCLATICN= 3.36 INCHES

AVERAGE ANNUAL NC. CF IRRIGATICN DAYS PUMPING FROM PIT= 4.0

AVERAGE ANNUAL DEPTH CF GROUNDWATER APPLIED= 24.81 INCHES OVER ENTIRE IRRIGATION AREA

SIZING TAILWATER RECOVERY SYSTEMS TO UTILIZE RUNOFF FROM PRECIPITATION ON IRRIGATED LANDS

by

LIANG-TSI MAO

B.S., National Taiwan University, 1975

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1977

ABSTRACT

Runoff from precipitation on furrow irrigated land is considered as an alternative source of irrigation water in Western Kansas. This helps to prolong the life of ground water supplies.

A continuous watershed simulation model was used to estimate the amount of runoff generated from field-size furrow irrigated areas. The runoff was then routed through various sizes of tailwater recovery pits to determine the amounts of runoff utilized, based on continuous pumping systems.

According to the results from Garden City and Larned for both Soil Type 3 and Soil Type 5, it was found that a greater percentage of precipitation is expected to become runoff as the quantity of precipitation increases and the permeability of the soil decreases.

Pit size is the main factor affecting the percentage of runoff utilized. When the storage volume of the pit increases to 5 times the normal tailwater recovery pit size, about 70 percent of the runoff from precipitation was utilized. This is up to 10 percent of the total water used for irrigation.

The quantity of ground water used decreases as the quantity of runoff utilized increases. Both of these terms can be expressed in a second-order polynomial equation.

The sum of all the costs affected by the use of runoff from precipitation determines the optimum pit size. The factors which determine the optimum pit size are quantity of runoff available to be utilized, pumping lifts of well and pit, type of fuel used, and fuel price.

The economic analysis showed that at present, it is not economical to build a larger pit to use runoff from precipitation on irrigated land. However, if the fuel price and well pumping lift rise above a certain level, it might become economically feasible to construct a larger pit to utilize runoff from irrigated land in the future.