A CONTINUOUS WATERSHED MODEL FOR EVALUATION AND DESIGN OF FEEDLOT RUNOFF CONTROL SYSTEMS

by

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INTRODUCTION

For the past two decades concern has grown in the U.S. over pollution of this nation's waters. Through the mid-sixties, the federal government formulated various general guidelines and provided financial assistance for antipollution programs, but encouraged the states to act on their own specific problems. As pollution levels increased through the late sixties, the federal government deemed it necessary to reorganize taking a firmer stance on the issue. Because of increased concern and the lack of pollution regulatory programs in some states, the U.S. Congress enacted the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500) in October of 1972. The Act (FWPCA) required the establishment of effluent guidelines for various categories of polluters; one of which was the feedlot industry.

The national water discharge permit program was initiated on December 22, 1972 when regulations were promulgated and published in the Federal Register (24) establishing a new "Part 124 National Pollutant Discharge Elimination System (NPDES)" and "State Elements Necessary for Participation." On May 22, 1973, regulations establishing policies and procedures for issuance of NPDES permits were published (25) as Part 125. Subsequently, the Environmental Protection Agency (EPA) published an amendment (26) to this Part on July 5, 1973. The amendment provided for an expansion of exclusions which eliminated categories of small concentrated animal feeding operations and certain agricultural and silvicultural activities from the permit program. In promulgating the amendment, the EPA contended that while some point sources within the excluded categories should be regulated to be consistent with the purpose of the FWPCA, it would be difficult administratively if not impossible to issue individual permits to all point sources. The Natural Resources Defense Council (NRDC) raised objection to this exercise of the EPA's discretion and challenged it in the Federal District Court of the District of Columbia in the case of "NRDC vs. Train." As a result of the court's ruling on June 10, 1975 to extend the NPDES permit program to include all point sources, the EPA proposed regulations (28) for applying the NPDES permit program to concentrated animal feeding operations on November 20, 1975.

Under the FWPCA, the EPA was charged to define and require the application of best practicable control technology currently available (BPT) to all existing facilities by July 1, 1977. Further, application of best available technology economically achievable (BAT) was required for all new and existing facilities by July, 1983. The effluent guidelines (27) published on February 14, 1974, in essence state "no discharge" except in the case of an extreme rainfall event. For the application of BPT, this event is the 10 year, 24 hour storm, while for application of BAT it is the 25 year, 24 hour storm.

As stated in the regulations of March 18, 1976 (29), feedlots are subject to case-by-case designation for evaluation under the NPDES permit program. This places a heavy burden on regulators who have to evaluate these facilities. A simple continuous watershed model originally developed by Koelliker (9) for evaluation of long term performance of runoff control facilities in Kansas and later used in other states has demonstrated usefulness as a design evaluation tool on the state level. Continuous watershed modeling involves the use of meteorological data as input to a computer program which simulates actual conditions occurring over a period of several years. Accordingly, a more complex computerized model which can appraise various management schemes of land disposal and evaporation facilities at any location could be of great use to regulators for permit evaluation. Additionally, a model of this nature could be a valuable aid for both designers and enforcement agencies. The following describes such a model.

THE MODEL

The model evolved through selection of components from three different classes of existing models. These were combined to function simultaneously as one model. The first component is a model to generate runoff from the feedlot surface. The second is a storage facility model which accounts for pond level fluctuations in response to feedlot runoff inputs and irrigation disposal outputs. The third is a soil-moisture accounting model which enables the monitoring of conditions and the testing of disposal alternatives in the disposal area. Combined, these components provide a means to view interactions of various irrigation management schemes with daily meteorological factors.

A review of the existing models from which these components were taken clearly indicated the importance of establishing an accurate and flexible means to compute evaporation and evapotranspiration rates. Various methods for calculating daily evaporation and evapotranspiration were evaluated. The method used was selected primarily for its virtue of versatility in order to fulfill the requirements of any component of the model.

Throughout the evaluation and testing process emphasis was placed upon selection of physically based parameters while attempting to minimize inputs required. The ultimate goal was the development of a complete model from which any function could be analyzed in realistic physical terms which would be readily adaptible to any geographic and climatic providence in the U.S. Achieving a realistic approach requires logical sequencing of operations. The general algorithm of the model is shown in Figure 1. The sequence of operations is an attempt to model the actual stream of events following a rainfall on the feedlot.

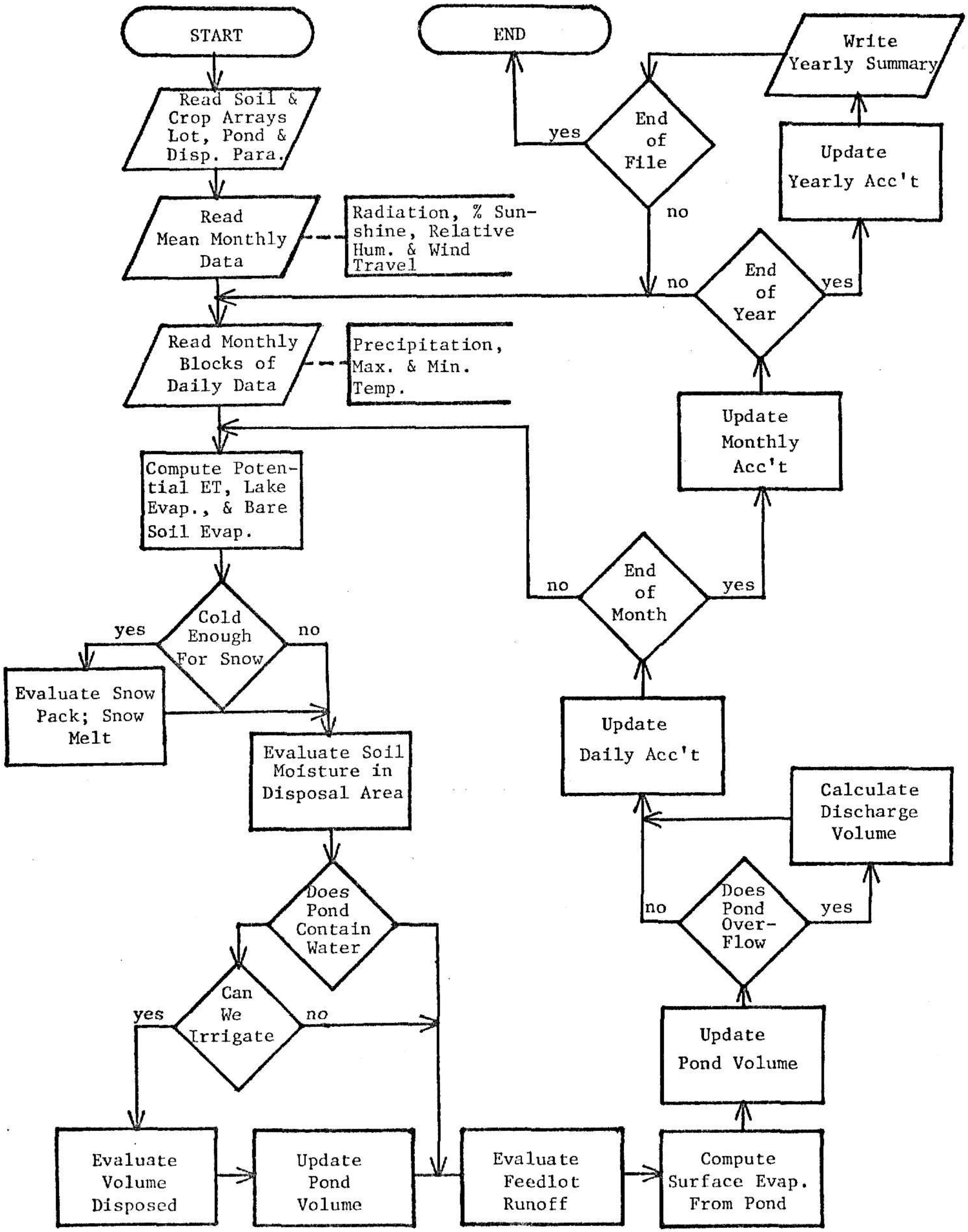
POTENTIAL EVAPOTRANSPIRATION

A number of temperature, radiation, humidity and combination methods for estimating potential evapotranspiration have been developed. The model requires a method which can be calibrated for use throughout the U.S. The method must not only give values which reflect differences in evaporation rates from the pond, bare soil, and vegetated disposal areas, but must also be applicable to the different climatic provinces of the country. In a recent study (2) fifteen methods were tested on four locations in Wyoming, Colorado, and Nevada. The Penman Combination method was ranked in the top five methods for estimating evapotranspiration. When calibrated and tested for Lake Hefner, Oklahoma (10), Kansas (34), Idaho and California (6), the Penman method produced reasonable results at all locations. The particular advantage of the method is its ability to estimate natural evaporation from water, bare soil, and vegetated areas. The original development is described by Penman (17) and an adaption of the method applied to irrigation scheduling is described by Jensen (6).

The method is a combination of the energy budget and mass transfer methods taking the form,

$$PET = \frac{\Delta}{\Delta + \gamma} (Rn - G) + \frac{\gamma}{\Delta + \gamma} (EA) \qquad (1)$$

FIGURE 1 - General Algorithm for Model



where PET is the potential evapotranspiration, G is the soil heat flux, Rn is the daily heat budget at the surface, Δ is the slope of the saturation vapor pressure-temperature curve, γ is the psychrometric constant, and EA is a function of wind speed and humidity.

The soil heat flux (G) is a result of rapid changes in air temperature. During the summer months when day to day variation in temperature and radiation are not great, soil heat flux is small and can be neglected. Evapotranspiration is inhibited during the winter months and the effect of this term on ET is small. For these reasons, G can be neglected for purposes of this model.

The terms $(\frac{\Delta}{\Delta + \gamma})$ and $(\frac{\gamma}{\Delta + \gamma})$ are mean air temperature weighting factors having a sum equal to 1.0. As reported (34), they can be calculated by

$$\frac{\Delta}{\Delta + \gamma} = 0.039\ (Ta)^{0.673} \quad \text{------------------------------} \quad (2)$$

$$(\frac{\gamma}{\Delta + \gamma}) = 1.0 - \frac{\Delta}{\Delta + \gamma} \quad \text{------------------------------} \quad (3)$$

to avoid the inconvenience of data tables and interpolation routines.

The heat budget term is developed in Gray (4, pp. 3.1-3.50) as follows:

$$Rn = (1.0 - r)\ Rsi - Rb \quad \text{------------------------------} \quad (4)$$

where Rsi is the total solar radiation incident to a water surface and

$$Rsi = Ra(a + b \times PSUNS) \quad \text{------------------------------} \quad (4a)$$

Then,

$$Rn = (1 - r)\ Ra\ (a + b \times PSUNS) \quad \text{----------------------} \quad (5)$$

where r is the mean daily shortwave reflectance or albedo, Ra is the extra-terrestrial solar radiation on a horizontal surface, PSUNS is the percentage of possible sunshine, a and b are geographical constants, and Rb is the actual outgoing longwave radiation, where

$$Rb = Pe(0.98 - E)(0.1 + 0.9(PSUNS)) \text{ ------------------- } (6)$$

and,

$$Pe = \sigma(ABST)^4/58.1 \text{ ------------------------------------ } (7)$$

where ABST is the absolute temperature, σ is the Stefan-Boltzmann constant, E is the emissivity, and according to Brunt,

$$E = c + d\sqrt{ESA} \text{ --- } (7a)$$

where ESA is the actual vapor pressure of the air, and

$$ESA = ES \times RHD \text{ -- } (8)$$

where RHD is the mean relative humidity, c and d are geographical constants, and according to Linsley (14, p. 35),

$$ES = 33.9[(0.00738T+0.8072)^8-0.000019\left|1.8Ta+48\right|+0.001316] \text{ --- } (9)$$

where ES is the saturation pressure of air at the mean daily air temperature, and Ta is the mean daily air temperature.

The aerodynamic term in Eq. (1) is derived as follows:

$$EA = f(u)(ES - ESA) \text{ ------------------------------------ } (10)$$

and

$$f(u) = 0.26 \ (e + 0.01 \ WVD) \text{ ------------------------------ } (11)$$

where f(u) is a function of wind speed and

$$WVD = W(\log 6.6/\log h) \text{ ---------------------------------- } (11b)$$

where WVD is the mean wind velocity at 2 meters above the ground, W is the measured wind velocity, and h is the height above the ground at which the wind is measured.

Constants a, b, c and d in Eqns. (4a) and (7a) are listed by Gray (4, 3.9 & 3.19) for various locations. In Eq. (11) the constant e has a major effect on accuracy of the equation. However, e may be determined experimentally by setting the reflectance coefficient (r) equal to 0.05 (the albedo of a water surface) and adjusting the e value until the calculated PET equals mean annual lake evaporation for the location.

The complete, calibrated Penman Combination equation for Topeka, Kansas is

$$PET = 0.039Ta^{0.673}[(1-r)Ra(0.22+0.54PSUNS)-2.010\times10^{-9}(0.98-0.68 - 0.036\sqrt{ESxRHD})(0.1+0.9PSUNS)]+(1-0.39Ta^{0.673}) \times 0.26(0.5+0.01WVD)(ES-ESxRHD) \qquad (12)$$

where a = 0.22, b = 0.54, c = 0.68, d = 0.036 and e = 0.5.

While an input value of r = 0.05 results in a potential equivalent to evaporation from a free water surface, the reflectance coefficients for green crops vary from 0.20 to 0.25 (4, p. 3.10). For this model, r = 0.23 will generally be used to calculate PET from the cropped disposal area while r = 0.20 will be used to calculate the potential evaporation rate from bare soil.

The remaining inputs to the Penman equation are solar radiation (Ra), relative humidity (RHD), wind travel (WVD), percent sunshine (PSUNS) and mean daily temperature (Ta). Although the Penman equation was determined to be the best available method for use in this model, it has the disadvantage of requiring these daily inputs which are not readily available at all locations. In an attempt to sharply reduce model input requirements, Anschutz (personal communication) conducted a study to determine the effects of using mean monthly values of mean daily humidity, wind travel, solar radiation and percent sunshine. These means are readily available from all first order weather stations in the U.S. Using a differential t-test daily PET's calculated with daily inputs tested on a monthly basis were statistically different at the 95% confidence level from daily PET's based on monthly averages for five out of twelve months over a 10-year period. When the PET's were blocked and tested in five-day intervals, there were only two out of twelve months in which the two methods were statistically different at the 95% level. More importantly, when the mean monthly values were incorporated as inputs to the Kansas Watershed Model (34), an agricultural watershed model previously using daily inputs, no statistically significant differences were noted in daily streamflows. Even with the use of monthly averages, there are notable daily fluctuations in PET as a result of the variability of daily mean temperatures. Although these tests are indicative rather than conclusive, they represent sufficient evidence and justification for using monthly averages in this model. The increase in mobility and decrease of input data more than compensate for a slight decrease in daily accuracy.

WATER MOVEMENT WITHIN THE DISPOSAL AREA

The disposal area can be conceived as a soil-water reservoir which is recharged by precipitation and irrigation waters and depleted by evapotranspiration. Most annual row crops and grasses develop their root zone in the upper 120 cm. (4 ft.) of soil. Since soil water is extracted through the plant roots, most evapotranspiration occurs from above this level. Root extraction pattern studies by Russell (19) and a consumptive use study by Manges (personal communication) conducted in England and Kansas have shown that approximately 70 percent is extracted from the upper 30 cm. (1 ft.) of soil, with nearly all of the remaining 30 percent being taken from the next 90 cm. (3 ft.). On this basis, the disposal area soil-moisture model simulates soil-water interactions above the 120 cm. (4 ft.) level by dividing the soil profile into two layers which are referred to as upper and lower zones, respectively. Evapotranspiration is proportioned in the two zones according to root densities, while evaporation from the soil surface is handled separately. Water which moves vertically downward through both zones is accounted as percolation out of the root zone.

Transfer of water from the soil to the atmosphere is handled by two processes; direct soil evaporation and transpiration. When soil lies fallow or annual row crops are in the early growth stage providing little vegetative cover, the transfer is accomplished by means of soil evaporation. As plant leaf surface areas increase through the growth stage, direct soil evaporation decreases and plant transpiration increases; hence, the transfer is termed evapotranspiration.

Soil Evaporation

Evaporation from soil generally occurs in two stages (18). First stage evaporation occurs when the soil is sufficiently wet to readily transport water to the surface. This is the constant rate stage in which evaporation proceeds at the potential rate calculated for bare soil. When a threshold amount, U, is reached, hydraulic properties of the soil begin to limit the evaporation rate. According to Ritchie (18), second stage evaporation is calculated by

$$Es = c't^{\frac{1}{2}} - c'(t-1)^{\frac{1}{2}} \quad (13)$$

where Es is the stage 2 evaporation, c' is a hydraulic coefficient of the soil, and t is the time after stage 1 evaporation.

Field work done by Kanemasu (8) using these relations have supplemented Ritchie's work, providing the values for U and c' shown in Table 1. Studies conducted by Bond (1) lead to similar relations using cumulative evaporation curves. The model treats both stage 1 and stage 2 evaporation in the same manner as Ritchie and Kanemasu.

Evapotranspiration

The actual rate of evapotranspiration (AET) is dependent upon atmospheric, plant, and soil factors (18). The atmospheric factors are incorporated in the computation of PET by the Penman method. The Blaney-Criddle method (21) is widely accepted in accounting for plant factors. This method is used to modify the potential rate by a plant consumptive use factor (k) which is determined from experimental data for each crop. Results of application to dry-land agricultural watersheds (34) and irrigated lands (6) display the versatility of the Blaney-Criddle method.

Under wet conditions evapotranspiration will proceed at the maximum rate. This relation continues until the soil-water deficit reaches a level which is equivalent to 0.3 of the maximum available moisture (θ_{max}) according to Kanemasu (8). Available moisture, or capillary water as defined by Israelsen (5, p. 162), is the moisture content of the soil between field capacity and the permanent wilting point. When the soil-water deficit falls below 0.3 θ_{max}, Kanemasu modifies the

Irrigation Soil Class	SCS Soil Group	Soil Profile Depth Ft.	Available Water, inches of water		Field Capacity, inches of water		Permanent Wilting Poing inches of water		Soil Moisture at Saturation inches of water		Upper Limit Stage 2 Evapor.	Empirical Coeff.
			Top 1' AVLFCU	1-4'* AVLFCL	Top 1' FCU	1-4'* FCL	Top 1' PWPUZ	1-4'* PWPLZ	Top 1' SMSATU	1-4'* SMSATL	mm U	mm day$^{-\frac{1}{2}}$ C
1	D	3	2.6	2.7	4.6	9.4	2.0	6.7	5.8	11.8	12	5.08
2	D	3	1.5	2.9	4.4	9.4	2.9	6.5	6.2	11.5	12	5.08
3	C	5	2.5	5.7	4.5	14.2	2.0	8.5	5.7	16.3	10	4.5
4	C	2.5	2.4	2.5	4.6	7.0	2.2	4.5	5.7	8.2	10	4.5
5	B	5	2.5	6.7	4.5	13.9	2.0	7.2	5.7	15.8	10	4.5
6	B	3	2.6	4.2	4.3	9.1	1.7	4.9	5.5	10.4	10	4.5
7	B	5	2.4	6.6	4.0	13.7	1.6	7.1	5.4	15.4	9	4.04
8	B	2.5	2.4	3.3	4.0	6.8	1.6	3.5	5.4	7.7	9	4.04
9	B	5	2.4	5.2	3.8	9.2	1.4	4.0	5.3	13.9	8	3.5
10	B	5	2.2	4.1	3.5	7.0	1.3	2.9	5.2	13.2	8	3.5
11	B	5	1.5	4.1	2.3	7.0	0.8	2.9	4.8	13.2	7	3.4
12	A	5	1.0	2.5	1.7	4.3	0.7	1.8	4.8	12.9	6	3.34

TABLE 1 - Properties Used In The Model

*Lower zone depth is taken as 3' except where soil profile depth limitations occur.

potential rate by the simple linear relation

$$Ks = \theta a/0.3\ \theta_{max} \quad \text{------------------------------------} \quad (14)$$

where θa is the actual available soil moisture content. With the application of Ks to the potential rate, the soil-water deficit allows AET to be at the maximum rate above 0.3 θ_{max} and limits it to zero at the permanent wilting point. The resulting relation for the actual rate of evapotranspiration is

$$AET = PET \times k \times Ks \quad \text{-----------------------------------} \quad (15)$$

<u>Surface Runoff</u>

The Soil Conservation Service method (30) is widely accepted for predicting the total volume of surface runoff produced by a design storm. The equation takes the form

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \quad \text{--} \quad (16)$$

where Q is direct surface runoff, P is precipitation, and S is the maximum potential difference between precipitation and runoff. The initial abstraction, IA = 0.2S, which consists of surface storage, interception losses, and water which infiltrates into the soil prior to runoff, must be satisfied before surface runoff can occur.

Development of the SCS method entailed assigning arbitrary runoff curve numbers to evaluated antecedent moisture, soil conditions, land use and conservation practices. For user convenience input runoff curve numbers (N) shown in Table 2 are specified by input soil (32) and crop types defined in Table 3 and Table 4, respectively. The input N (30) is based on condition II antecedent moisture, which is between 0.5 and 0.8 of field capacity (8,18) for the specified soil during the growing season or between 0.6 and 0.9 of field capacity during the dormant season. When the soil moisture is less than 0.5 or 0.6 of field capacity,

Soil Class	Row Crops	Alfalfa	Wheat	Pasture	Fallow
1	86	83	84	80	84
2	86	83	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

TABLE 2 - SCS Runoff Curve Numbers for Condition II*

*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.

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

TABLE 3 - Irrigation Design Class Descriptions for Soils in the Disposal Area

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

TABLE 4 - Crop Types

dependent upon the season, N is modified to a condition I antecedent soil moisture by

$$N_I = N \times 0.39e^{(-0.009xN)} \quad (17)$$

When the soil moisture is greater than the upper limit set for the season, the condition III curve number is obtained by the equation

$$N_{III} = N \times 1.95e^{(-0.00663xN)} \quad (17a)$$

Then by definition

$$S = \frac{1000}{N} - 10 \quad (18)$$

and S is substituted into Eq. (16) to calculate the runoff volume. The use of Eqns. (17) and (17a) to modify N alleviates the inefficiencies associated with look-up tables and interpolation schemes in computer simulation.

Interception

After calculation of surface runoff, interception losses must be separated from the remainder of the initial abstraction. Many equations exist which take into account variations of evaporation rates, vegetation canopy, rainfall intensity and total event volume. Use of one of these methods would require many complex inputs which are unnecessary for other functions in the model. A less complex approach for computer simulations (20)(14, p. 323) requires fixing an interception-storage capacity which must first be satisfied before water from any event is available for infiltration. For this model, the interception-storage was fixed at 2.54 mm (0.1 in.) and depleted at the potential rate. According to Ward (32), this storage should account for from 10 to 20 percent of the annual precipitation. Of the previously tested Kansas and Oregon stations approximately 16 to 18 percent of the annual precipitation was accounted as interception-storage losses which evaporated back into the atmosphere.

Infiltration and Redistribution

Water infiltrates at a higher rate at the beginning of a storm. The infiltration rate and the redistribution of water within the soil profile is dependent upon the hydraulic properties of the soil (5, p. 152). Actual rates are difficult to simulate because of the variability of influencing factors. Saxton (20) has modeled infiltration by means of physical redistribution. Using this scheme, a 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. Movement of gravitational water is then computed by the one-dimensional Darcy equation for unsaturated flow using moisture-tension and moisture-conductivity relationships.

Redistribution is approached in a similar manner by this model with some simplifying modifications. Since field capacity is generally evaluated two days after saturation (5, p. 163) and relationships required for use of the Darcy equation are difficult to program, the model allows soil moisture to decrease to field capacity after two days if it is not already below that level as a result of AET needs. This is accomplished by setting the soil moisture equal to field capacity and redistributing the excess to the next zone. Since the lower zone generally does not receive water as a result of small events, greater periods of time pass between recharges. When left undisturbed for greater periods of time, soils will gravitationally achieve a soil-moisture level which is less than field capacity. Accordingly, the lower zone soil moisture is decreased to 0.9 of field capacity when the time between recharges exceeds two days and the excess is considered to percolate out of the root zone. This modified method appears to result in reasonable estimates of vertical movement of water for the soil groups tested.

Snow on the Disposal Area

At many locations in the U.S., a sizable snow pack accumulates during the winter months. For this reason, a rational method of accumulating and dissipating snow must be incorporated to approximate actual conditions on the disposal area. Numerous snowmelt methods exist which are based on thermodynamic principles, empiricisms, and degree-day factors. Approaches such as presented by Leaf (12) based on thermodynamic principles are good representations of actual snow physics. The primary disadvantage of this type of approach is that it requires many inputs. For this reason a thermodynamic approach is considered too rigorous for use in this general model. Empiricims developed to approximate the thermodynamic principles are simpler but generally provide less satisfactory results (14, p. 275). The degree-day approach stands on the virtue of simplicity in requiring only dry-bulb temperature as input. The method has the disadvantage of neglecting humidity, radiation, and other factors which influence snow melt. In spite of this, good results have been obtained (13) using a degree-day approach.

For purposes of this model, precipitation events occurring on days having an average temperature $\leq 0°C(32°F)$ were accumulated as water equivalents of snow. The snow melt function used in this model as presented by Gray (4, pp. 9.12-9.14) is

$$M = C(Ta-Tb) \qquad (19)$$

where M is the snow melt, Ta is the mean daily atmospheric temperature, Tb is the base temperature, and C is the degree-day coefficient. This computes snow melt as a result of atmospheric conditions. If the snow is initially considered to be at 0°C(32°F), then the relation used by Linsley (13) to compute snow melt by rainfall is

$$D = (1/144)(P)(Ta-32) \qquad (20)$$

where D is the snow melted by rainfall, P is the amount of rainfall, and Ta is the mean daily temperature. The heat of fusion of ice is 79 cal./g. (144 BTU/lb.) while the specific heat of water is 1 cal./g. (1 BTU/lb.).

Evaporation from snow (sublimation) works basically on the same principles as evaporation from a free water surface (4, pp. 3.7-3.8). Approximately 5 percent of incident shortwave radiation is reflected from a free water surface while from 80 to 90 percent is reflected by a clean, dry snow surface. Because of changes in crystalline structure, density, and the amount of dirt on the surface, the albedo drops to 50 percent or less as snow ages. Accordingly, an average albedo (r) of 70 percent has been chosen for application of the Penman equation to a snow surface in this model. Additionally, it has been assumed that a water equivalent of 2.54 mm. (0.1 in.) in the pack provides sufficient cover to treat the evaporation calculation in terms of a snow surface. This is accomplished with ease by applying a value of r = 0.70 to the Penman method when the pack contains a water equivalent in excess of 2.54 mm. (0.1 in.). The resulting daily sublimation from the pack is small, generally less than 0.25 mm. (0.01 in.), but through the winter months this may account for noticeable dissipation of the pack.

Criteria for Disposal on the Area

Water from the storage facility will not be applied on the disposal area under the following conditions:

1) when there is < one full day's irrigation water in the facility;
2) when the ground is frozen;
3) when the mean daily temperature < 0°C(32°F), and
4) when the upper zone soil moisture is greater than a specified percentage of field capacity.

An additional condition that could be easily added is one which does not allow irrigation when the crop on the area is not in its growing stage. The design of the model allows for simple modification to accommodate almost any irrigation management scheme. The soil is considered to be frozen if the sum of the previous two days temperature < 0°C(64°F), i.e., the 2-day average temperature < 0°C(32°F). Thawing is considered to occur when the sum of the average temperatures for any three consecutive day period is > 10°C(114°F), i.e., the 3-day average temperature > 3°C(38°F).

The percentage of upper zone field capacity (PSMN), which defines the third condition for irrigation is an input variable which allows various irrigation management schemes to be tested. By setting PSMN = 0.0, a non-irrigation or pure surface evaporation system can be tested.

FEEDLOT FUNOFF

Feedlot surfaces greatly differ from disposal area surfaces. Repeated animal milling works the surface, compacting underlying soil layers. As a result, normal infiltration is impaired greatly and largely influenced by the development of the lot. Difficulties therefore arise when attempting to apply normal soil-moisture models to a feedlot.

Models incorporating the SCS method to predict feedlot runoff volume have been tested in Kansas (9), Oregon (33), and Minnesota (11). Reasonable results were obtained by using curve number (N) varying from 91 to 98 depending on surface type and antecedent conditions. General agreement exists that for antecedent conditions I and II, N = 91 is satisfactory while N = 97 works well for condition III antecedent moisture on unsurfaced lots.

During extensive testing with feedlot runoff data from feedlots at Gretna, Nebraska (23), Bushland, Texas (3), and Pratt, Kansas (15), the SCS method was evaluated along with numerous modifications. Attempts to evaluate runoff curve numbers by means of modeling the soil-moisture deficit of the feedlot surface provided less satisfactory results than a much simpler model used by Koelliker (9). Studies by Miner (16) and Swanson (23) suggest that rainfalls of certain intensity and duration are required before runoff occurs from the feedlot surface. Accordingly, variations of antecedent moisture required to produce runoff were tested. It was discovered that calculated runoff quantities resulting from large rainfall events were underestimations of actual runoff quantities. Since infiltration is greatly impeded in a developed lot, it was assumed that above a certain maximum amount of water required to saturate the soil above the impervious layer and fill depression storage, any additional precipitation would run directly off. Various event magnitudes were tested to evaluate the maximum storm occurring before any excess essentially all runs off the feedlot surface.

The model which eventually provided the best results specifies that surface runoff will not occur if

1) the 3-day antecedent moisture and the precipitation on the day of concern is < 1.3 cm. (0.5 in.);

2) the average temperature for the day < -1°C(30°F);

3) the soil is frozen.

While the ground is frozen, all precipitation is accumulated as snow on the feedlot. When the soil thaws, the accumulated volume of snow is allowed to run off with N = 97. Snow on the feedlot is handled differently than on the disposal area because of major differences in the two surfaces. In most parts of the U.S., a volume nearly equivalent to the accumulated winter precipitation quantity is retained in the storage facility during the course of the season. Even at a high N, routing small melts during winter months through the SCS equation would result in a significantly smaller volume. Urine addition by confined animals compensates for sublimation losses from snow and may account for differences discussed. Irrigation conditions are generally unfavorable in winter so the timing of additions to the pond is not as important as the volume accumulated during the season.

Best results are obtained by partitioning the year into a growing season and dormant season; April-October and November-March, respectively. During the growing season, a maximum of 3.18 cm. (1.25 in.) is routed through the SCS equation with N = 97 if the 3-day antecedent moisture is > 1.91 cm. (0.75 in.) or N = 91 if the antecedent moisture ≤ this amount. For any day having an event > 3.18 cm. (1.25 in.), the excess is considered to run directly off the feedlot surface. During the dormant season, the maximum precipitation routed through the SCS equation is lowered to 2.54 cm. (1.0 in.) and N = 91 is used when 3-day antecedent moisture < 1.27 cm. (0.5 in.). Otherwise, N = 97 is used during this season. Calculated runoffs exceeding 0.06 in. are then reduced by that amount.

A regression analysis between calculated values of feedlot runoff and actual data resulted in a normal range of r^2 values between 0.80 and 0.85 on unsurfaced lots. At the present time no attempts to simulate surfaced lots have been made since there is a lack of actual data for this type of lot. The regression analysis on unsurfaced lot data appears to justify the procedures described above for modeling the feedlot runoff.

THE STORAGE FACILITY

A runoff control structure generally resembles an inverted frustrum of a pyramid. For this reason the configuration of the general prismatoid (Figure 2), which allows independent variations of base length (L), base width (W), and side slopes (S), was used in the model. These parameters along with the maximum depth of water (HMAX) are input variables to the program and define the maximum volume of water which the facility can contain before a discharge occurs.

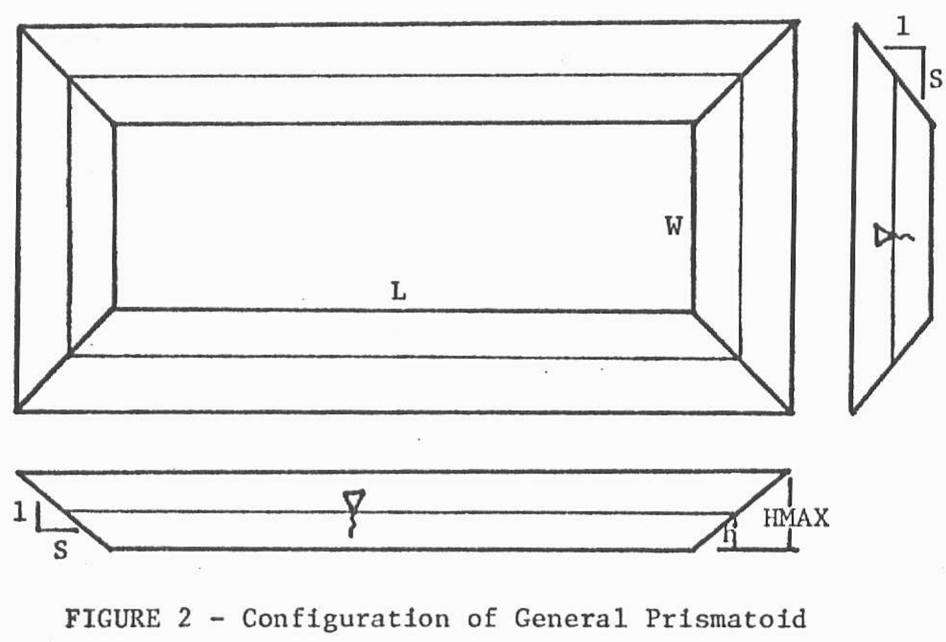


FIGURE 2 - Configuration of General Prismatoid

By specifying a particular size and shape of pond, the surface area can be computed for any storage volume. The volumetric equation for a general prismatoid (22) is

$$V = \frac{1}{6} h \ (B1 + 4Bm + B2) \text{ ------------------------------ } (21)$$

where V is the volume, h is the depth, B1 is the bottom surface area, B2 is the top surface area, and Bm is the area of a plane at h/2 above the bottom.

Feedlot runoff contains a high suspended solids load which impedes seepage from the storage facility. Conservation and irrigation ponds containing water which does not have large concentrations of suspended solids tend to seal over a period of time. Although seepage may continue for certain soils and for facilities which experience wet/dry cycles, no verified exfiltration rates are available. For this reason, a sealed condition or zero exfiltration is assumed for the pond. The inputs to the facility include runoff from the feedlot and direct contributions of precipitation to the receiving area. Outflows consist of water pumped out for irrigation purposes, surface evaporation, and overflows.

<u>Pond Volume Accounting Hierarchy</u>

In budgeting the inputs and outputs of the storage facility, the volume is the basic quantity which varies in response to climate and disposal requirements. Although it is probably of no particular consequence in terms of final results, the order in which the accounting proceeds is as follows:

1) The calculated volume of water disposed for the present day is deducted from the volume of water remaining in the pond at the end of the previous day.

2) Surface evaporation is deducted. The calculation of surface evaporation is accomplished by using Eq. (21) and Newton's

Method of Successive Approximations to evaluate the depth of water (h). Direct solution for h involves the solution of a cubic equation which, as a result of imaginary roots, may create difficulties with a computer solution. The water surface area (B2) is then calculated and multiplied by lake evaporation (from the Penman equation) to obtain the surface evaporation. The pond is considered to be frozen when the soil is frozen and no surface evaporation occurs when the pond is frozen.

3) The feedlot runoff volume calculated for the day and the precipitation falling directly on the pond receiving area is added to the volume in the pond. The direct receiving area is the maximum surface area for h equal to HMAX.

4) The calculated volume is compared to the maximum volume of the facility (VOLMAX). If the volume exceeds VOLMAX, the excess is accounted as discharge and the pond volume is set equal to VOLMAX. Either the calculated volume or VOLMAX, then, is the volume of water remaining at the end of the day.

DISCUSSION AND RESULTS OF PRELIMINARY TESTING

The model has been thoroughly tested with data from Topeka, Kansas and has been run for other Kansas and Oregon stations. Required inputs of solar radiation, relative humidity, percent sunshine, and wind speed were taken as mean monthly daily averages from meteorological data. Daily inputs of precipitation and maximum and minimum temperature were obtained off data tapes purchased from the National Weather Service, Asheville, North Carolina. Presently, the model is capable of reading data from any 9-track tape prepared with Asheville format. Storage facility sizes tested were equivalent to 1x, 2x, and 3x multiples of the volume accumulated from the 25-year, 24 hour storm, provided all that fell on the feedlot surface ran off.

At Topeka, Kansas the 1x facility proved to be very insufficient allowing 29 discharges during the 25-year period between 1949 and 1973. The 2x facility provided better control by decreasing the number of discharges occurring during this period to 13. As was expected, the 3x facility was sufficient to hold the accumulated process waters having no discharges during this period. Using the management scheme of irrigating when the soil moisture in the disposal area is below 90 percent of field capacity, a maximum of 82.5 percent of the 3x facility volume was required. During this period the average precipitation was 34.3 inches causing an average runoff of 13.0 inches from the feedlot surface. This was accumulated over a 40 acre feedlot and disposal was on an 80 acre area having sorghum as the growing crop. Less than one minute of computer execution time was required to process the 25 years of data.

During the next year, the model will be calibrated and tested at locations throughout the U.S. The capabilities and versatility of the model will be examined during this time. At present, the model specifies only one irrigation disposal area. In the future, the model will be modified to enable simulation of irrigation on various portions of the area at one time. This will allow a wider variety of irrigation practices to be evaluated.

SUMMARY

Increasing levels of water pollution and public concern have prompted the formation and imposition of federal regulations in an attempt to alleviate sources of pollution. Implementation of the NPDES program and provisions for application to all point sources including concentrated animal feeding operations have placed a heavy burden on administration and enforcement agencies. On the state level, simple continuous watershed models have proven useful as design aids and design

evaluation instruments for storage facilities. Accordingly, a model which can analyze various management schemes and evaluate the full perspective of land disposal and evaporation techniques is a necessary tool not only for enforcement agencies, but for the feedlot operators as well.

A physically based model which can readily evaluate most any land disposal or evaporation scheme has been developed. The model has the capability of being applied at any location in the U.S. with only minor calibration. Input data requirements include meteorological factors which are readily available for all parts of the country. Preliminary testing has demonstrated the capabilities and accuracy of the model. Specific systems can easily be programmed and evaluated utilizing a minimum of computer time.

THIS BOOK CONTAINS NUMEROUS PAGES WITH MULTIPLE PENCIL AND/OR PEN MARKS THROUGHOUT THE TEXT.

THIS IS THE BEST IMAGE AVAILABLE.

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APPENDIX II - Notation

The following symbols are used in this paper:

a,b,c,d & e = geographical constants for use in the Penman equation

ABST = absolute air temperature, in degrees Kelvin

Bm = area of the midsection of the storage facility, in square feet

B1 = area of the bottom of the storage facility, in square feet

B2 = the water surface area in storage facility, in square feet

C = degree-day coefficient (usually 0.05-0.06), in inches per day - degree Fahrenheit

C' = hydraulic coefficient of soil

D = show melted by rainfall, in inches of water

E = emissivity

Ea = convective loss, in millimeters of water evaporated per day

ES = saturation vapor pressure, in millibars

ESA = actual vapor pressure of the air in millibars

Es = stage 2 evaporation, in inches of water per day

G = sensible heat flux to or from the soil

h = depth of water in the storage facility, in feet

HMAX = maximum depth of water allowable in the storage facility, in feet

IA = initial abstraction, in inches of water

k = Blaney-Criddle consumptive use coefficient

Ks = coefficient for soil-moisture conditions

M = atmospheric snow melt, in inches of water

N = SCS runoff curve number

P = precipitation, in inches

PET = potential evaporation, in millimeters of water

PSUNS = percentage of possible sunshine

Q = direct surface runoff, in inches

r = mean daily shortwave reflectance or albedo

Ra = extra-terretrial solar radiation on a horizontal surface, in millimeters of water evaporated per day

Rb = actual outgoing longwave radiation, in millimeters of water per day

Rn = heat at the surface, in millimeters of water per day

Rsi = total solar radiation incident to a water surface, in millimeters of water evaporated per day

S = maximum potential difference between precipitation and runoff, in inches

t = time after stage 1 evaporation, in days

Ta = mean daily temperature, in degrees Fahrenheit

Tb = base temperature, in degrees Fahrenheit

V = volume of water in the storage facility, in cubic feet

VOLMAX = maximum volume of water held by the storage facility, in cubic feet

W = measured wind speed, in miles per day

WVD = mean wind speed at 2 meters above the ground, in miles per day

γ = psychrometric constant in the Bowen ratio equation

Δ = slope of the saturation vapor pressure-temperature curve

θa = actual available soil moisture content, in inches of water

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

σ = Stefan-Boltzman constant (2.01×10^{-9} mm/day °K)

APPENDIX III

Computer Printouts

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          C          FROS - VERSION I
          C   JOINTLY PROGRAMMED BY THE CIVIL AND AGRICULTURAL ENGG. DEPT.
          C             KANSAS STATE UNIVERSITY
          C                 MARCH 1976
          C
0001            INTEGER CROP,CAY,FROZE,SOIL,STINC,T,YEAR,YEARS,YEND,YSTART
0002            REAL IA,IAADD,IAET,KCROP,KS,LAKEVP,LKEVPT,LTAREA,L,M,MA
0003            REAL MAXVOL,MR
0004            DIMENSION AMONTH(13),AVLFCL(12),AVLFCU(12),C(12),FCL(12),FCU(12)
0005            DIMENSION KCROP(6,12),NDIM(12),PCACCT(13,8),PREC(31),PSUNS(12)
0006            DIMENSION PWPLZ(12),PWPUZ(12),RA(12),RCM(12,7),RCN(12,7),RHD(12)
0007            DIMENSION SMACCT(13,8),SMSATL(12),SMSATU(12),TAVG(31),TMAX(31)
0008            DIMENSION TMIN(31),U(12),WIND(12)
0009            COMPLEX*16 KROP*16(6)/'WHEAT','SORGHUM','CORN','SOY BEANS',
               1     'PASTURE','ALFALFA'/
0010            DATA AMONTH/'JAN.','FEB.','MAR.','APR.','MAY ','JUNE','JULY',
               1     'AUG.','SEPT','OCT.','NOV.','DEC.','TOT.'/
0011            DATA AVLFCU/2.6,1.5,2.5,2.4,2.5,2.6,2.4,2.4,2.4,2.2,1.5,1.0/
0012            DATA AVLFCL/2.7,2.9,5.7,2.5,6.7,4.2,6.6,3.3,5.2,4.1,4.1,2.5/
0013            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/
0014            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/
0015            DATA FCL/5.4,9.4,14.2,7.0,13.9,9.1,13.7,6.8,9.2,7.0,7.0,4.3/
0016            DATA NDIM/31,28,31,30,31,30,31,31,30,31,30,31/
0017            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/
0018            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/
0019            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/
0020            DATA SMSATL/11.8,11.5,16.3,8.2,15.8,10.4,15.4,7.7,13.9,13.2,13.2,
               1     12.9/
0021            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/
0022            DATA AET,AETLZ,AETUZ,B2,DISVOL,DPERC,EQ,EXCESS,IA,IAADD,IAET,M,MA,
               1     MR,PACK,PACKPY,PDVOL,PERC,PCNVOL,P1,P2,P3,SNCMLT,TDPERC,TIME,
               2     TRNOF,T1,T2/28*0.0/
0023            DATA CROP,CAY,ICAY,SOIL,T/5*0/
0024            DATA SMLZ,SMMAXL,SMLZ/9.35,2.2,3.25/
0025            NAMELIST/ALPHA/CROP,DCRM,GROW,PDT,PSMN,RCROP,SOIL
0026            NAMELIST/BETA/DSAREA,DSRATE,HMAX,INDST,L,LTAREA,MSTART,S,STORM,W,
               *YEND,YSTART
          C
          C        ***** INPUTS *****
          C
          C
          C***  READ THE SOIL AND CROP ARRAYS
0027            READ(5,20) NAME,OF,CITY,AND,STATE
0028         20 FORMAT(20X,5A4)
0029            READ(5,40) ((KCROP(I,J),J=1,12),I=1,6)
0030         40 FORMAT(12F4.2)
0031            READ(5,60) ((RCN(I,K),K=1,7),I=1,12)
0032         60 FORMAT(7(F2.0,1X))
          C***  READ THE LOT,POND AND DISPOSAL PARAMETERS
0033            READ(5,ALPHA)
0034            READ(5,BETA)
          C***  READ THE MONTHLY AVERAGE METEOROLOGICAL DATA
0035            READ(5,80) (PSUNS(I),RHD(I),RA(I),WIND(I),I=1,12)
0036         80 FORMAT(2X,F2.2,F2.0,F4.2,F3.1)
          C
          C***  A1,A2,A3,A4,AND A5 ARE COEFFICIENTS USED IN VOLUME ROUTINE
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```
0037            A1=L*W
0038            A2=S*(L+W)
0039            A3=4./3.*S**2
0040            A4=2.*A2
0041            A5=4.*S**2
          C***  VOLMAX IS THE MAXIMUM VOLUME HELD BY THE STORAGE FACILITY
0042            VOLMAX=(A1*HMAX+A2*HMAX**2+A3*HMAX**3)/3630.
          C***  PSAREA IS THE DIRECT RECEIVING AREA OF THE FACILITY
0043            PSAREA=((W+2.*S*HMAX)*(L+2.*S*HMAX))/43560.
0044            SMPD=SMLZ+SMLZ
0045            YEARS=YEND-YSTART+1
0046            WRITE(6,100)NAME,OF,CITY,AND,STATE,YSTART,YEND,STORM,LTAREA,L,W,S,
               *HMAX,VOLMAX,PSAREA,DSAREA,KROP(CROP),SOIL,DSRATE,PSMN
0047        100 FORMAT('1',10X///////////10X,'STATION:',3X,5A4,10X,I4,'  TO  ',I4,
               1////10X,'SIZE OF CRITICAL EVENT  ',F4.2////10X,'FEEDLOT AREA',2X,
               2F5.2,'ACRES'////10X,'POND 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 POND VOLUME--  ',F9.2,' ACRE-INCHES'//25X,'(E) DIRECT
               6 RECEIVING AREA (FOR PRECIPITATION) --  ',F8.2,' ACRES'////10X,
               7'DISPOSAL AREA VARIABLES:'//25X,'(A) DISPOSAL AREA--   ',F5.2,
               8'  ACRES'//25X,'(B) CROP--  ',2A8//25X,'(C) SOIL TYPE--  ',I3,
               9'   (SCS) SOIL TYPES)'//25X,'(D) DISPOSAL RATE--  ',F5.2,
              11'   INCHES/DAY ON DISPOSAL DAYS'//25X,'(E) IRRIGATION MANAGEMENT--
              12  IRRIGATION BELOW  ',F5.2,'  FIELD CAPACITY')
          C
          C         ***** ENTER YEARLY LOOP *****
          C
0048            DO 1500 NY=1,YEARS
0049            DO 140 I=1,13
0050            DO 120 J=1,8
0051            PDACCT(I,J)=0.0
0052        120 SMACCT(I,J)=0.0
0053        140 CONTINUE
0054            IDISCA=0.0
0055            MAXVOL=0.0
0056            LKEVPT=0.0
0057            IF(NY.GT.1) MSTART=1
0058            WRITE(6,160)
0059        160 FORMAT('1',46X,'***** ANNUAL SUMMARY *****')
          C
          C         ***** ENTER MONTHLY LOOP *****
          C
0060            DO 1280 NM=MSTART,12
          C
          C
0061        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)
0062        200 FORMAT(I2,I4,2I2,31F4.2,62F3.0)
0063            IF(STIND.NE.INDST) GO TO 180
0064            IF(YEAR.LT.YSTART-1900) GO TO 180
0065            IF(YEAR.GT.YEND-1900) GO TO 1520
0066            IF(MONTH.LT.MSTART.AND.YEAR.EQ.YSTART-1900) GO TO 180
0067            DSDAY=0
0068            NDIM(2)=28
0069            IF(NM.EQ.2.AND.TMAX(29).LT.900) NDIM(2)=29
0070            NDAYS=NDIM(NM)
          C
```

```
            C        ***** ENTER DAILY LOOP *****                                  00216000
            C                                                                      00217000
0071             DO 1240 ND=1,NDAYS                                               00218000
            C                                                                      00219000
            C***   TAVG IS THE AVERAGE DAILY AIR TEMPERATURE, DEGREE FAHRENHEIT    00220000
0072             TAVG(ND)=(TMAX(ND)+TMIN(ND))/2.0-100.0                           00221000
            C***   THE FOLLOWING STATEMENTS CORRECT  FOR MISSING DATA ON INPUT TAPE 00222000
0073             IF(TAVG(ND).GT.120) TAVG(ND)=PDT                                 00223000
0074             IF(PREC(ND).GT.99.97) PREC(ND)=0.0                               00224000
            C***   THE FOLLOWING CARD EVALUATES WHETHER THE 24 HOUR DESIGN STORM   00225000
            C***   HAS BEEN EXCEEDED.                                              00226000
0075             IF(PREC(ND).GE.STORM/1.14) WRITE(6,220) NM,ND,YEAR,PREC(ND)      00227000
0076         220 FORMAT(20X,I2,'/',I2,'/',I2,'  25 YEAR STORM  ',F10.2,' INCHES ') 00228000
            C                                                                      00229000
            C *** CALCULATION OF POTENTIAL EVAPOTRANSPIRATION BY MEANS OF PENMAN    00230000
            C                                      COMBINATION EQUATION ***        00231000
            C                                                                      00232000
0077             R=RCROP                                                          00233000
            C***   THE FOLLOWING CARD CHECKS FOR SNOW COVER                        00234000
0078             IF(PACK.GT.0.1) R=0.70                                           00235000
            C***   THE NEXT TWO CARDS CONVERT TAVG TO ABSOLUTE, DEGREE KELVIN      00236000
0079             CENT=(TAVG(ND)-32.0)*100.0/180.0                                 00237000
0080             ABST=CENT+273.16                                                 00238000
            C***   ES IS THE DAILY CALCULATED SATURATED VAPOR PRESSURE, IN MILLIBARS 00239000
0081             ES=33.9*((0.00738*CENT+0.8072)**8-0.000019*ABS(1.8*CENT+48)      00240000
                1  +0.00136)                                                       00241000
            C***   ESA IS THE DAILY CALCULATED ACTUAL VAPOR PRESSURE, IN MILLIBARS 00242000
0082             ESA=ES*RHD(NM)/100.0                                             00243000
            C***   RN IS THE CALCULATED DAILY NET RADIATION, IN MM OF WATER        00244000
0083             RN=(1-R)*RA(NM)*(0.22+0.54*PSUNS(NM))-2.010E-09*ABST**4*         00245000
                1(0.58-0.68-0.036*SQRT(ESA))*(0.1+0.9*PSUNS(NM))                  00246000
            C***   WINDD IS THE MONTHLY AVERAGE WINDRUN, MILES/DAY AT 2 METERS HEIGHT00247000
0084             WINDD=(WIND(NM)*24)*0.555                                        00248000
            C***   EA IS THE CONVECTIVE LOSSES, MM WATER                          00249000
0085             EA=0.26*(0.5+0.01*WINDD)*(ES-ESA)                                00250000
0086             IF(TAVG(ND)) 240,240,260                                         00251000
0087         240 DELTA=0.0                                                        00252000
0088             GO TO 280                                                        00253000
0089         260 DELTA=0.039*TAVG(ND)**0.673                                      00254000
0090         280 GAMMA=1-DELTA                                                    00255000
            C***   PET IS THE CALCULATED DAILY POTENTIAL EVAPOTRANSPIRATION, INCHES 00256000
0091             PET=((DELTA*RN)+(GAMMA*EA))/25.4                                 00257000
            C***   CALCUATE LAKE AND BARE SOIL EVAPORATION                        00258000
0092             RNSOIL=RN*((1.0-0.20)/(1.0-R))                                   00259000
0093             RNLAKE=RN*((1.0-0.05)/(1.0-R))                                   00260000
0094             PETBS=((DELTA*RNSOIL)+(GAMMA*EA))/25.4                           00261000
0095             LAKEVP=((DELTA*RNLAKE)+(GAMMA*EA))/25.4                          00262000
0096             PDT=TAVG(ND)                                                     00263000
0097             IF(TAVG(ND).LT.20.0) PET=0.0                                     00264000
0098             IF(TAVG(ND).LT.20.0) PETBS=0.0                                   00265000
0099             IF(TAVG(ND).LT.20.0) LAKEVP=0.0                                  00266000
0100             IAADD=IAET-PET                                                   00267000
0101             IF(IAADD.GT.0.1) IAADD=0.1                                       00268000
0102             IF(IAADD.LT.0.0) IAADD=0.0                                       00269000
            C***   MODIFY PET BY THE PLANT CONSUMPTIVE USE COEFFICIENT             00270000
0103             AET=KCROP(CROP,NM)*PET                                           00271000
0104             IF(PET.LE.IAET) PET=0.0                                          00272000
            C                                                                      00273000
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             C                   *** CALCULATION OF MOISTURE ADDED TO DISPOSAL
             C                          DUE TO SNOWMELT ON THE AREA  ***
             C
             C
0105                SNOVAP=0.0
0106                M=0.0
0107                PRECIP=PREC(ND)
0108                WATER=PRECIP
0109                IF(PACK.GT.0.1) SNOVAP=PET
0110                PACK=PACK-SNOVAP
0111                IF(TAVG(ND)-32) 300,300,320
0112            300 IF(PRECIP) 420,420,340
0113            320 IF(PACK) 460,460,360
0114            340 PACK=PACK+PRECIP
0115                WATER=0.0
0116                GO TO 460
             C***   MA IS SNOWMELT DUE TO ATMOSPHERIC CONDITIONS
0117            360 MA=0.05*(TAVG(ND)-34)
0118                IF(MA.LT.0.0) MA=0.0
0119                IF(PACK-MA) 400,400,380
             C***   MR IS SNOWMELT DUE TO RAIN
0120            380 MR=(PRECIP*(TAVG(ND)-32))/144
0121                M=MR+MA
0122                IF(PACK-M) 400,420,420
0123            400 M=PACK
0124                PACK=0.0
0125                GO TO 440
0126            420 PACK=PACK-M
0127            440 WATER=M+PRECIP
             C
             C
             C          *** EVALUATION OF SOIL MOISTURE AND CALCULATION OF ACTUAL
             C                      EVAPOTRANSPIRATION FROM DISPOSAL AREA ***
             C
0128            460 RAIN=WATER+(DISVOL/DSAREA)
0129                IF(DISVOL.GT.0.0.AND.PRECIP.LT.0.4) GO TO 600
0130                IF(RAIN.LE.0.0) GO TO 580
             C***   CALCULATE SURFACE RUNOFF VOLUME BY SCS METHOD
0131                IF(KCROP(CROP,NM).LE.0.0) GO TO 520
0132                IF(SMUZ.LT.0.5*FCU(SOIL)) GO TO 480
0133                IF(SMUZ.GT.0.8*FCU(SOIL)) GO TO 500
0134                GO TO 540
             C***   MODIFY RUNOFF CURVE NUMBER TO CONDITION I ANECEDENT MOISTURE
0135            480 RCM(SOIL,CROP)=RCN(SOIL,CROP)*0.39*EXP(0.009*RCN(SOIL,CROP))
0136                GO TO 560
             C***   MODIFY RUNOFF CURVE NUMBER TO CONDITION III ANECEDENT MOISTURE
0137            500 RCM(SOIL,CROP)=RCN(SOIL,CROP)*1.95*EXP(-0.00663*RCN(SOIL,CROP))
0138                GO TO 560
0139            520 IF(SMUZ.LT.0.6*FCU(SOIL)) GO TO 480
0140                IF(SMUZ.GT.0.9*FCU(SOIL)) GO TO 500
0141            540 RCM(SOIL,CROP)=RCN(SOIL,CROP)
0142            560 SI=1000.0/RCM(SOIL,CROP)-10.0
0143                ER=RAIN-0.2*SI
0144                IF(ER.LT.0.0) GO TO 600
0145                RNOF=ER**2/(RAIN+0.8*SI)
0146                GO TO 620
0147            580 RNOF=0.0
             C***   EVALUATE INTERCEPTION STORAGE
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0148            IA=0.0                                                           00332000
0149            GO TO 640                                                        00333000
0150        600 RNCF=0.0                                                         00334000
0151        620 IA=0.1                                                           00335000
0152            IF(IA.GT.RAIN) IA=RAIN                                           00336000
0153            IF((IA+IAADD).GE.0.1) IA=0.1-IAADD                               00337000
          C***  EVALUATE PERCOLATION INTO UPPER ZONE                             00338000
0154        640 PERC=RAIN-RNCF-IA                                                00339000
0155            UZEVAP=0.0                                                       00340000
          C***  CALCULATE PRESENT STORAGE AVAILABLE IN UPPER ZONE                00341000
0156            SMMAXU=0.9*SMSATU(SOIL)-SMUZ                                     00342000
          C***  EVALUATE WATER CASCADED TO LOWER ZONE FOR STORAGE                00343000
0157            PERCL=PERC-SMMAXU                                                00344000
0158            IF(PERCL.LT.0.0) PERCL=0.0                                       00345000
0159            IF (SMUZ.GT.FCU(SOIL)) GO TO 660                                 00346000
0160            EXCESS=0.0                                                       00347000
0161            GO TO 680                                                        00348000
          C***  EVALUATE GRAVITATIONAL WATER IN UPPER ZONE                       00349000
0162        660 EXCESS=SMUZ-FCU(SOIL)                                            00350000
          C***  IF THE CROP IS DORMANT OR THE SOIL LIES FALLOW, SOIL             00351000
          C***  EVAPORATION IS EVALUATED                                         00352000
0163        680 IF(KCROP(CROP,MM).LE.0.0) GO TO 860                              00353000
          C***  CHECK WHETHER SOIL MOISTURE LIMITS AET FROM THE UPPER ZONE       00354000
0164            IF(SMUZ-(0.3*(AVLFCU(SOIL))+PWPUZ(SOIL)))700,700,760             00355000
          C***  CALCULATE AET FROM THE UPPER ZONE WHEN LIMITED BY SOIL MOISTURE  00356000
0165        700 AVAILU=SMUZ-PWPUZ(SOIL)                                          00357000
0166            IF(AVAILU.LE.0.0) AVAILU=0.0                                     00358000
0167            AETUZ=0.7*AET*(AVAILU/(0.3*AVLFCU(SOIL)))                        00359000
          C***  EVALUATE AVAILABLE WATER IN THE LOWER ZONE                       00360000
0168            AVAILL=SMLZ-PWPLZ(SOIL)                                          00361000
0169            IF(AVAILL.LE.0.0) AVAILL=0.0                                     00362000
          C***  CHECK WHETHER SOIL MOISTURE LIMITS AET FROM THE LOWER ZONE       00363000
0170            IF(SMLZ-(0.3*(AVLFCL(SOIL))+PWPLZ(SOIL))) 720,720,740            00364000
          C***  CALCUATE AET FROM THE LOWER ZONE WHEN LIMITED BY SOIL MOISTURE   00365000
0171        720 AETLZ=0.3*AET*(AVAILL/(0.3*AVLFCL(SOIL)))                        00366000
0172            GO TO 780                                                        00367000
0173        740 AETLZ=AET-AETUZ                                                  00368000
0174            GO TO 780                                                        00369000
          C***  EVALUATE AET FROM BOTH ZONES UNDER WET CONDITIONS                00370000
0175        760 AETUZ=0.7*AET                                                    00371000
0176            AETLZ=0.3*AET                                                    00372000
0177            AVAILL=SMLZ-PWPLZ(SOIL)                                          00373000
0178            IF(SMLZ.LE.0.3*(AVLFCL(SOIL))+PWPLZ(SOIL)) GO TO 720             00374000
0179        780 IF(PERC-SMMAXU) 800,800,820                                      00375000
          C***  EVALUATE SOIL MOISTURE                                           00376000
0180        800 SMUZ=SMUZ+PERC-AETUZ-EXCESS                                      00377000
0181            SMLZ=SMLZ-AETLZ+EXCESS                                           00378000
0182            GO TO 960                                                        00379000
0183        820 SMUZ=SMUZ+SMMAXU-EXCESS-AETUZ                                    00380000
0184            SMMAXL=0.9*FCL(SOIL)-SMLZ                                        00381000
0185        840 SMLZ=SMLZ+PERCL-AETLZ+EXCESS                                     00382000
0186            GO TO 960                                                        00383000
          C***  CALCULATE EVAPORATION FROM BARE SOIL SURFACE(SEVAP) FOR MONTHS   00384000
          C***  OCTOBER THROUGH MARCH OR WHEN THE DISPOSAL AREA IS FALLOW        00385000
0187        860 AETUZ=0.0                                                        00386000
0188            AETLZ=0.0                                                        00387000
0189            IF(PACK.GT.0.0) GO TO 920                                        00388000
0190            IF(SMUZ.GE.FCU(SOIL)) EC=0.0                                     00389000
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0191            IF(SMUZ.LT.(FCU(SOIL)-U(SOIL))) GO TO 880
           C*** CALCULATE STAGE 1 SOIL EVAPORATION
0192            UZEVAP=SMUZ-(FCU(SOIL)-PETBS)
0193            IF(UZEVAP.LT.0.0) UZEVAP=0.0
0194            EC=EC+UZEVAP
0195            T=0.0
0196            IF(EC.GT.U(SOIL)) GO TO 880
0197            GO TO 900
           C*** CALCULATE STAGE 2 SOIL EVAPORATION
0198        880 T=T+1
0199            UZEVAP=C(SOIL)*(T**0.5)-C(SOIL)*((T-1)**0.5)
0200        900 IF(UZEVAP.GT.(PETBS-IAET)) UZEVAP=PETBS-IAET
0201            IF(UZEVAP.LT.0.0) UZEVAP=0.0
0202            IF(SMUZ-PWPUZ(SOIL).LT.UZEVAP) UZEVAP=SMUZ-PWPUZ(SOIL)
0203            GO TO 940
0204        920 UZEVAP=0.0
0205        940 SMUZ=SMUZ-UZEVAP+PERC-EXCESS
0206            IF(SMUZ.LE.PWPUZ(SOIL)) SMUZ=PWPUZ(SOIL)
0207            SMLZ=SMLZ+PERCL+EXCESS
0208        960 IF(SMLZ.LE.PWPLZ(SOIL)) SMLZ=PWPLZ(SOIL)
0209            DPERC=SMLZ-0.9*FCL(SOIL)
0210            IF(DPERC.LT.0.0) DPERC=0.0
0211            IF(SMLZ.GT.0.9*FCL(SOIL)) SMLZ=0.9*FCL(SOIL)
0212            AETUZ=AETUZ+UZEVAP
           C*** SM IS SOIL THE MOISTURE IN THE GROWING ZONE, INCHES
0213            SM=SMUZ+SMLZ
0214            IAET=IA+IAACD
           C
           C
           C             *** EVALUATION OF VOLUME DISPOSED***
           C
           C*** T1 IS THE PREVIOUS DAY'S AVERAGE TEMPERATURE FAHRENHEIT DEGREES,
           C*** T2 IS THE AVERAGE TEMPERATURE OF THE DAY TWO DAYS PRIOR OF TODAY
0215            THAWED=TAVG(ND)+T1+T2
0216            FREEZE=TAVG(ND)+T1
0217            T2=T1
0218            T1=TAVG(ND)
0219            IF(FREEZE.LT.64.0) FROZE=1
0220            IF(THAWED.GT.114.0) FROZE=0
           C*** WHEN FROZE EQUALS 1 THE SOIL IS CONSIDERED TO BE FROZEN. IT IS
           C*** THAWED WHEN FROZE EQUALS 0.
0221            IF(FROZE.EQ.1) GO TO 980
           C*** SMUZ IS THE SOIL MOISTURE IN THE TOP 12 INCHES OVER THE DISPOSAL
           C*** AREA, FCU(SOIL) IS THE FIELD
           C*** CAPACITY TO UTILIZE PRECIPITATION ON THE DISPOSAL AREA.  WE WILL N
           C*** IRRIGATE SHOULD THE SOIL MOISTURE BE GREATER THAN THE PERCENTAGE C
           C*** CAPACITY SPECIFIED BY THE VARIABLE PSMN.
0222            IF(SMUZ.GT.PSMN*FCU(SOIL)) GO TO 980
0223            IDISDA=IDISDA+1
0224            DISVOL=DSRATE*DSAREA
0225            IF(PONVOL.LE.DISVOL) GO TO 980
           C*** IF THE POND VOLUME IS LESS THAN THE VOLUME REQUIRED FOR ONE FULL
           C*** DAY OF IRRIGATION, IT WILL BE ASSUMED THAT NO IRRIGATION WILL
           C*** OCCUR ON THAT DAY.
0226            PONVOL=PONVOL-DISVOL
0227            GO TO 1000
0228        980 DISVOL=0.0
0229       1000 CONTINUE
```

```
              C
              C
              C***  UPDATE DISPOSAL DAY ACCOUNT
 0230               IF(DISVOL.GT.0.0) DSDAY=DSDAY+1
              C
              C
              C              *** CALCULATION OF FEEDLOT RUNOFF ***
              C
              C***  CALCULATE 3 DAY ANTECEDENT MOISTURE
 0231               AM=P1+P2+P3
 0232               P1=P2
 0233               P2=P3
 0234               P3=PRECIP
 0235               IF (SNOW.GT.0.0.AND.FROZE.EQ.0) GO TO 1020
 0236               IF(PRECIP.LE.0.0) GO TO 1100
 0237               IF (FROZE.EQ.1) GO TO 1080
 0238               IF(AM.LE.0.5.AND.PRECIP.LE.0.5) GO TO 1100
              C***  CALCULATE FEEDLOT RUNOFF USING 3 DAY ANTECEDENT MOISTURE
              C***  CONDITIONS AND A MODIFICATION OF THE SCS METHOD
 0239          1020 AM1=AM+PRECIP
 0240               PRESIP=PRECIP+SNOW
 0241               RC=97.0
 0242               IF(MONTH.LT.4.OR.MONTH.GT.10) GO TO 1040
 0243               IF(AM.LT.0.75) RC=91.0
 0244               IF(AM1.GT.GROW.AND.PRECIP.GT.GROW) PRESIP=GROW
 0245               GO TO 1060
 0246          1040 IF(AM.LT.0.50) RC=91.0
 0247               IF (SNOW.GT.0.0) RC=97.0
 0248               IF(AM1.GT.DORM.AND.PRECIP.GT.DORM) PRESIP=DORM
 0249          1060 CS=1000.0/RC-10.0
 0250               RUNOFF=(PRESIP-0.2*CS)**2/(PRESIP+0.8*CS)
 0251               RUNOFF=RUNOFF+PRECIP-PRESIP+SNOW
 0252               SNOW=0.0
 0253               IF(RUNOFF.GT.0.06) RUNOFF=RUNOFF-0.06
 0254               IF(PRESIP-0.2*CS.LT.0.0) GO TO 1100
 0255               GO TO 1120
 0256          1080 SNOW=SNOW+PRECIP
 0257          1100 RUNOFF=0.0
              C
              C
              C
              C             *** CALCULATION OF SURFACE AREA AND DETERMINATION OF
              C                  SURFACE EVAPORATION FROM STORAGE FACILITY ***
              C
              C***  THE FOLLOWING CALCULATION EXPRESSES THE VOLUME OF WATER IN THE
              C***  STORAGE FACILITY IN CUBIC FEET.
 0258          1120 IF(PONVOL.LE.0.0) GO TO 1160
              C
 0259               V=PONVOL*3630
              C***  THE FOLLOWING CALCULATIONS DETERMINE THE SURFACE AREA OF THE
              C***  STORAGE FACILITY AS A FUNCTION OF STORAGE VOLUME.  AREA IS IN
              C***  SQUARE FEET VOLUME IS IN CUBIC FEET.  THE STORAGE FACILITY IS
              C***  SHAPED LIKE A FRUSTRUM OF A PYRAMID.  INPUT PARAMETERS TO SIZE
              C***  THE FACILITY ARE (L) OF THE BASE IN FEET, WIDTH OF THE BASE(W) IN
              C***  FEET AND SLOPE OF INSIDE EMBANKMENTS GIVEN AS A RATIO OF RUN TO
              C***  RISE(S). IT IS ASSUMED THE POND DOES NOT LEAK. INPUTS TO THE
              C***  STORAGE  WILL BE RUNOFF AND PRECIPITATION. LOSSES FROM IT INCLUDE
              C***  EVAPORATION AND DISPOSAL VOLUME. B2 IS THE SURFACE AREA OF THE
```

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C***  LIQUID IN SQUARE FEET.
      HAPPX=(PCNVCL/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
C***  BY FREE SURFACE EVAPORATION.
      IF((SEVAP/3630).GT.PCNVCL) SEVAP=PONVCL*3630
      PCNVOL=PCNVCL-(SEVAP/3630)
      IF(PCNVOL.LE.0.0) PCNVCL=0.0
C
C***  THE VOLUMES OF CALCULATED RUNOFF FROM THE FEEDLOT AND
C***  PRECIPITATION FALLING ON THE FACILITY ARE ADDED TO THE VOLUME
C***  OF WATER IN THE STORAGE FACILITY(ACRE-IN).
      PCNVCL=PCNVCL+(RUNOFF*LTAREA)+(PRECIP*PSAREA)
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
C***  HAS OVERFLOWED AND IF SO, THE QUANTITY DISCHARGED
      DSCHRG=0.0
      IF(PCNVCL-VOLMAX) 1220,1220,1180
 1180 DSCHRG=PCNVCL-VOLMAX
      PCNVCL=VOLMAX
      WRITE(6,1200) NM,ND,YEAR,DSCHRG
 1200 FORMAT(20X,I2,'/',I2,'/',I2,'  ~  DISCHARGE OF',F10.2,' ACRE-IN')
C
C
 1220 SMACCT(NM,2)=SMACCT(NM,2)+PRECIP
      SMACCT(NM,3)=SMACCT(NM,3)+DISVOL/DSAREA
      SMACCT(NM,4)=SMACCT(NM,4)+IA
      SMACCT(NM,5)=SMACCT(NM,5)+RNOF
      SMACCT(NM,6)=SMACCT(NM,6)+DPERC
      SMACCT(NM,7)=SMACCT(NM,7)+AETLZ+AETLZ+SNOVAP
      SMACCT(NM,8)=SMACCT(NM,8)+SM-SMPD
      SMPD=SM
      PDACCT(NM,3)=PDACCT(NM,3)+RUNOFF*LTAREA/DSAREA
      PDACCT(NM,6)=PDACCT(NM,6)+SEVAP/(3630*DSAREA)
      PDACCT(NM,7)=PDACCT(NM,7)+DSCHRG/DSAREA
      PDACCT(NM,8)=PDACCT(NM,8)+(PONVOL-PDVCL)/DSAREA
      PDVCL=PCNVCL
      IF(PONVCL.GT.MAXVOL) MAXVCL=PCNVCL
C
 1240 CONTINUE
C
C
C        ***** EXIT DAILY LOOP *****
```

```
      C
      C      ***** EXIT DAILY LOOP *****
      C
0298           SMACCT(NM,1)=AMONTH(NM)
0299           PDACCT(NM,1)=AMONTH(NM)
0300           PDACCT(NM,2)=SMACCT(NM,2)*PSAREA/DSAREA
0301           PDACCT(NM,4)=DSDAY
0302           PDACCT(NM,5)=SMACCT(NM,3)
0303           DO 1260 J=2,8
0304           PDACCT(13,J)=PDACCT(13,J)+PDACCT(NM,J)
0305      1260 SMACCT(13,J)=SMACCT(13,J)+SMACCT(NM,J)
0306           SMACCT(13,1)=AMONTH(13)
0307           PDACCT(13,1)=AMONTH(13)
      C
0308      1280 CONTINUE
      C
      C      ***** EXIT MONTHLY LOOP *****
      C
0309           DSNOW=PACK-PACKPY
0310           PACKPY=PACK
0311           PCWW=((PDACCT(13,2)+PDACCT(13,3)-PDACCT(13,7))/
              1     (PDACCT(13,2)+PDACCT(13,3)))*100.
0312           WRITE(6,1300) YEAR
0313      1300 FORMAT('0',27X,'WATER ACCOUNT FOR STORAGE FACILITY (IN INCHES OVER
              1 DISPOSAL AREA) - 19',I2//9X,'-----------------------------------------
              2-------------------------------------------------------------------
              3---------------'/29X,'INFLOWS',50X,'OUTFLOWS'/17X,'---------------
              4-------------',23X,'----------------------------------------'/
              59X,'MONTH',3X,'PRECIPITATION',2X,'FEEDLOT RUNOFF',3X,'NO. DISPOSAL
              6 DAYS',3X,'DISPOSAL VOL.',2X,'SURFACE EVAP.',2X,'DISCHARGE',4X,
              7'CHANGE IN VOL.')
0314           WRITE(6,1320) ((PDACCT(I,K),K=1,8),I=1,13)
0315      1320 FORMAT(10X,A4,7X,F6.2,8X,F6.2,15X,F3.0,12X,F6.2,10X,
              1 F6.2,7X,F6.2,9X,F6.2)
0316           WRITE(6,1340) YEAR
0317      1340 FORMAT('0',35X,'WATER BALANCE (INCHES) IN THE DISPOSAL AREA - 19',
              1I2/10X,'-----------------------------------------------------------
              2-----------------------------------------------------------'/32X,
              3 'INPUTS',38X,'OUTPUTS'/21X,'----------------------------',3X,
              4------------------------------------------------'/9X,'MONTH',
              57X,'PRECIPITATION',4X,'IRRIGATION',3X,'INTERCEPTION',2X,'SURFACE R
              6UNOFF',3X,'PERCOLATION',8X,'AET',8X,'CHANGE IN SM')
0318           WRITE(6,1360) ((SMACCT(I,K),K=1,8),I=1,13)
0319      1360 FORMAT(10X,A4,7F15.2)
0320           WRITE(6,1380) PCWW
0321      1380 FORMAT('0',10X,'PERCENT OF WASTEWATER CONTROLLED=',F10.2)
0322           WRITE (6,1400) IDISDA
0323      1400 FORMAT('0',10X,'POTENTIAL DISPOSAL DAYS=',I4)
0324           WRITE(6,1420) PACK,DSNOW
0325      1420 FORMAT('0',10X,'PACK ON DECEMBER 31 =',F5.2,15X,
              1'CHANGE IN SNOW STORAGE=',F5.2)
0326           WRITE(6,1440)
0327      1440 FORMAT('0',10X,'INPUTS-OUTPUTS-CHANGE IN SNOW STORAGE=CHANGE IN
              1SOIL MOISTURE')
0328           MAXVOL=MAXVOL*100.0/VOLMAX
0329           WRITE(6,1460) MAXVOL
0330      1460 FORMAT('0',10X,'PERCENT OF MAXIMUM POND VOLUME REQUIRED =',F7.2)
0331           WRITE(6,1480) LKEVPT
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0332          1480 FCRMAT('0',10X,'ESTIMATED LAKE EVAPCRATICN, INCHES =',F6.2)     0062000C
0333          1500 CCNTINUE                                                         0C621000
             C                                                                      00622000
             C         ***** EXIT YEARLY LOOP *****                                 00623000
             C                                                                      00624CC0
0334          1520 STCP                                                             00625000
0335               END                                                              00626000
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STATICN: TOPEKA, KANSAS 1949 TC 1973

SIZE CF CRITICAL EVENT 6.10

FEECLCT AREA 4C.COACRES

PCND VARIABLES:

(A) BASE DIMENSICN- 400.00 FEET BY 200.00 FEET

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

(C) MAXIMUM DEPTH-- 9.CC FEET

(D) MAXIMUM PCND VCLUME-- 240.92 ACRE-INCHES

(E) CIRECT RECEIVING AREA (FOR PRECIPITATION) -- 2.65 ACRES

DISPCSAL AREA VARIABLES:

(A) CISPOSAL AREA-- 80.00 ACRES

(B) CROP-- SORGHUM

(C) SOIL TYPE-- 3 (SCS) SOIL TYPES)

(D) CISPOSAL RATE-- C.61 INCHES/DAY ON DISPCSAL DAYS

(E) IRRIGATICN MANAGEMENT-- IRRIGATICN BELCW 0.90 FIELD CAPACITY

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

WATER ACCOUNT FOR STORAGE FACILITY (IN INCHES OVER DISPOSAL AREA) - 1956

	INFLCWS			CUTFLCWS			
MCNTH	PRECIPITATION	FEEDLOT RUNOFF	NO. DISPCSAL DAYS	CISPCSAL VOL.	SURFACE EVAP.	DISCHARGE	CHANGE IN VCL.
JAN.	0.02	0.0	0.	C.C	0.01	C.0	0.02
FEB.	0.02	0.52	1.	0.61	0.C2	C.0	-C.C9
MAR.	C.01	0.C3	C.	0.0	0.07	0.0	-0.03
APR.	C.13	0.74	0.	0.0	C.12	C.0	0.75
MAY	C.C8	0.14	1.	0.61	0.17	C.0	-C.56
JUNE	C.18	C.92	C.	C.0	0.20	0.0	C.90
JULY	C.15	0.87	3.	1.83	0.22	0.0	-1.02
AUG.	C.C8	C.28	1.	0.61	0.10	C.0	-C.35
SEPT	0.03	0.16	C.	0.0	0.11	0.0	0.08
CCT.	0.04	0.0	0.	0.0	0.C9	C.0	-0.C5
NOV.	C.C6	C.45	C.	0.0	0.04	0.0	0.47
CEC.	0.03	0.00	0.	0.0	0.01	C.0	0.01
TOT.	C.84	4.11	6.	3.66	1.14	C.0	C.15

WATER BALANCE (INCHES) IN THE DISPOSAL AREA - 1956

	INPUTS		OUTPUTS				
MCNTH	PRECIPITATICN	IRRIGATICN	INTERCEPTICN	SURFACE RUNOFF	PERCOLATION	AET	CHANGE IN SM
JAN.	C.75	0.C	0.12	0.0	C.0	0.24	-0.12
FEB.	0.70	0.61	0.34	0.01	C.C	0.18	1.29
MAR.	0.42	0.0	0.29	0.00	0.0	C.19	-C.C6
APR.	3.94	0.0	0.51	1.58	C.0	1.06	0.79
MAY	2.36	0.61	0.90	0.33	C.0	1.57	0.17
JUNE	5.32	0.C	C.82	2.27	0.0	1.66	0.57
JULY	4.44	1.83	1.26	1.38	0.0	5.72	-2.09
AUG.	2.35	0.61	0.70	0.09	0.0	4.15	-1.58
SEPT	1.C2	0.0	C.10	0.00	0.0	1.11	-C.19
CCT.	1.33	0.0	0.40	0.0	0.C	C.29	0.64
NOV.	1.96	0.C	C.34	0.06	0.0	C.64	C.91
CEC.	0.76	0.0	C.48	0.0	0.0	0.18	0.10
TOT.	25.35	3.66	6.27	5.73	0.0	17.C0	0.01

PERCENT OF WASTEWATER CONTROLLED= 1C0.00

FOTENTIAL CISFOSAL DAYS= 155

PACK ON DECEMBER 31 = C.C CHANGE IN SNOW STCRAGE= 0.0

INFUTS-CUTFUTS-CHANGE IN SNOW STCRAGE=CHANGE IN SCIL MOISTURE

PERCENT CF MAXIMUM FCND VCLUME RECUIREC = 60.21

ESTIMATED LAKE EVAPORATICN, INCHES = 45.85

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

8/ 2/68 - DISCHARGE OF 57.66 ACRE-IN
8/ 9/68 - DISCHARGE OF 10.12 ACRE-IN
8/10/68 - DISCHARGE OF 37.69 ACRE-IN

WATER ACCOUNT FOR STORAGE FACILITY (IN INCHES OVER DISPOSAL AREA) - 1968

	INFLOWS			OUTFLOWS			
MONTH	PRECIPITATION	FEEDLOT RUNOFF	NO. DISPOSAL DAYS	DISPOSAL VOL.	SURFACE EVAP.	DISCHARGE	CHANGE IN VOL.
JAN.	0.03	0.21	0.	0.0	0.01	0.0	0.23
FEB.	0.02	0.0	0.	0.0	0.02	0.0	0.00
MAR.	0.02	0.09	0.	0.0	0.09	0.0	0.02
APR.	0.14	0.52	3.	1.83	0.14	0.0	-1.31
MAY	0.11	0.12	1.	0.61	0.14	0.0	-0.52
JUNE	0.11	0.61	1.	0.61	0.20	0.0	-0.09
JULY	0.34	2.96	1.	0.61	0.20	0.0	2.50
AUG.	0.24	1.58	5.	3.05	0.20	1.32	-2.34
SEPT	0.08	0.48	1.	0.61	0.14	0.0	-0.18
OCT.	0.14	1.07	0.	0.0	0.10	0.0	1.11
NOV.	0.05	0.21	1.	0.61	0.04	0.0	-0.39
DEC.	0.07	0.0	0.	0.0	0.01	0.0	0.06
TOT.	1.34	8.26	13.	7.93	1.28	1.32	-0.92

WATER BALANCE (INCHES) IN THE DISPOSAL AREA - 1968

	INPUTS		OUTPUTS				
MONTH	PRECIPITATION	IRRIGATION	INTERCEPTION	SURFACE RUNOFF	PERCOLATION	AET	CHANGE IN SM
JAN.	0.89	0.0	0.26	0.13	0.0	0.10	0.73
FEB.	0.56	0.0	0.27	0.03	0.09	0.10	0.05
MAR.	0.46	0.0	0.27	0.02	0.0	0.14	0.03
APR.	4.20	1.83	1.03	1.16	1.40	2.73	-0.29
MAY	3.37	0.61	0.92	0.39	0.07	2.29	0.31
JUNE	3.18	0.61	0.43	1.55	0.53	1.62	-0.34
JULY	10.17	0.61	1.08	4.87	0.0	5.58	-0.74
AUG.	7.40	3.05	1.31	3.67	0.0	6.22	-0.74
SEPT	2.50	0.61	0.62	0.48	0.0	3.54	-1.53
OCT.	4.19	0.0	0.58	2.05	0.0	0.93	0.63
NOV.	1.56	0.61	0.50	0.38	0.0	1.13	0.16
DEC.	2.10	0.0	0.30	0.67	0.0	0.50	0.41
TOT.	40.58	7.93	7.57	15.40	2.09	24.88	-1.32

PERCENT OF WASTEWATER CONTROLLED= 86.27

POTENTIAL DISPOSAL DAYS= 60

PACK ON DECEMBER 31 = 0.22 CHANGE IN SNOW STORAGE=-0.10

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

PERCENT OF MAXIMUM POND VOLUME REQUIRED = 100.00

ESTIMATED LAKE EVAPORATION, INCHES = 47.52

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

WATER ACCOUNT FOR STORAGE FACILITY (IN INCHES OVER DISPOSAL AREA) - 1970

	INFLOWS			OUTFLOWS			
MONTH	PRECIPITATION	FEEDLOT RUNOFF	NO. DISPOSAL DAYS	DISPOSAL VOL.	SURFACE EVAP.	DISCHARGE	CHANGE IN VOL.
JAN.	0.01	0.22	1.	0.61	0.01	0.0	-0.39
FEB.	0.01	0.0	0.	0.0	0.02	0.0	-0.01
MAR.	0.03	0.02	0.	0.0	0.03	0.0	0.03
APR.	0.12	1.00	1.	0.61	0.11	0.0	0.40
MAY	0.18	0.99	1.	0.61	0.16	0.0	0.40
JUNE	0.19	1.42	0.	0.0	0.22	0.0	1.40
JULY	0.05	0.08	3.	1.83	0.20	0.0	-1.90
AUG.	0.03	0.00	0.	0.0	0.17	0.0	-0.14
SEPT	0.25	1.91	2.	1.22	0.14	0.0	0.80
OCT.	0.08	0.25	0.	0.0	0.09	0.0	0.24
NOV.	0.04	0.0	0.	0.0	0.04	0.0	-0.00
DEC.	0.05	0.0	0.	0.0	0.01	0.0	0.04
TOT.	1.05	5.89	8.	4.88	1.20	0.0	0.86

WATER BALANCE (INCHES) IN THE DISPOSAL AREA - 1970

	INPUTS		OUTPUTS				
MONTH	PRECIPITATION	IRRIGATION	INTERCEPTION	SURFACE RUNOFF	PERCOLATION	AET	CHANGE IN S
JAN.	0.19	0.61	0.26	0.0	0.0	0.16	0.58
FEB.	0.34	0.0	0.21	0.00	0.0	0.05	0.07
MAR.	1.03	0.0	0.38	0.18	0.0	0.19	0.27
APR.	3.49	0.61	0.57	0.76	0.0	2.12	0.64
MAY	5.46	0.61	1.11	1.35	0.0	2.67	0.94
JUNE	5.82	0.0	0.88	2.49	0.0	1.57	0.88
JULY	1.39	1.83	0.63	0.05	0.0	5.62	-3.08
AUG.	0.83	0.0	0.44	0.0	0.0	2.48	-2.09
SEPT	7.70	1.22	1.24	2.70	0.0	1.93	2.44
OCT.	2.49	0.0	0.70	0.51	0.0	0.85	1.04
NOV.	1.23	0.0	0.47	0.12	0.0	0.33	0.31
DEC.	1.65	0.0	0.43	0.30	0.0	0.04	0.85
TOT.	31.62	4.88	7.33	8.47	0.0	18.02	2.84

PERCENT OF WASTEWATER CONTROLLED= 100.00

POTENTIAL DISPOSAL DAYS= 99

PACK ON DECEMBER 31 = 0.03 CHANGE IN SNOW STORAGE=-0.17

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

PERCENT OF MAXIMUM POND VOLUME REQUIRED = 76.67

ESTIMATED LAKE EVAPORATION, INCHES = 48.05

A CONTINUOUS WATERSHED MODEL FOR EVALUATION AND DESIGN OF FEEDLOT RUNOFF CONTROL SYSTEMS

by

Theodore A. Bean

B.S., Kansas State University, 1974

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements of the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
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1976

ABSTRACT

A continuous watershed model has been developed for the purpose of evaluation and design of feedlot runoff control systems. This computerized model programmed in the standard Fortran IV language basically consists of three components; 1) functions to generate runoff from the feedlot surface, 2) functions which simulate water movement and soil-moisture conditions within an agricultural disposal area, and 3) functions to monitor inflows, outflows, and water-level fluctuations of the storage facility. The functions used in this model are based on physical parameters which will enable use in any geographical province in the U.S. Required inputs consist of meteorological data, soil, and crop parameters which are readily available. The model may be used by designers, feedlot managers, and regulatory agencies for the evaluation and design of feedlot control systems.