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APPLICATION OF A COMPUTER MODEL IN DESIGNING KANSAS FEEDLOT WASTE CONTROL SYSTEMS

by

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A MASTER'S THESIS

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1977

Approved:

[Signature]
Major Professor
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INTRODUCTION

In compliance with Public Law 92-500, the Environmental Protection Agency (EPA) has set guidelines to control the problem of feedlot pollution. The effluent guidelines that are to be met by 1983 state that no discharge will occur except in the case of an extreme rainfall event (25 year - 24 hr storm or greater).

The Kansas feedlot industry is one of the major industries of the state [in 1975 - 2,264,000 animals, worth approximately $747 million (1)]. The resulting pollution hazard is of major concern. The magnitude of the problem for the United States as a whole might be best understood if the BOD loads from feedlots are compared to BOD loads caused by wastewater discharged by municipalities. Figure 1 is a comparison between these two sources, in which the two percent curves for feedlots represent the percentage of the total animal waste BOD generated which could be considered to be involved with the feedlot runoff (2). The two curves give a range for the expected BOD loads, since the exact quantity is not known. Figure 1 indicates the magnitude of the environmental problem associated with feedlots, is a matter of concern in an agricultural state such as Kansas. Presently, very few feedlot runoff control systems exist. This problem may be due in part to the lack of any type of design values for sizing control facilities and the effects management would play in their operation.

The objective of this thesis is to provide a uniform basis for the evaluation of feedlot runoff control systems and to propose a method for preliminary design of such facilities.
THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE. THIS IS AS RECEIVED FROM CUSTOMER.
Fig. 1. - Comparison of BOD Discharge to Streams From Municipalities and Animal Feedlots.
BACKGROUND

Through a grant from EPA, a computer model to simulate feedlot wastewater production and disposal techniques was developed at Kansas State University by Bean (3). The main objective of the grant was to develop a computer simulation program to evaluate the performance of feedlot disposal facilities for any location in Kansas. In addition, the program was to generate design criteria for sizing feedlot pond storage, and evaporation or land disposal facilities in Kansas.

An equation was postulated to establish the design criteria for the case of disposal to a cropped disposal area. The equation determines the pond size required to meet specific levels of wastewater control as a function of important variables as follows,

\[ V = V_{\text{Location}_{95-100}} \times C_{\text{Soil}} \times C_{\text{Crop}} \times C_{\text{DA/LA}} \]

\[ \times C_{\text{DSRATE}} \times C_{\text{H/HMAX}} \times C_{\text{PAVLU}} \]  

(1)

where

\[ V \] = volume of the pond;

\[ V_{\text{Location}_{95-100}} \] = a basic pond volume which depends on climate (location) and percent control required

\[ C_{\text{Soil}} \] = a coefficient for the particular disposal area soil

\[ C_{\text{Crop}} \] = a coefficient related to the crop grown on the disposal area

\[ C_{\text{DA/LA}} \] = a coefficient to account for the ratio of disposal area to feedlot area

\[ C_{\text{DSRATE}} \] = a coefficient reflecting the effect of disposal rate to the disposal area

\[ C_{\text{H/HMAX}} \] = a coefficient to account for variability of pond evaporation with pond shape
\( C_{PAVLU} \) = a coefficient accounting for the level of management, which in turn depends upon the available soil moisture (AVSM), where AVSM is defined as Field Capacity (FC) minus Permanent Wilting Point (PWP).

The case of feedlot disposal by pond evaporation was tested only where climatic conditions permit disposal in this manner. An equation for pure evaporation similar to Eq. (1) is

\[
SA = f(V_{\text{Location}})
\]

where \( SA \) = surface area, which depends only on location (that is, climate), if the pond depth is assumed constant.

In addition to these disposal techniques, this thesis also deals with revision of the program to incorporate multiple disposal areas into the program. The original computer program consisted of a single disposal area for irrigation from the pond. The revised multiple disposal area program has four disposal plots instead of only one. A more detailed description is given later on its operation. With the revised multiple disposal area program, comparisons are made to the original single area program to investigate the effect it has on the amount of water used for irrigation and the percent of wastewater controlled.
PROGRAM DESCRIPTIONS

The main components represented in the model are the feedlot, the pond, and the disposal area as shown in Fig. 2 (4).

The operation of each of these components is briefly described in this text, a more detailed description has been presented by Bean (3). Figure 3 (3, p. 5) is a flow chart showing the components of the program to be described.

Feedlot.--In the operation of the feedlot runoff section the first item to be considered is whether the precipitation or the soil is frozen, in which case it would be allocated to the snow accumulation account. If the average temperature is \(-1^\circ C (30^\circ F)\), the precipitation is snow. If the sum of the previous two day's average temperatures are \(>0^\circ C (64^\circ F)\), the soil is frozen. If the combined temperatures are greater than \(0^\circ C (64^\circ F)\), precipitation from rainfall on that day or snowmelt from the pack, or a combination of both, are involved in the runoff event. However, when conditions are dry, that is, the 3-day antecedent moisture conditions (AMC) and the precipitation is \(<1.3 \text{ cm (0.5 in.)}\), the runoff is considered to be zero in the program.

A modified version of the Soil Conservation Service (SCS) equation is used to calculate runoff from the feedlot. During the dormant season (November-March), a runoff curve number \(N=91\) is used when the 3-day AMC \(\leq 1.3 \text{ cm (0.5 in.)}\) and a maximum runoff of \(2.5 \text{ cm (1.0 in.)}\) is calculated by the equation. The fraction of any rainfall \(>2.5 \text{ cm (1 in.)}\) is added to the runoff for the day. During the growing season (April-October), a maximum runoff of \(3.2 \text{ cm (1.25 in.)}\) is calculated using \(N=91\) when AMC \(\leq 1.9 \text{ cm (0.75 in.)}\). Precipitation \(>3.2 \text{ cm (1.25 in.)}\) is allocated to runoff.
Fig. 2 - Process Schematic of Feedlot Runoff Model [Adapted From Zovne, et al. (4)]
Fig. 3. General Algorithm for Model [Adapted from Bean (3)].
A runoff curve number \( N = 97 \) is used in either season when \( AMC > 1.3 \text{ cm (0.5 in.)} \) in the dormant season, or \( > 1.9 \text{ cm (0.75 in.)} \) in the growing season.

The \( N \) values are used as follows

\[
S = \frac{1000}{N} - 10
\]  

(3)

where \( S \) is substituted into the SCS equation

\[
Q = \frac{(P - 0.2S)^2}{P + 0.88}
\]  

(4)

where \( Q = \) direct surface runoff

\( P = \) precipitation

\( S = \) the maximum potential difference between precipitation and runoff.

Figure 4 is a flowchart of the described operations of the feedlot.

**Pond.**—In the pond storage section, the inputs are wastewater runoff from the feedlot and direct rainfall. The losses from the pond are evaporation, irrigation disposal, and overflow discharge. The configuration of the standard pond is shown in Fig. 7.

Evaporation from the pond is at the lake evaporation rate. Irrigation water depends upon disposal area wetness and other factors to be discussed subsequently. Overflow discharge occurs when the pond's maximum depth is exceeded. Exfiltration losses from the pond are considered to be zero.

**Disposal Area.**—The variables included in the moisture balance of the disposal area is shown in the Disposal Area section of Fig. 2. The soil horizon is divided into an upper 30 cm (1 ft) zone and a lower 90 cm (3 ft) zone. Soil moisture is increased by the infiltrated portion of precipitation and runoff, and decreased by percolation and evapotranspiration (ET).
Fig. 4. Flow Chart of Calculated Feedlot Runoff.
Potential evapotranspiration is calculated using the Penman Combination Equation,

\[
\text{PET} = 0.039 \, \text{Ta}^{0.673} \left[ (1 - r) \, \text{Ra}(0.22 + 0.54 \, \text{PSUNS}) \\
- 2.010 \times 10^{-9} \, T^4 \left( 0.98 - a - b \, v \frac{\text{ES} \times \text{RHD}}{\text{PSUNS}} \right) \\
+ (1 - 0.039 \, \text{Ta}^{0.673}) \right] \times 0.26(e + 0.01 \, \text{WVD})(\text{ES} - \text{ES} \times \text{RHD})
\]

where

- \text{PET} = \text{potential evapotranspiration, in inches}
- \text{Ta} = \text{mean daily air temperature, in \(^\circ\text{F}\)}
- \text{T} = \text{mean daily air temperature, in \(^\circ\text{K}\)}
- \text{Ra} = \text{solar radiation, in mm of water}
- \text{PSUNS} = \text{percent sunshine, in \%/100}
- \text{ES} = \text{saturated vapor pressure at Ta, in millibars}
- \text{RHD} = \text{relative humidity, in \%/100}
- \text{WVD} = \text{wind travel, in miles/day.}

The variables \(a, b, e\) are constants determined for the location. The variable \(r\) is the reflectance coefficient (albedo). A value of \(r = 0.05\) is used for free water surfaces (pond evaporation), 0.23 for crops, and 0.20 for bare soil (5). The variable \(\text{ES}\) is the saturation pressure of air at the mean daily air temperature and is calculated by (3)

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

The total evaporation budget of the disposal area is composed of evaporation from water in interception storage, bare soil evaporation, and crop transpiration. Evaporation from interception storage is accomplished at the PET rate, with \(r = 0.20\).
Evaporation from the bare soil and crop transpiration is in two phases. When available soil moisture ($\theta_a$) is greater than 0.3 of the maximum available soil moisture ($\theta_{max}$), rates of water losses are at the PET rate. In the second phase, when $\theta_a < 0.3 \theta_{max}$, water losses of the bare soil are calculated by the following equation

$$E_s = c't^{1/2} - c'(t-1)^{1/2}$$  \hspace{1cm} (7)

where $E_s = \text{soil evaporation}$

$c' = \text{a hydraulic coefficient of the soil}$

$t = \text{the time after phase 1 evaporation}$

The $c'$ values for the twelve SCS soils have been tabulated by Bean (3, p.14).

Crop transpiration and evaporation from the soil upon which the crop is grown is designated as actual evapotranspiration (AET). In the second phase of evaporation, AET from the disposal area is calculated by the Blaney-Criddle Method (6)

$$\text{AET} = \text{PET} \times K \times \left(\frac{\theta_a}{0.3 \theta_{max}}\right)$$  \hspace{1cm} (8)

where $\theta_a = \text{actual available soil moisture}$

$K = \text{crop coefficient which depends upon crop stage of growth}$

The SCS equation, Eq. 4, is also used to compute runoff from the disposal area. $N$ values for the various soils have been tabulated by Bean (3, p.14). The initial abstractions (IA) must first be satisfied before surface runoff can occur. The IA consists of surface storage, interception losses, and water that infiltrates the soil prior to runoff. The maximum amount of this storage is fixed at 2.54 mm (0.1 in.).

The SCS method involves assigning runoff curve numbers to specific antecedent moistures, soil types, and land-use and conservation practices (4). The input $N$ values are based on condition II antecedent moisture.
Condition II is an upper zone soil moisture between 0.6 and 0.9 of available moisture during the dormant season, and 0.5 to 0.8 during growing season. When the soil moisture is less than 0.5 or 0.6 of available moisture, depending upon the season, N is assumed to be a condition I antecedent soil moisture given by

\[ N_I = N \times 0.39 e^{(-0.009 \times N)} \]  \hspace{1cm} (9)

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

\[ N_{III} = N \times 1.95 e^{(-0.00663 \times N)} \]  \hspace{1cm} (10)

The N values are then used in Eqs. 3 and 4 (4).

After runoff and interception amounts are deducted, the remaining excess precipitation infiltrates into the upper soil zone. The amount of water in this zone is limited to 0.9 of saturation, with any excess amount being released directly to the lower zone. If infiltration causes the upper zone moisture to be greater than field capacity, the moisture in excess of field capacity and not depleted by AET is cascaded in two days to the lower zone. When the field capacity of the lower zone is exceeded, the excess moisture above 0.9 field capacity and not depleted by AET is also cascaded downward in two days. Moisture in excess of 0.9 saturation is released directly downward. Excess from this zone is considered to percolate out of the root zone and is sometimes called groundwater recharge.

**Snowmelt.**—Snowmelt from the snowpack on the disposal area is approached on a degree day basis. As defined previously, precipitation occurring on a day with an average temperature \( \leq 0^\circ C \) (32°F) is considered snow. The snowmelt function (4) used in the model is

\[ M = C(Ta - Tb) \]  \hspace{1cm} (11)
in which \( M = \) snowmelt
\[ C = \) degree day coefficient
\[ Ta = \) mean daily atmospheric temperature
\[ Tb = \) base temperature.

This computes snowmelt as a result of atmospheric conditions. If snow is initially considered to be at 0°C (32°F), the equation to compute snowmelt by rainfall (4) is
\[ D = \frac{1}{144}(P)(Ta - 32) \]  
(12)
in which \( D = \) snowmelt by rainfall
\[ P = \) amount of precipitation
\[ Ta = \) mean daily temperature.

The constants used in this equation are 79 cal/g (144 BTU's/lb) for the heat of fusion of ice and 1 cal/g (1 BTU/lb) for the specific heat of water. The total snowmelt runoff \( (M+D) \) is added to the precipitation and disposal wastewater for the day.

**Multiple Disposal Areas.**--The program developed by Bean (3), used a single disposal area. As an attempt to more closely approximate typical agricultural management practices, a program having multiple disposal areas was developed from the original program.

Figure 5 is a flowchart of the multiple disposal area subroutine. The disposal area section of the program is set up so that it cycles through this section the number of times equal to the number of plots. If irrigation water is available, irrigation will occur on the plot having the lowest available soil moisture. If only one plot is used, the program is equivalent to the single area disposal program. If multiple plots are used, the individual plot area is specified and the size can be varied from
Fig. 5 - Flow Chart of Modification for Multiple Disposal Areas
plot to plot. Each individual plot can have any one of the seven crops on any one of the 12 soils programmed into the computer package. From the practical standpoint, however, plots should have equal areas and the same soil type.
CALIBRATION

The model was tested on five base stations; Colby, Ellsworth, Garden City, Independence, and Topeka. Five supplemental or satellite stations were required to adequately define irrigation facility requirements for Fig. 8. They are Belleville, Dodge City, Goodland, Hays, and Horton. They represent a good geographical cross-section of the state. In addition, they cover the statewide variations in the moisture deficit, which is defined as the difference between the long-term mean annual lake evaporation and the long-term mean annual precipitation. Each of these stations has the long term climatological data required for the simulation program. These are the maximum and minimum daily temperature and daily precipitation. Four of the base stations have at least 60 years of continuous data, while Topeka has a record on file of only 25 years.

Calibration of the model is an important first step in any simulation program. The most important calibration factor in the model is the adjustment of the computed average annual lake evaporation to the published values (7). Table 1 gives values for the ten stations.

In a calibration method developed by Bean (Personal communication), appropriate values of a, b, and e are selected for use in the Penman equation for PET. To justify calibration with respect to evaporation (lake), it should be noted that evaporation accounts for 80% loss from rainfall and streamflow into the state (personal communication -- Hyde S. Jacobs, Prof. of Agronomy, Kansas State University). In western Kansas, where rainfall and streamflow are both small, 98% is assumed to be lost by evapotranspiration. Calibration with respect to evaporation is not only justified, but vital, inasmuch as it plays such a large part in the water budget.
<table>
<thead>
<tr>
<th>Location</th>
<th>BASE STATIONS</th>
<th>Estimated Annual Lake Evaporation (cm (in))</th>
<th>Annual Precipitation (cm (in))</th>
<th>Moisture Deficit (cm (in))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colby</td>
<td></td>
<td>139.4 (54.9)</td>
<td>46.2 (18.2)</td>
<td>93.2 (36.7)</td>
</tr>
<tr>
<td>Ellsworth</td>
<td></td>
<td>115.1 (45.3)</td>
<td>68.6 (27.0)</td>
<td>46.5 (18.3)</td>
</tr>
<tr>
<td>Garden City</td>
<td></td>
<td>153.4 (60.4)</td>
<td>46.2 (18.2)</td>
<td>107.2 (42.2)</td>
</tr>
<tr>
<td>Independence</td>
<td></td>
<td>108.5 (42.7)</td>
<td>91.2 (35.9)</td>
<td>17.3 (6.8)</td>
</tr>
<tr>
<td>Topeka</td>
<td></td>
<td>110.7 (43.6)</td>
<td>87.1 (34.3)</td>
<td>23.6 (9.3)</td>
</tr>
<tr>
<td><strong>Supplemental Stations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belleville</td>
<td></td>
<td>103.1 (40.6)</td>
<td>76.2 (30.0)</td>
<td>26.9 (10.6)</td>
</tr>
<tr>
<td>Dodge City</td>
<td></td>
<td>158.0 (62.2)</td>
<td>52.6 (20.7)</td>
<td>105.4 (41.5)</td>
</tr>
<tr>
<td>Goodland</td>
<td></td>
<td>130.8 (51.5)</td>
<td>40.4 (15.9)</td>
<td>90.4 (35.6)</td>
</tr>
<tr>
<td>Hays</td>
<td></td>
<td>146.8 (57.8)</td>
<td>59.4 (23.4)</td>
<td>87.4 (34.4)</td>
</tr>
<tr>
<td>Horton</td>
<td></td>
<td>94.5 (37.2)</td>
<td>93.2 (36.7)</td>
<td>1.3 (0.5)</td>
</tr>
</tbody>
</table>
In calibrating the program, deep percolation and surface runoff averages from the disposal area were adjusted to reasonably expected values for the climate at the location. Since these values are indirectly determined, there is no way of confirming them, except to say they are reasonable.

In Table 2, the long-term percolation and runoff averages for each base station are compared. Values are compared for natural conditions (that is, no irrigation), and when the disposal area is irrigated. Under irrigated conditions, both percolation and runoff increase. Since irrigation rates are assumed to produce no runoff, the increased runoff is attributable to days when both irrigation and rainfall occur.
TABLE 2.—Long-Term (25 years or more) Average Values of Percolation and Runoff on Disposal Area\(^a\).

<table>
<thead>
<tr>
<th>Location and Time Period (1)</th>
<th>Natural Conditions</th>
<th>Irrigated Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Annual Percolation cm (in) (2)</td>
<td>Average Annual Runoff cm (in) (3)</td>
</tr>
<tr>
<td>Colby (1950-1974)</td>
<td>0.0 (0.0)</td>
<td>1.5 (0.6)</td>
</tr>
<tr>
<td>Ellsworth (1946-1970)</td>
<td>0.2 (0.1)</td>
<td>7.6 (3.0)</td>
</tr>
<tr>
<td>Garden City (1950-1974)</td>
<td>0.0 (0.0)</td>
<td>1.8 (0.7)</td>
</tr>
<tr>
<td>Independence (1948-1972)</td>
<td>0.5 (0.2)</td>
<td>22.9 (9.0)</td>
</tr>
<tr>
<td>Topeka (1949-1973)</td>
<td>0.8 (0.3)</td>
<td>19.6 (7.7)</td>
</tr>
</tbody>
</table>

\(^a\)Crops were all corn on the area soil types were 5 for Colby, Ellsworth, and Garden City; and 3 for Topeka and Independence.
TESTING

Evaporation.--The first phase of testing was to evaluate the percentage of wastewater controlled when disposal was by means of evaporation from the pond. The only variable of importance for this system is the pond's surface area, which is governed by the maximum depth and volume. In all runs, the pond maximum depth (HMAX) was held constant at 1.8 m (6 ft). The pond side slopes are 3:1 (run:rise) and length to width of base of the pond is 3:1, in all the test runs.

Single Disposal Area.--This phase of the testing was concerned with irrigation from the pond onto a single disposal area. The testing procedure was conducted to establish constants for use in Eq. 1.

The initial step was to establish standards for comparison. For a location, the standard run yielded the smallest pond volume required for 100% wastewater control. The latest 25 years of data for a given location was used as a standard testing period. Of these 25 years, the worst 10-12 year period was used for all comparison runs. The worst years were those requiring the greatest utilization of the pond storage capacity.

In the standard run for each location the crop on the disposal area was corn, the soil was a Type 5 with medium permeability for Kansas, the feedlot was 16.2 ha (40 ac) and the disposal area was 32.4 ha (80 ac), the irrigation rate was 1.3 cm/day (0.5 in/day), the irrigation management level was 90% (comparisons for Ellsworth were made at the 50% level), the maximum pond depth was 2.7 m (9 ft), and no irrigation occurred if the volume of water in the pond was less than 5% of the maximum volume. Table 3 shows the resulting dimensions.
TABLE 3.--Dimensions for Standard Ponds.

<table>
<thead>
<tr>
<th>Location</th>
<th>Length in m (ft)</th>
<th>Width in m (ft)</th>
<th>Maximum Depth in m (ft)</th>
<th>Maximum Pond Surface Area in m² (ac)</th>
<th>Maximum Pond Volume m³ (ac-in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colby</td>
<td>124 (405)</td>
<td>41 (135)</td>
<td>2.7 (9)</td>
<td>8000 (1.99)</td>
<td>17800 (174)</td>
</tr>
<tr>
<td>Ellsworth</td>
<td>183 (600)</td>
<td>61 (200)</td>
<td>2.7 (9)</td>
<td>15400 (3.81)</td>
<td>36200 (353)</td>
</tr>
<tr>
<td>Garden City</td>
<td>119 (390)</td>
<td>40 (130)</td>
<td>2.7 (9)</td>
<td>7600 (1.88)</td>
<td>16700 (163)</td>
</tr>
<tr>
<td>Independence</td>
<td>188 (615)</td>
<td>63 (205)</td>
<td>2.7 (9)</td>
<td>16100 (3.98)</td>
<td>37900 (370)</td>
</tr>
<tr>
<td>Topeka</td>
<td>265 (870)</td>
<td>88 (290)</td>
<td>2.7 (9)</td>
<td>29500 (7.30)</td>
<td>72300 (706)</td>
</tr>
</tbody>
</table>

**SUPPLEMENTAL STATIONS**

<table>
<thead>
<tr>
<th>Location</th>
<th>Length in m (ft)</th>
<th>Width in m (ft)</th>
<th>Maximum Depth in m (ft)</th>
<th>Maximum Pond Surface Area in m² (ac)</th>
<th>Maximum Pond Volume m³ (ac-in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belleville</td>
<td>174 (570)</td>
<td>58 (190)</td>
<td>2.7 (9)</td>
<td>14100 (3.50)</td>
<td>33000 (322)</td>
</tr>
<tr>
<td>Dodge City</td>
<td>137 (450)</td>
<td>46 (150)</td>
<td>2.7 (9)</td>
<td>9500 (2.36)</td>
<td>21500 (210)</td>
</tr>
<tr>
<td>Goodland</td>
<td>114 (375)</td>
<td>38 (125)</td>
<td>2.7 (9)</td>
<td>7100 (1.76)</td>
<td>15600 (152)</td>
</tr>
<tr>
<td>Hays</td>
<td>165 (540)</td>
<td>55 (180)</td>
<td>2.7 (9)</td>
<td>12500 (3.19)</td>
<td>30000 (292)</td>
</tr>
<tr>
<td>Horton</td>
<td>261 (855)</td>
<td>87 (285)</td>
<td>2.7 (9)</td>
<td>28600 (7.07)</td>
<td>70000 (683)</td>
</tr>
</tbody>
</table>
In the comparison runs, one of the standard variables was changed to obtain the range in percent wastewater controlled from a wide range of crops, soils, irrigation rates and management levels, and feedlot to disposal area ratios. The crops consisted of corn, wheat, grain sorghum, soy beans, pasture, and alfalfa. The twelve irrigation soil classes described in reference (3) were tested. The disposal rates tested were 1.3 cm/day (0.5 in./day), 2.5 cm/day (1.0 in./day), 3.8 cm/day (1.5 in./day), 5.1 cm/day (2.0 in./day). The feedlot area to disposal area ratios were 1:1, 1:2, 1:3, and 1:4. The irrigation management levels were 50% and 90% of available soil moisture. The 50% level represents a normal irrigation scheme in which water is only put on the crop when it is needed. The 90% level represents a high rate disposal option which puts water on the field whenever there is available storage.

**Multiple Disposal Areas.**—The third and final phase of testing was the use of the multiple disposal area program. The program was tested with these same standard variables, with the exception that the disposal area was subdivided into 4 equal sized areas each having the same crop on the same soil and 50% Management Level was used. It was not possible to consider different crops or soils within the plots. With 6 crops and 12 soil types the number of combinations is almost infinite and not seriously worth considering. The disposal rate in all runs was held constant at 5.1 cm/day (2 in./day) over the 4 hectares (10 acre) disposal area.
RESULTS

Evaporation.---The climatic variables for each station are given in Table 1 for comparison. Evaporation is governed by moisture deficit, so moisture deficit was used to develop a relationship between pond size and percent control. A large variation in this parameter (moisture deficit) is evident for Kansas, although more humid climates can have negative values.

From the test runs, Fig. 6 was constructed to show the resulting relationship between moisture deficit and the required pond size for design purposes. For any particular value of moisture deficit (LKET-PREC), a value of maximum pond surface area to feedlot area (ordinate value from Fig. 6) can be chosen within the 95-100% control limits. The pond area thus computed would control 95-100% of the total feedlot runoff generated over a long period of time. This range was used because below 95%, the number of discharges that occur are quite numerous. Caution must be taken, that the graphs are not extrapolated past there present points, especially at lower moisture deficits.

From this plot, meteorological averages for any location in Kansas can be used to size the necessary pond for wastewater control by evaporation. The only necessary data are the annual lake evaporation, precipitation, and the feedlot size.

\[ F(V_{\text{Location}}) = (\text{Feedlot Area})[F(MD)] \]  \hspace{1cm} (13)

\[ SA = F(V_{\text{Location}}) \]  \hspace{1cm} (14)

where \( SA \) = pond surface area for a 1.8 m (6 ft) depth

\( MD \) = moisture deficit

\( F(MD) \) = the ordinate value from Fig. 6, given the moisture deficit.
Fig. 6 - Relationship Between Moisture Deficit and Maximum Pond Surface Area/Feedlot Area For Evaporation Pond Design (Data Point Values Given in Table 4)
TABLE 4.--Data Used to Construct Evaporation Design Curve (Fig. 6).

<table>
<thead>
<tr>
<th>Location</th>
<th>Percentage Obtained %</th>
<th>Feedlot Area in acres</th>
<th>Maximum Pond Surface Area in acres</th>
<th>Max. Pond Area Feedlot Area (4)/(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topeka</td>
<td>99.8</td>
<td>40</td>
<td>52.6</td>
<td>1.32</td>
</tr>
<tr>
<td></td>
<td>97.8</td>
<td>40</td>
<td>41.2</td>
<td>1.03</td>
</tr>
<tr>
<td></td>
<td>83.9</td>
<td>40</td>
<td>33.6</td>
<td>0.84</td>
</tr>
<tr>
<td>Ellsworth</td>
<td>99.5</td>
<td>40</td>
<td>20.4</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>96.8</td>
<td>40</td>
<td>18.1</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>93.6</td>
<td>40</td>
<td>16.4</td>
<td>0.41</td>
</tr>
<tr>
<td>Independence</td>
<td>99.4</td>
<td>40</td>
<td>62.1</td>
<td>1.55</td>
</tr>
<tr>
<td></td>
<td>98.8</td>
<td>40</td>
<td>58.8</td>
<td>1.47</td>
</tr>
<tr>
<td></td>
<td>97.0</td>
<td>40</td>
<td>52.6</td>
<td>1.32</td>
</tr>
<tr>
<td>Garden City</td>
<td>100.0</td>
<td>40</td>
<td>7.2</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>97.7</td>
<td>40</td>
<td>5.9</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>94.5</td>
<td>40</td>
<td>5.2</td>
<td>0.13</td>
</tr>
<tr>
<td>Colby</td>
<td>99.5</td>
<td>40</td>
<td>7.2</td>
<td>0.18</td>
</tr>
</tbody>
</table>
Fig. 7 - Configuration of Storage Facility
[Adapted From Zovne, et al. (4)]
To illustrate the use of Fig. 6 and Eq. (14), the design of a pond for Ellsworth will be shown.

At Ellsworth, $L_K = 115$ cm (45.3 in.) and $P_R = 69$ cm (27.0 in.). Taking the difference between the two, moisture deficit = 46 cm (18.3 in.). With value from the abscissa of Fig. 6, values of 0.39 (95% wastewater control) and 0.55 (100% wastewater control) are read from the graph. With a feedlot size of 8.1 ha (20 ac), Eq. 13 yields a pond surface area of 3.2 ha (8 ac) for 95% control and 4.4 ha (11 ac) for 100 control.

To determine the pond volume from this surface area, the equation for a general prismatoid shown in Fig. 7 is used (5).

$$V = \frac{1}{6} h(B1 + 4Bm + B2)$$  \hspace{1cm} (14)

where $V$ = volume, in $m^3$ (ft$^3$)

$h$ = height, in $m$ (ft)

$B1$ = bottom surface area, in $m^2$ (ft$^2$)

$B2$ = top surface area, in $m^2$ (ft$^2$)

$Bm$ = area of a plane at $h/2$ above the bottom.

The computed values for Ellsworth with 95% control are,

$B2 = SA = 3.2$ ha (8.0 ac)

$B2 = L \times W$

$L = 3W$ (assumed)

$B2 = 3L^2$

$W = 103.9$ m (340.8 ft)

$L = 311.9$ m (1022.5 ft)

$$V = \frac{1}{6} \left(\frac{1}{6}\right) \left[\left(311.9 - 11.0\right)\left(103.9 - 11.0\right)\right.$$

$$\left.\left.+ \left(311.9 - 5.5\right)\left(103.9 - 5.5\right)\right) + \left(311.9\right)\left(103.9\right)\right]$$
\[ V = 55192 \text{ m}^3 \text{ (537 ac-in)} \]

where \( L \) = length of pond at the maximum wet depth

\( W \) = width of the pond at the maximum wet depth

**Single Disposal Area.**--The results for the irrigation disposal tests are summarized in Table 5. The numbers in Table 5 are ratios of the largest pond volume required for the test run to the largest pond volume required for the standard run. Both values were taken from the worst (requiring the largest pond volume) year in a particular run. This approach was taken rather than using the percent of wastewater controlled, as for evaporation, because it is a better indicator of the effects of various assumptions on the systems response.

In interpreting Table 5, the average of the values (Average of the Locations--column 7) will correspond to the variable it represents in Eq. 1, e.g., \( C_{\text{Soil}} \) for a soil 2 is 0.8. This would indicate a pond volume requirement that was 80% of the standard volume at the location if the soil was the only variable changed from the standard conditions.

For initial design purposes, Fig. 8 was constructed. In this graph, as with pure evaporation, the moisture deficit was assumed to be the key variable in determining pond volume. The two solid lines on Fig. 8 are to be used for design. The solid line for 100% Control has an \( r^2 = 0.85 \), giving a correlation coefficient of 0.92. These values are for all the stations except Independence. With Independence, the dashed line represents an \( r^2 = 0.71 \) for all ten stations. Comparing \( r^2 \) terms for both plots, it was felt that Independence was not a representative station, and was therefore dropped from the plot. \( V_{\text{Location 95-100}} \) is evaluated from Fig. 8 and the following relationship
TABLE 5.—Ratio of Pond Size for Other than Standard Conditions to Standard Conditions for Irrigation Disposal Design.

<table>
<thead>
<tr>
<th>Parameter (1)</th>
<th>Topeka (2)</th>
<th>Colby (3)</th>
<th>Ellsw. (4)</th>
<th>Garden City (5)</th>
<th>Indep. (6)</th>
<th>Average of the Locations (7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil 1</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>C_{soil}</td>
</tr>
<tr>
<td>Soil 2</td>
<td>0.86</td>
<td>0.91</td>
<td>0.84</td>
<td>0.72</td>
<td>0.84</td>
<td>0.83</td>
</tr>
<tr>
<td>Soil 3</td>
<td>1.00</td>
<td>1.00</td>
<td>1.02</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Soil 4</td>
<td>1.00</td>
<td>1.00</td>
<td>1.02</td>
<td>0.94</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td>Soil 5</td>
<td>1.00*</td>
<td>1.00*</td>
<td>1.00*</td>
<td>1.00*</td>
<td>1.00*</td>
<td>1.00*</td>
</tr>
<tr>
<td>Soil 6</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Soil 7</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.94</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td>Soil 8</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.94</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td>Soil 9</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.94</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td>Soil 10</td>
<td>0.96</td>
<td>1.00</td>
<td>1.02</td>
<td>0.88</td>
<td>0.99</td>
<td>0.98</td>
</tr>
<tr>
<td>Soil 11</td>
<td>0.86</td>
<td>0.91</td>
<td>0.88</td>
<td>0.72</td>
<td>0.99</td>
<td>0.87</td>
</tr>
<tr>
<td>Soil 12</td>
<td>0.69</td>
<td>0.91</td>
<td>0.79</td>
<td>0.72</td>
<td>0.83</td>
<td>0.79</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.81</td>
<td>0.91</td>
<td>1.13</td>
<td>0.42</td>
<td>0.80</td>
<td>C_{crop}</td>
</tr>
<tr>
<td>Sorghum</td>
<td>0.86</td>
<td>0.91</td>
<td>1.15</td>
<td>0.83</td>
<td>1.02</td>
<td>0.99</td>
</tr>
<tr>
<td>Corn</td>
<td>1.00*</td>
<td>1.00*</td>
<td>1.00*</td>
<td>1.00*</td>
<td>1.00*</td>
<td>1.00*</td>
</tr>
<tr>
<td>Beans</td>
<td>0.86</td>
<td>0.91</td>
<td>1.44</td>
<td>0.83</td>
<td>1.06</td>
<td>1.02</td>
</tr>
<tr>
<td>Pasture</td>
<td>0.79</td>
<td>0.91</td>
<td>0.91</td>
<td>0.54</td>
<td>0.82</td>
<td>0.78</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>0.79</td>
<td>0.91</td>
<td>0.88</td>
<td>0.54</td>
<td>0.83</td>
<td>0.79</td>
</tr>
</tbody>
</table>
TABLE 5 (Continued)

<table>
<thead>
<tr>
<th>Disposal Rate</th>
<th>C_{DSR\text{RATE}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.27 cm/day (0.50 in.)</td>
<td>1.00* 1.00* 1.00* 1.00* 1.00*</td>
</tr>
<tr>
<td>2.54 cm/day (1.00 in.)</td>
<td>0.83 1.00 0.95 0.94 0.78 0.90</td>
</tr>
<tr>
<td>3.81 cm/day (1.50 in.)</td>
<td>0.83 1.00 0.91 0.87 0.74 0.87</td>
</tr>
<tr>
<td>5.08 cm/day (2.00 in.)</td>
<td>0.83 1.00 0.86 0.84 0.73 0.85</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disposal Area</th>
<th>C_{DA/1A}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lot Area</td>
<td></td>
</tr>
<tr>
<td>1:1</td>
<td>1.20 1.00 1.05 1.06 1.28 1.12</td>
</tr>
<tr>
<td>2:1</td>
<td>1.00* 1.00* 1.00* 1.00* 1.00* 1.00*</td>
</tr>
<tr>
<td>3:1</td>
<td>1.00 1.00 0.86 0.93 0.95 0.97</td>
</tr>
<tr>
<td>4:1</td>
<td>1.00 1.00 0.91 0.89 0.94 0.85</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth Relationship</th>
<th>C_{H/HMAX}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.22 m (4 ft)</td>
<td>1.12 1.04 1.19 1.04 1.20 1.12</td>
</tr>
<tr>
<td>1.83 m (6 ft)</td>
<td>1.05 1.02 1.08 1.02 1.13 1.06</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Management</th>
<th>C_{PAVLV}</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% vs. 90%</td>
<td>2.36 1.38 1.27 1.06 1.14 1.44</td>
</tr>
</tbody>
</table>

*Standard Run
Fig. 8 - Relationship Between Moisture Deficit and Design Pond Volume/Constants (Data Point Values Given in Tables 6 & 7)
### TABLE 6.—Data Used to Construct Irrigation Design Curve for 100% Control (Fig. 8)\(^a\).

<table>
<thead>
<tr>
<th>Location</th>
<th>25 year - 24 hour storm (P-25)(^b) in.</th>
<th>Feedlot Area ac.</th>
<th>Volume Required ac-in.</th>
<th>Ordinate Value Fig. 8, (\frac{(4)}{(2)\times(3)})</th>
<th>Number of storms (\geq 25) yr - 24 hr. storm in the test period</th>
<th>A storm (\geq 25) yr - 24 hr. storm, occurred in the critical year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colby</td>
<td>4.5</td>
<td>40</td>
<td>169.7</td>
<td>0.94</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td>Ellsworth</td>
<td>5.4</td>
<td>40</td>
<td>385.5</td>
<td>1.78</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Garden City</td>
<td>4.5</td>
<td>40</td>
<td>169.8</td>
<td>0.94</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td>Independence</td>
<td>6.7</td>
<td>40</td>
<td>363.2</td>
<td>1.36</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td>Topeka</td>
<td>6.1</td>
<td>40</td>
<td>680.9</td>
<td>2.54</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td>Belleville</td>
<td>5.1</td>
<td>40</td>
<td>354.4</td>
<td>1.74</td>
<td>2</td>
<td>No</td>
</tr>
<tr>
<td>Dodge City</td>
<td>4.6</td>
<td>40</td>
<td>193.1</td>
<td>1.05</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>Goodland</td>
<td>4.3</td>
<td>40</td>
<td>145.3</td>
<td>0.84</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td>Hays</td>
<td>4.7</td>
<td>40</td>
<td>284.3</td>
<td>1.51</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>Horton</td>
<td>5.9</td>
<td>40</td>
<td>689.1</td>
<td>2.92</td>
<td>1</td>
<td>Yes</td>
</tr>
</tbody>
</table>

\(^a\)Moisture deficits obtained from Table 1.

\(^b\)Values from Ref. (7).
TABLE 7.—Data Used to Construct Irrigation Design Curve for 95% Control (Fig. 8).

<table>
<thead>
<tr>
<th>Location</th>
<th>25 yr. - 24 hr storm in. (2)</th>
<th>Feedlot Area ac. (3)</th>
<th>Volume Required ac-in (4)</th>
<th>Ordinate Value Fig. 8, (\frac{(4)}{(2) \times (3)})</th>
<th>Percentage Obtained % (6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colby</td>
<td>4.5</td>
<td>40</td>
<td>95.0</td>
<td>0.52</td>
<td>97.4</td>
</tr>
<tr>
<td>Ellsworth</td>
<td>5.4</td>
<td>40</td>
<td>144.1</td>
<td>0.67</td>
<td>96.7</td>
</tr>
<tr>
<td>Garden City</td>
<td>4.5</td>
<td>40</td>
<td>66.2</td>
<td>0.37</td>
<td>95.6</td>
</tr>
<tr>
<td>Independence</td>
<td>6.7</td>
<td>40</td>
<td>249.0</td>
<td>0.93</td>
<td>98.6</td>
</tr>
<tr>
<td>Topeka</td>
<td>6.1</td>
<td>40</td>
<td>185.7</td>
<td>0.76</td>
<td>94.6</td>
</tr>
<tr>
<td>Belleville</td>
<td>5.1</td>
<td>40</td>
<td>144.1</td>
<td>0.71</td>
<td>95.6</td>
</tr>
<tr>
<td>Dodge City</td>
<td>4.6</td>
<td>40</td>
<td>96.8</td>
<td>0.53</td>
<td>96.0</td>
</tr>
<tr>
<td>Goodland</td>
<td>4.3</td>
<td>40</td>
<td>60.6</td>
<td>0.35</td>
<td>95.6</td>
</tr>
<tr>
<td>Hays</td>
<td>4.7</td>
<td>40</td>
<td>96.8</td>
<td>0.51</td>
<td>95.7</td>
</tr>
<tr>
<td>Horton</td>
<td>5.9</td>
<td>40</td>
<td>240.9</td>
<td>1.02</td>
<td>96.4</td>
</tr>
</tbody>
</table>
\[ V_{\text{Location,95-100}} = P_{25} \text{(Feedlot area)} f(MD) \]  \quad (15)

where \( P_{25} \) = the 25 year-24 hour storm for the location (Table 6); and \( f(MD) \) = the appropriate ordinate value from Fig. 8 for either 95% or 100% control.

To determine if Eq. 1 is valid, comparisons are made between calculated values using Eq. 1 and actual runs. The following three examples are included to demonstrate the use of Eq. 1 and Fig. 8 for determining pond volume requirements.

Example 1:

Location: Ellsworth, Kansas

Feedlot Area: 40 acres

Disposal Area: 40 acres; Sorghum, Soil Type 5; 0.50 in./day, 50% Management Level

Design for 100% Control

\[ V = V_{\text{Location,100}} \times C_{\text{PAVLU}} \times C_{\text{DA/LA}} \times C_{\text{Crop}} \times \text{other} \]

\[ V_{\text{Location,100}} = (P-25) \times (\text{Feedlot Area}) \times (\text{Ordinate Value from Fig. 8}) \]

\[ V = (5.4 \text{ in.} \times 40 \text{ ac} \times 2.7) \times (1.44) \times (1.12) \times (0.99) \]

\[ V = 930 \text{ ac-in.} \]

Actual Volume Required from Test Program:

\[ V = 805 \text{ ac-in.} \]

Example 2:

Location: Garden City, Kansas

Feedlot Area: 40 acres

Disposal Area: 40 ac; Corn; Soil Type 5; 0.50 in./day; 50% Management Level
Design for 100% Control

\[ V = V_{Location} \times C_{PAVLU} \times C_{DA/LA} \]

\[ V = (4.5 \text{ in.} \times 40 \text{ ac} \times 0.95) \times (1.44) \times (1.12) \]

\[ V = 276 \text{ ac-in.} \]

Actual Volume Required from Test Program:

\[ V = 334 \text{ ac-in.} \]

Example 3:

Location: Topeka, Kansas

Feedlot Area: 40 ac

Disposal Area: 80 ac; Corn; Soil Type 3; 0.50 in./day; 90% Management Level

Design for 100% Control

\[ V = V_{Location} \times C_{Soil} \]

\[ V = (6.1 \text{ in.} \times 40 \text{ ac} \times 2.25) \times (1.00) \]

\[ V = 550 \text{ ac-in.} \]

Actual Volume Required from Test Program:

\[ V = 680 \text{ ac-in.} \]

**TABLE 8.**—Comparison of Design Equation to Actual Results

<table>
<thead>
<tr>
<th>Location</th>
<th>Volume from Actual Test ( m^3 ) (ac-in.)</th>
<th>Volume from Eq. 1 &amp; Fig. 8 ( m^3 ) (ac-in.)</th>
<th>Equation Volume Actual Volume x 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ellsworth</td>
<td>82500 (805)</td>
<td>95300 (930)</td>
<td>116</td>
</tr>
<tr>
<td>Garden City</td>
<td>34200 (334)</td>
<td>28300 (276)</td>
<td>83</td>
</tr>
<tr>
<td>Topeka</td>
<td>69700 (680)</td>
<td>56400 (550)</td>
<td>81</td>
</tr>
</tbody>
</table>
These examples and Table 9 show that the design procedure will result in a pond size within ±20% of the value predicted by the simulation program.

**Multiple Disposal Areas.**—The final results are concerned with comparisons of multiple disposal to single area disposal. Specifically, the tests were performed to determine whether multiple disposal would significantly reduce the size of facilities. Table 10 summarizes the results of these tests. All but one of the stations (Ellsworth) showed an increase in the amount of wastewater used for irrigation, resulting in better wastewater control.

**TABLE 9.**—Comparison of Single to Multiple Disposal Area Programs

<table>
<thead>
<tr>
<th>Location (1)</th>
<th>Single Area</th>
<th></th>
<th>Multiple Areas</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Irrigation Volume over Disposal Area in cm (in.) (2)</td>
<td>Percentage of Wastewater Controlled (3)</td>
<td>Irrigation Volume over Disposal Area in cm (in.) (4)</td>
<td>Percentage of Wastewater Controlled (5)</td>
</tr>
<tr>
<td>Colby</td>
<td>10.80 (4.25)</td>
<td>97.3</td>
<td>11.48 (4.52)</td>
<td>98.8</td>
</tr>
<tr>
<td>Ellsworth</td>
<td>16.89 (6.65)</td>
<td>100.0</td>
<td>16.10 (6.34)</td>
<td>90.3</td>
</tr>
<tr>
<td>Garden City</td>
<td>10.03 (3.95)</td>
<td>100.0</td>
<td>10.46 (4.12)</td>
<td>100.00</td>
</tr>
<tr>
<td>Independence</td>
<td>18.59 (7.32)</td>
<td>79.5</td>
<td>24.31 (9.57)</td>
<td>89.1</td>
</tr>
<tr>
<td>Topeka</td>
<td>17.78 (7.00)</td>
<td>81.6</td>
<td>23.62 (9.30)</td>
<td>87.8</td>
</tr>
</tbody>
</table>

*Standard volumes and conditions used for both programs, except irrigation management was at the 50% level instead of 90%, and a 40 ac disposal area (4 plots at 10 ac each for the multiple disposal area program) was used instead of 80 ac.*
CONCLUSIONS

Evaporation.—A graphical method for selecting the pond surface area for a given location was developed from the test runs. The relationship between moisture deficit and pond volume requirements for 95-100% control was derived as shown in Fig. 6. The preliminary sizing of evaporation ponds was shown to be a relatively simple procedure which involves the determination of moisture deficit from readily available published records of annual precipitation and evaporation.

Figure 6 indicates that the pond size for wastewater control >95% becomes very large for locations with a moisture deficits <51 cm (20 in.). An irrigation control system may be the more viable alternative for these locations.

In summary for control facilities for a 16.2 ha (40 ac) feedlot, the range of required surface area of a 1.8 m (6 ft) deep evaporation pond for Eastern Kansas is 10-17.8 ha (25-44 ac); for Central Kansas, the range is approximately 6-10 ha (15-25 ac); and for Western Kansas, less than 6 ha (15 acres).

Single Disposal Area.—The results shown in Table 5 may be interpreted as follows. 1) Soils. Essentially all soils except types 2, 11, and 12, produce the same results as the standard type 5 soil. Type 2 and type 11 and 12 soils reduced pond volume requirements. Thus, the soils really fall into only three major groups. The primary difference between types 2, 11, 12 and the others is that they have a smaller capacity for water storage (as available soil moisture), hence, these soil profiles fill up and dry up faster than the others, and more moisture is lost to percolation. 2) Crops. The difference
for crops is mainly between small grains (wheat, pasture, alfalfa) and row crops (sorghum, corn, soy beans). Small grains generally use more water because of their longer growing season, therefore the $C_{\text{Crop}}$ factors are less than one and facility requirements would be somewhat smaller for these crops.

3) Disposal Rate and Disposal Area. Increasing disposal rates or disposal areas by the previously prescribed increments, such as 1.3 cm/day (0.5 in./day) increased to 2.5 cm/day (1.0 in./day) produces the same change as increasing the feedlot to disposal area ratio as from 1:1 to 1:2. This is due to the fact that an equal amount of irrigation water is withdrawn from the pond as a result of doubling either one of these variables. The effect of increasing the disposal rate past 2.5 cm/day (1.0 in./day) or increasing the disposal area to greater than twice the feedlot area is inconsequential. This result appears due to the fact that the pond is pumped dry by the increased rates.

4) Pond Depth. Decreasing the maximum pond depth resulted in a larger volume requirement. As pond depth decreased (holding pond volume constant), the surface area is increased. Although evaporation is increased, so is the area exposed to precipitation. During wet periods when $L_{\text{KET}}$ is small, this larger surface area results in more water received from rainfall as well as the water from feedlot runoff.

5) Irrigation Management. Disposal Management shows that on the average, a pond having 44% more volume is required when irrigation is at soil moistures less than 50% versus irrigation at less than 90%. Topeka shows extreme changes due to management. This is due to the moisture deficit. The pond will have water in it more often and the disposal area will be wetter more often (due to the lower moisture deficit). The smaller moisture deficit keeps the available soil moisture high, above the 50% level more often, which limits irrigation.
Multiple Disposal Areas.—Using multiple disposal areas usually increases the percentage of wastewater controlled, thus decreasing the required pond size. The largest effect was at Independence where the increase in percent controlled was 9.6%. Otherwise, multiple disposal did not greatly effect facility requirements. On the average, a multiple disposal scheme reduces the required pond volume by approximately 2%, which is not large enough to justify its inclusion to correct the pond volume as calculated by Eq. 1.

One factor which should be discussed is Public Law 92-500 and control of feedlot runoff by using the 25 year - 24 hour storm storage criteria. Table 6 lists six of these storms as occurring during the simulation period. These were not always a factor in producing the worst year for runoff (that is, the year requiring the largest pond storage volume). In looking at Ellsworth and Horton, where the storms occurred in the most critical years, they were only indirectly responsible. They filled the ponds, but a later rainstorm or generally wet condition produced the maximum required storage.
SUMMARY

A feedlot runoff control model has been developed to improve the design of these facilities in Kansas. The testing of the program has resulted in guidelines and design approaches for sizing evaporation and irrigation disposal systems. The program for irrigation disposal schedules irrigation on the basis of soil moisture in the disposal area. This idealized control operation can only be achieved in reality by good management of the system by feedlot operators. Poor management would result in more frequently occurring discharges. Evaporation systems do not require this level of management, which makes this method attractive, particularly in Central and Western Kansas. In Eastern Kansas moisture deficits are low and the rainfalls high, which causes control facilities, either evaporation or irrigation, to be much larger.
APPENDIX I.—REFERENCES


APPENDIX II.--INPUT/OUTPUT

Input.--All input data, including dimensions of the facilities and calibration constants are input by the namelist option. Namelists ALPHA and BETA contain the following variables, which are grouped by type, as follows.

Feedlot Variables

LTAREA - feedlot area in acres

Pond Variables

L - pond length in feet
W - pond width in feet
HMAX - maximum pond height in feet
S - side slope in feet/foot
PCVMAX - minimum pond volume as a fraction of the maximum volume, below which no irrigation will occur. A value of 0.05 (5%) is normally used.

Disposal Area Variables

CROP - crop grown on the disposal area; wheat = 1, sorghum = 2, corn = 3, soybeans = 4, pasture = 5, alfalfa = 6, fallow soil = 7 (the number following the crop is the actual reference number in the program).

SOIL - soil type; SCS Soils 1-12. The soil type is input by integer corresponding to type. Soil parameters are pre-programmed into the source deck by type number.

DSAREA - disposal area in acres

DSRATE - depth of irrigation water applied to DSAREA in inches

PAVLJU - percentage upper zone available soil moisture
BRUNTA, BRUNTB, and E - values used for calibration of the model (Penman Equation)

STORM - values used for 25 year-24 hour storm at the location.

Other Variables

YSTART - year the data is started for the computer test run

YEND - year terminating the run

INDST - the number corresponding to the data set of the tape input

Caution must be used with these variables. The program only operates in the English system units tabulated above.

Multiple Disposal Area Program.--The only change in that CROP, DSAREA, and SOIL must be input for each plot up to NPLOTS, which is the number of separate plots.

As an aid to the programmer, the input variables are not only printed at the beginning of the program output, but at the end as well. Figure 9 is an example of the format of the input parameter print-out.

Output.--The computer output consists of monthly and annual summaries for each year, and a final summary for the total simulation period. Figure 10 is an example of an individual year (1958) account and the final summary for the simulation period is shown by Fig. 11.

In interpreting the value from a yearly summary, discharges and storms of a magnitude equal to or greater than the 25 year-24 hour storm are printed at the top. Figure 10 has one such storm. A water balance of the pond is printed next. This balance is expressed in inches over the disposal area. The number of disposal days in the actual number of days irrigation occurred. As a check, the sum of the inflows will equal the outflows in this account. As a comparison, the value for precipitation doesn't usually
STATION: BELLEVILLE, KANSAS 1944 TO 1973

CRITICAL EVENT- 5.10 INCHES

FEEDLOT AREA- 40.00 ACRES

POND VARIABLES:
(A) BASE DIMENSION-- 300.00 FEET BY 150.00 FEET
(B) SIDE SLOPE-- RUN: RISE = 3.0 : 1
(C) MAXIMUM DEPTH-- 9.00 FEET
(D) MAXIMUM POND VOLUME-- 144.10 ACRE-INCHES
(E) DIRECT RECEIVING AREA (FOR PRECIPITATION)-- 1.66 ACRES

DISPOSAL AREA VARIABLES:
(A) DISPOSAL AREA-- 90.00 ACRES
(B) CROP-- CORN
(C) SOIL TYPE-- 5 (SCS) SOIL TYPE
(D) DISPOSAL RATE-- 0.50 INCHES/DAY ON DISPOSAL DAYS
(E) IRRIGATION MANAGEMENT-- IRRIGATION BELOW 0.90 AVAILABLE MOISTURE
### Annual Summary

- **7/4/58 - Discharge of 1.81 acre-in**
- **7/5/58 - Discharge of 1.03 acre-in**
- **9/5/58 - Critical Event Exceeded**
- **9/6/58 - Discharge of 121.39 acre-in**
- **9/6/58 - Discharge of 32.35 acre-in**

#### Water Account for Storage Facility (in inches over disposal area - 1958)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>0.02</td>
<td>0.08</td>
<td>0.0</td>
<td>0.0</td>
<td>0.03</td>
<td>0.0</td>
<td>0.10</td>
</tr>
<tr>
<td>Feb.</td>
<td>0.02</td>
<td>0.20</td>
<td>0.0</td>
<td>0.0</td>
<td>0.03</td>
<td>0.0</td>
<td>0.10</td>
</tr>
<tr>
<td>Mar.</td>
<td>0.06</td>
<td>1.15</td>
<td>3.0</td>
<td>0.0</td>
<td>0.03</td>
<td>0.0</td>
<td>0.03</td>
</tr>
<tr>
<td>Apr.</td>
<td>0.04</td>
<td>0.04</td>
<td>3.0</td>
<td>1.11</td>
<td>0.03</td>
<td>0.0</td>
<td>-1.08</td>
</tr>
<tr>
<td>May</td>
<td>0.04</td>
<td>1.00</td>
<td>2.0</td>
<td>0.61</td>
<td>0.04</td>
<td>0.0</td>
<td>0.42</td>
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<tr>
<td>June</td>
<td>0.08</td>
<td>0.34</td>
<td>2.0</td>
<td>0.43</td>
<td>0.04</td>
<td>0.0</td>
<td>-0.46</td>
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<tr>
<td>July</td>
<td>0.20</td>
<td>2.50</td>
<td>6.0</td>
<td>2.50</td>
<td>0.05</td>
<td>0.0</td>
<td>0.04</td>
</tr>
<tr>
<td>Aug.</td>
<td>0.03</td>
<td>0.06</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.04</td>
</tr>
<tr>
<td>Sept.</td>
<td>0.24</td>
<td>5.25</td>
<td>3.0</td>
<td>1.50</td>
<td>0.03</td>
<td>1.93</td>
<td>0.79</td>
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<tr>
<td>Oct.</td>
<td>0.00</td>
<td>0.0</td>
<td>2.0</td>
<td>0.0</td>
<td>0.01</td>
<td>0.0</td>
<td>-0.04</td>
</tr>
<tr>
<td>Nov.</td>
<td>0.02</td>
<td>0.05</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.04</td>
</tr>
<tr>
<td>Dec.</td>
<td>0.00</td>
<td>0.02</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.04</td>
</tr>
<tr>
<td>Tot.</td>
<td>0.91</td>
<td>9.58</td>
<td>19.0</td>
<td>7.93</td>
<td>0.47</td>
<td>1.96</td>
<td>0.03</td>
</tr>
</tbody>
</table>

### Water Balance (inches) in the disposal Area - 1958

<table>
<thead>
<tr>
<th>MONTH</th>
<th>Precipitation</th>
<th>Irrigation</th>
<th>Interception</th>
<th>Surface Runoff</th>
<th>Percolation</th>
<th>AET</th>
<th>Change in SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>1.17</td>
<td>0.0</td>
<td>0.37</td>
<td>0.51</td>
<td>0.0</td>
<td>0.26</td>
<td>0.68</td>
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<tr>
<td>Feb.</td>
<td>0.86</td>
<td>0.0</td>
<td>0.24</td>
<td>0.35</td>
<td>0.0</td>
<td>0.37</td>
<td>0.25</td>
</tr>
<tr>
<td>Mar.</td>
<td>3.07</td>
<td>0.50</td>
<td>0.57</td>
<td>0.48</td>
<td>0.0</td>
<td>0.71</td>
<td>2.05</td>
</tr>
<tr>
<td>Apr.</td>
<td>1.82</td>
<td>1.11</td>
<td>0.99</td>
<td>0.10</td>
<td>0.0</td>
<td>2.17</td>
<td>-0.33</td>
</tr>
<tr>
<td>May</td>
<td>4.19</td>
<td>0.61</td>
<td>0.96</td>
<td>1.02</td>
<td>0.0</td>
<td>1.79</td>
<td>-1.22</td>
</tr>
<tr>
<td>June</td>
<td>3.63</td>
<td>0.17</td>
<td>1.97</td>
<td>3.72</td>
<td>0.0</td>
<td>3.69</td>
<td>-2.63</td>
</tr>
<tr>
<td>July</td>
<td>9.70</td>
<td>2.50</td>
<td>1.97</td>
<td>3.72</td>
<td>0.0</td>
<td>6.23</td>
<td>0.30</td>
</tr>
<tr>
<td>Aug.</td>
<td>1.62</td>
<td>0.0</td>
<td>0.45</td>
<td>0.0</td>
<td>0.0</td>
<td>5.53</td>
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</tr>
<tr>
<td>Sept.</td>
<td>11.69</td>
<td>1.50</td>
<td>1.11</td>
<td>3.52</td>
<td>0.0</td>
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<tr>
<td>Oct.</td>
<td>0.17</td>
<td>0.31</td>
<td>0.33</td>
<td>0.0</td>
<td>0.0</td>
<td>1.07</td>
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<td>Nov.</td>
<td>0.92</td>
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<td>1.13</td>
<td>0.0</td>
<td>0.0</td>
<td>0.84</td>
<td>-0.22</td>
</tr>
<tr>
<td>Dec.</td>
<td>0.00</td>
<td>0.0</td>
<td>0.21</td>
<td>0.0</td>
<td>0.0</td>
<td>0.27</td>
<td>-0.25</td>
</tr>
<tr>
<td>Tot.</td>
<td>39.88</td>
<td>7.93</td>
<td>6.32</td>
<td>9.29</td>
<td>0.0</td>
<td>24.10</td>
<td>3.55</td>
</tr>
</tbody>
</table>

**Percent of wastewater controlled** = 81.09

**Potential Disposal days** = 122

**Pack on December 31** = 0.0

**Change in snow storage** = -0.45

**Inputs-Outputs= Change in snow storage= Change in soil moisture**

**Percent of maximum pond volume required** = 100.00

**Estimated potential evapotranspiration, inches** = 35.73

**Estimated lake evaporation, inches** = 34.16
This book contains numerous pages with the original printing being skewed differently from the top to the bottom. This is as received from the customer.
METEOROLOGICAL SUMMARY

AVERAGE ANNUAL LAKE EVAPORATION = 40.55 INCHES
AVERAGE MAY - OCTOBER LAKE EVAPORATION, INCHES = 33.24 OR 82.0 % OF ANNUAL

AVERAGE ANNUAL PRECIPITATION = 30.03 INCHES
AVERAGE ANNUAL POTENTIAL EVAPOTRANSPIRATION = 37.12 INCHES
PRECIPITATION RANGE = 32.57 INCHES (FROM A LOW OF 15.90 INCHES TO A HIGH OF 48.47 INCHES)

SUMMARY OF POND OPERATIONS

NC. OF YEARS HAVING A DISCHARGE = 8
AVERAGE NO. OF DISCHARGES / YEAR HAVING A DISCHARGE = 6.38
AVERAGE DISCHARGE = 15.69 ACRE-INCHES
AVERAGE PERCENT OF WASTEWATER CONTROLLED = 95.61
TOTAL DISCHARGE VOLUME = 809.41 ACRE-INCHES
TOTAL NO. OF DISCHARGES = 51
MAXIMUM DISCHARGE = 132.21 ACRE-INCHES

SUMMARY OF DISPOSAL AREA

AVERAGE ANNUAL DEPTH OF WASTEWATER APPLIED = 5.43 INCHES OVER ENTIRE DISPOSAL AREA
AVERAGE ANNUAL DISPOSAL AREA RUNOFF = 4.57 INCHES
AVERAGE ANNUAL DISPOSAL AREA PERCOLATION = 1.33 INCHES
AVERAGE ANNUAL NO. OF DISPOSAL DAYS = 15.5
equal the precipitation value for the disposal area because the former 
values is the amount of rainfall on the pond surface divided by the disposal 
area, which is usually larger.

The next account balance is that of the disposal area. SM is the soil 
motion. Input minus Outputs minus change in Snow Storage equals the 
change in soil moisture. Below this account, account history pertaining 
to snow storage is given.

After the monthly accounts an overall summary is printed, which includes 
percent of wastewater controlled. This is calculated as follows;

\[
\text{Percent of Wastewater Controlled} = \frac{\Sigma \text{Inflows} - \Sigma \text{Discharges}}{\Sigma \text{Inflows}} \times 100\%
\]

Potential Disposal Days are the number of days in the year the soil 
motion falls below maximum available soil moisture times the management 
level PAVLU. Maximum Pond Volume is the maximum volume the wastewater 
ocupies in a year as compared to the maximum pond volume. Values up to 100\% 
are only obtained, any additional water is discharged. Estimated lake 
evaporation is the amount of water that would evaporate from the pond, if 
water was always available.

In interpreting the values from the Final Summary, Fig. 11, values 
labeled as averages are the yearly sums of that quantity divided by the 
number of years involved in the computer run. Values labeled as totals 
are sums of the yearly values for that particular quantity. In interpreting 
values in the multiple disposal program, values for all the plots are summed 
and then divided by the number of years and the number of plots, and are 
then entered in the Disposal Section as was done in the single area program.
APPENDIX III.—NOTATION

a constant in the Penman Equation
AET actual evapotranspiration, in inches
AMC antecedent soil moisture, in inches
b constant in the Penman Equation
C degree day coefficient for snowmelt, in in./day-°F
C_Crop coefficient related to disposal area crop
C_CA/LA coefficient related to ratio of feedlot area to disposal area
C_DSRATE coefficient related to disposal rate
C_H/HMAX coefficient to adjust for differing pond depths
C_PAVLV coefficient related to management of disposal
C_Soil coefficient related disposal area soil type
c' hydraulic coefficient of the soil, in mm day^{-1/2}
D snowmelt by rainfall
e constant in Penman Equation
ES saturation air pressure, in millibars
E_s soil evaporation
ET evapotranspiration
K crop coefficient
M snowmelt, in inches
MD moisture deficit, in inches
N runoff curve number
P precipitation, in inches
PET potential evapotranspiration, in inches
PSUNS percent sunshine
Q direct surface runoff, in inches
r reflectance coefficient
\( R_a \)  
solar radiation

RHD  
relative humidity

S  
maximum potential difference between precipitation and runoff

SA  
pond surface area, in acres

T  
average daily temperature (°K)

Ta  
average daily temperature (°C)

V  
pond volume, in ac-in.

\( V_{Location \text{ basic pond volume which depends on location and percent control required}}^{95-100} \)

\( \theta_a \)  
actual available soil moisture, in inches

\( \theta_{max} \)  
maximum available soil moisture, in inches
ILLEGIBLE DOCUMENT

THE FOLLOWING DOCUMENT(S) IS OF POOR LEGIBILITY IN THE ORIGINAL

THIS IS THE BEST COPY AVAILABLE
INTEGER CRP, FP, SCIL, STEND, YEAR, YEND, YSTART
DIMENSION PRT, PREV, KENV, NNODS
REAL IA, IAD, ISZ, KOD, KPS, KCE, LKE, LKEVPT, LKEVPT2, LKAREA, LKHA
REAL IRAVEL, LIREM, LIRESUB, LIREMAX, LW
DIMENSION AREA(1, IA, ISZ(1, 1))
DIMENSION ETC(1, IA, ISZ(1, 1)), T(1, IA, ISZ(1, 1))
DIMENSION ADD(1, IA, ISZ(1, 1)), ETU(1, IA, ISZ(1, 1)), ETL(1, IA, ISZ(1, 1)), IAD(1, IA, ISZ(1, 1)), IET(1, IA, ISZ(1, 1))
DIMENSION CMH, CMF, CMF2, CMF1
DIMENSION USCM, LUSCM, ETA(1, IA, ISZ(1, 1)), NIA(1, IA, ISZ(1, 1)), NKF(1, IA, ISZ(1, 1)), NKF2(1, IA, ISZ(1, 1)), NKF1(1, IA, ISZ(1, 1)), NKF2(1, IA, ISZ(1, 1)), NKF1(1, IA, ISZ(1, 1))
FORTRAN IV LEVEL 21

CMAIN

DATE = 77173 16/34/22

9' (SCS) SOIL TYPES: MID
11' INCHES DAY/CN DISPOSAL CAUSE
12' IRRIGATION RELAX 

**** ENTER YEARLY LOOP ****

0C77

EC 1500 NY=1, YEARS

EC 160 1=1,13

0C79

DN 150 J=1,6

C630

120 DESCSST/(1,J,1)=0.0

C681

140 CONTINUE

C682

DT 145 J=1,13

C683

DT 140 J=1,13

C684

DT 140 X=1, PLETS

C685

140 SMACT/(1,J,K)=0.0

C686

140 CONTINUE

C687

140 CONTINUE

C688

E DSO=(0.0

C689

MAXCEL=0.0

C690

LKEVPT=0.0

C691

VCLR=0.0

C692

IRM((Y,M,T)) MSTART=1

C693

PRPRF(I,1,160)

C694

160 FCN1M1(I,' 46X, * ANNUAL SUMMARY *** ***)

C695

**** ENTER MONTHLY LOOP ****

0C99

DO 1280 M=MSTART,12

C99

1280 PACE((1,1200+1,(152)), KAN,STAND, YEAR, MONTH, (PRECI1),I=1,31)

1(TMAMX(I),1=1,31),TMAMN(I),1=1,31)

C103

203 FCN1M2(I,' 42X, * MONTHLY SUMMARY *** ***)

C104

IF(PRECI1,I=0) GO TO 180

C105

IF(YEAR,LT,YSTART-1900) GO TO 180

C106

IF(YEAR,GT,YEND-1900) GO TO 180

C107

IF(MONTH,LT,YSTART,AND,YEAR,FY,YSTART-1900) GO TO 180

C108

ACTIF=5.0

C109

C110

C111

C112

C113

C114

C115

C116

C117

**** ENTER DAILY LOOP ****

01C7

DO 1240 ND=1,NDAYS

C7

TA VG IS THE AVERAGE DAILY AIR TEMPERATURE, DEGREE FAHRENHEIT

C8

TVDW(ND)-(TMAMX(ND)+TMAMN(ND))/2.0-100.0

C9

THE FOLLOWING STATEMENTS CORRECT FOR MISSING DATA ON INPUT TAPE

C10

IF(TAVG(ND),GT,120) TAVG(ND)=FOT

C11

IF(PRECI(ND),LT,0.1) PRECI(ND)=0.0

C12

THE FOLLOWING CAL P8 EVALUATES WHETHER THE 24 HOUR DESIGN STORM

C13

HAS BEEN EXCEEDED

C14

IF(PRECI(ND),GT,YSTART,AND,YEAR,(PRECI(ND))

C15

220 FCN1M3,(20X,12,/*,12,/*,12,/*, CRITICAL EVENT EXCEEDED */

C16

12X," FIG. 1" INCH STORM

C17

00000132
**FORTRAN IV**

```
C *** CALCULATION OF POTENTIAL EVAPOTRANSPIRATION BY MEANS OF PENMAN
    C EQUATION ***
    C
    C
0113  P=RCMCP
C***  THE FOLLOWING CARD CHECKS FOR SNOW COVER
    C
0114  IF(FCAPQ*GT.0.1) P=0.70
    C
0115  C***  THE NEXT TWO CARDS CONVERT TANG TO ABSOLUTE, DEGREE KELVIN
    C
0116  C=CTAUG(ND)-32.01*100.0/180.0
0117  AAST=CENT+273.16
    C
0118  C***  ES IS THE DAILY CALCULATED SATURATED VAPOR PRESSURE, IN MILLIBARS
    C
0119  ES=33.9*EXP((0.0073*CENT+0.872)*0.00010*AABS(1.0+CENT/48)
0120  1.0+0.0036
0121  IF(FCAPQLT.0.0) ES=0.0
    C
0122  C***  ESA IS THE DAILY CALCULATED ACTUAL VAPOR PRESSURE, IN MILLIBARS
    C
0123  ESA=ES=PONTO(ND)/100.0
    C
0124  C***  RN IS THE CALCULATED DAILY NET RADIATION, IN MJ OF WATER
    C
0125  AN=(1.0-FCAPQ)/(0.22+0.56*PSUNS(ND)-0.0135*FCAPQ)
0126  1.0+0.0036
0127  IF(FCAPQLT.0.0) AN=0.0
C***  WIND IS THE MONTHLY AVERAGE WINDRUN, MILES/DAY AT 2 METERS HEIGHT
0128  WIND=(MIN(NDM)/24.0+.55)*20.0
    C
0129  C***  EA IS THE CONVECTIVE LOSSES, MM WATER
    C
0130  EA=0.26*(PONTO(ND)/E-E-SA)
    C
0131  240 DELTA=0.0
0132  240 DELTA=0.0
0133  240 DELTA=0.0
0134  240 DELTA=0.0
0135  240 DELTA=0.0
C***  pet IS THE CALCULATED DAILY POTENTIAL EVAPOTRANSPIRATION, INCHES
0136  PET=(DELTA*AN*(GAMMA*EA/25.4)
    C
0137  C***  calculate lake and bare soil evaporation
0138  RNLKE=RNLKE*(1.0-0.201/4.0-0.83)
0139  RNLKE=RNLKE*(1.0-0.201/4.0-0.83)
0139  PETES=(PET=(1.0-0.201)*(GAMMA*EA/25.4)
0140  LKE=KE=(DELTA*AN*(GAMMA*EA/25.4)
0141  LKE=KE=(DELTA*AN*(GAMMA*EA/25.4)
0142  LKE=KE=(DELTA*AN*(GAMMA*EA/25.4)
0143  CONTINUE

C *** CALCULATION OF MOISTURE ADDED TO DISPOSAL AREA
    C
    C
0144  SNDVAP=0.0
0145  M=0.0
0146  PRECIP=PRECP(ND)
0147  WATER=PRECP
0148  IF(FCAPQ*GT.0.1) SNDVAP=PET
0149  PACK=PACK-SNVAP
0150  IF(TANGEND1-721) SNDVAP=0.0
0151  300 IF(PRECIP) 420.420,340
```
32) IF(PACK) 460,460,360
0153 343 PACK=PACK+PRECP
0154 WATER=0,0
0155 GO TO 460
C** MA IS SNOWMELT DUE TO ATMOSPHERIC CONDITIONS
0156 360 MA=0.08MA/(TAVG(MD)-36)
0157 IF(FLD,LT,0.01 MA=0.0
0158 IF(PACK=MA) 400,400,360
C** MR IS SNOWMELT DUE TO RAIN
0159 380 MR=PRECP/(TAVG(MD)-321)/144
0160 W=04/34
0161 IF(PACK=MR) 420,420,420
0162 430 PACK=0,0
0163 GO TO 440
0164 PACK=PACK-5
0165 440 PACK=PACK
0166 GO TO 460
C
C *** EVALUATION OF SOIL MOISTURE AND CALCULATION OF ACTUAL
C EVAPOTRANSPIRATION FROM DISPOSAL AREA ***
0167 460 FCHW=PISVCL
0168 DC 445 LK=1,APLETS
0169 Z(LK)=T(LK)
0170 G(LK)=E(LK)
0171 SPECIAL(LK)=SPECIAL(LK)
0172 ET(LK)=ET(LK)
0173 L25(MK)=L25(LK)
0174 L25(LK)=L25(LK)
0175 L25=0
0176 JJ=1
0177 RAIN=0
0178 RAINWATER
0179 AAAA=AAA
0180 IF(RAIN=1)GO TO 981
0181 DISVCL=0
0182 JJ=JJ+1
0183 459 CRP=AREA(JJ,1)
0184 SOIL=AREA(JJ,2)
0185 S=AREA=AREA(JJ)
0186 IF(DISVCL,GT,0.0)AND.PRECP.LT.0.4) GO TO 600
0187 IF(PRECV.LT.0.0) GO TO 380
C** CALCULATE SURFACE RUNOFF VOLUME BY SCS METHOD
0188 IF(S=S/F(P(RM,CRP)+K1,LK,LE,0.0)) GO TO 520
0189 IF(S=S/F(P(RM,SOIL)+K1,LK,LE,0.0)) GO TO 480
0190 IF(S=S/F(K2,SOIL)+C1) GO TO 500
0191 GO TO 940
C** MODIFY RUNOFF CURVE NUMBER TO CONDITION I ANTECEDENT MOISTURE
0192 480 RM=053l,CRP=RM(SOIL,CRP)+0.5*EXP(-0.5*Y+RM(SOIL,CRP))
0193 GO TO 500
C** MODIFY RUNOFF CURVE NUMBER TO CONDITION III ANTECEDENT MOISTURE
0194 500 RM=053l,CRP=RM(SOIL,CRP)+1.5*EXP(-0.5*Y+RM(SOIL,CRP))
0195 GO TO 500
0196 IF(S=S/F(K2,SOIL)+C1) GO TO 480
0197 IF(S=S/F(K2,SOIL)+C1) GO TO 500
0198 500 RM=053l,CRP=RM(SOIL,CRP)+1.5*EXP(-0.5*Y+RM(SOIL,CRP))
0199 500 GO TO 500
C 51=1000.0/RM(500,CRP)-10.0
0200 520 GO TO 520
0201 520 GO TO 520
0202 520 GO TO 520
0203 520 GO TO 520
0204 520 GO TO 520
0205 520 GO TO 520
0206 520 GO TO 520
0207 520 GO TO 520
0208 520 GO TO 520
0209 520 GO TO 520
0200 ER=RAIN-0.2*SI
0211 IF(SF=LT.0.01 GO TO 660
0222 PVCF=PVCF/2/(RAIN+0.8*SI)
0233 GO TO 620
0243 C*** EVALUATE INTERCEPTION STORAGE
0244 980 VUP=V0.0
0255 IA=4.0
0266 GO TO 640
0277 RNCF=6.0
0288 620 IA=0.1
0299 IF(IA.1.RAIN) IA=RAIN
0310 IF(IAA.1.IAADD(JJ)) IA=IAA-IAADD(JJ)
0321 C*** EVALUATE PERCOLATION INTO UPPER ZONE
0332 PERC=RAIN-PUCF-IA
0343 UZS=69.0
0354 C*** CALCULATE PRESENT STORAGE AVAILABLE IN UPPER ZONE
0365 SMLXJ=9.0+MAX(SMLXJ,SMUZ(JJ))
0376 C*** EVALUATE WATER CASCADING TO LOWER ZONE FOR STORAGE
0387 PERC=PUCF-SMNXU
0398 IF(PERC.0.01 PERCL=0.0
0409 IF(PERC.LT.0.01 PERCL=PERC)
0410 IF (SMUZ(JJ).LT.SMLXJ) GO TO 660
0421 EXCESS=SMLXJ
0432 GC TO 660
0443 C*** EVALUATE GRAVITATIONAL WATER IN UPPER ZONE
0454 660 EXCESS=SMUZ(JJ)-SMLXJ
0465 C*** IF THE GRASS IS ORMANT OR THE SOIL LIES FALLOW, SCIL
0476 C*** EVAPORATION IS EVALUATED
0487 690 IF(CKRCAPCFCP,AM,LE,0.01 GC TO 860
0500 C*** PMECYR BET BY THE PLANT CONSUMTIVE USE COEFFICIENT
0511 AM2=AM1*KRCAPCFCP
0522 T(JJ)=4.0
0533 C*** CHECK WHETHER SOIL MOISTURE LIMITS ARE FROM THE UPPER ZONE
0544 T(JJ)=6.0*(AVAILU-SCIL)
0555 IF(SMUI(JJ).LT.3.0*(AVAILU-SCIL)) SCILU=6.0 T(JJ)
0566 C*** CHECK WHETHER SOIL MOISTURE LIMITS ARE FROM THE LOWER ZONE
0577 SCILSCILU=SMUZ(JJ)-PWPLZ(JJ)
0588 SCIL=AVAILL-SCIL
0599 C*** CHECK WHETHER SOIL MOISTURE LIMITS ARE FROM BOTH ZONES UNDER WET CONDITIONS
0610 SCIL=SCIL+PWPLZ(JJ)
0621 GO TO 700
0632 AETL=0.3*ACT+
0643 GO TO 700
0654 C*** EVALUATE ART FROM BOTH ZONES UNDER WET CONDITIONS
0665 GO TO 700
0676 AETL=0.3*ACT+
0687 AETL=0.3*ACT+
0698 SCIL=AVAILU-SCIL
0709 IF(SMUI(JJ).LE.3.0*(AVAILU-SCIL)) PWPLZ(JJ)=0.0
0720 SCIL=AVAILU-SCIL
0731 C*** EVALUATE ART FROM THE LOWER ZONE WHEN LIMITED BY SOIL MOISTURE
0742 AETL=0.3*ACT+
0753 AETL=0.3*ACT+
0764 AETL=0.3*ACT+
0775 AETL=0.3*ACT+
0786 AETL=0.3*ACT+
0797 AETL=0.3*ACT+
0808 AETL=0.3*ACT+
0819 AETL=0.3*ACT+
0830 C*** EVALUATE ART FROM BOTH ZONES UNDER WET CONDITIONS
0841 C*** EVALUATE ART FROM BOTH ZONES UNDER WET CONDITIONS
0852 SCIL=AVAILU-SCIL
0863 SCIL=AVAILU-SCIL
0874 SCIL=AVAILU-SCIL
0885 SCIL=AVAILU-SCIL
0896 SCIL=AVAILU-SCIL
0907 SCIL=AVAILU-SCIL
0918 SCIL=AVAILU-SCIL
0929 SCIL=AVAILU-SCIL
0940 C*** EVALUATE ART FROM BOTH ZONES UNDER WET CONDITIONS
0951 C*** EVALUATE ART FROM BOTH ZONES UNDER WET CONDITIONS
CONTINUE
SCIL=1AREAIL(1,2)
SWATER=MUZ(JJ)-PWPUZ(SOIL)
SUMPS=NPCLS=1
DO 1253 MT=1,AECTPS
SNIL=1AREAM(TI,2)
IF(SNILJ(JJ,JJ)-PWPUZ(SOIL),LE,SWATER) SWATER=MUZ(JJ)-PWPUZ(SOIL)
CONTINUE
C C 00000332
C *** EVALUATION OF VOLUME DISPOSED ***
C T1 IS THE PREVIOUS DAY'S AVERAGE TEMPERATURE, IN FAHRENHEIT
C T2 IS THE AVERAGE TEMPERATURE OF THE DAY TWO DAYS PRIOR TO TODAY
C T2 IS THE AVERAGE TEMPERATURE OF THE DAY TWO DAYS PRIOR TO TODAY
C T2=1
C T2=TAVG(NO)
C IF(TFAZE=L,G,FROZE=1)
C IF(TFAZE=L,FROZE=1,PROZE=0)
C WHEN PROZE EQUALS 1 THE SOIL IS CONSIDERED TO BE FROZEN IT IS THAWED
C WHEN PROZE EQUALS 0
C IF(TFAZE=L,G) GO TO 590
C SNIL IS THE SOIL MOISTURE IN THE TOP 12 INCHES OVER THE DISPOSAL
C AREA; AVLFU IS THE AVAILABLE WATER CAPACITY OF THAT SOIL
C IRRIGATION WILL NOT OCCUR ON DAYS THAT THE SOIL MOISTURE IS AT
C A LEVEL GREATER THAN THAT OF THE PERCENTAGE OF AVAILABLE WATER
C SPECIFIED BY THE VARIABLE PAULU.
C SDIL=1AREACL(1,2)
C IF(SNILJ(JJ,JJ),PCL1,*G(PAULU=AVLFU(SOIL)+PWPUZ(SOIL))) GO TO 990
C IDISMA=IDISGA=1
C IF(PENV=*L,PKMVMAX=VCLMAX) GO TO 990
C DISVOL=DISVATER/2
C DISVOL=DISVATER/2
C IF THE PCL1 VOLUME IS LESS THAN THE VOLUME REQUIRED FOR ONE FULL
C DAY OF IRRIGATION, IT WILL BE ASSUMED THAT NO IRRIGATION WILL OCCUR
C ON THAT DAY.
C PENV=PKMV=PKMV+GDISVOL
C IF(PENV=PKMV+GDISVOL) GO TO 1000
C DISVOL=DISVCL+DISVOL
C PENV=GDISVCL
C GO TO 1000
C DISVCL=0
C C 00000354
C *** DAY OF IRRIGATION, IT WILL BE ASSUMED THAT NO IRRIGATION WILL OCCUR
C *** ON THAT DAY.
C PENV=PKMV+GDISVOL
C IF(PENV=PKMV+GDISVOL) GO TO 1000
C DISVOL=DISVCL+DISVOL
C PENV=GDISVCL
C GO TO 1000
C DISVCL=0
C C 00000358
C C *** UPDATE DISPOSAL DAY ACCOUNT
C 1000 IF(DISVCL=3.01) OOSDAY=OOSDAY+1
C C C 00000362
C C *** CALCULATE 3 DAY ANTECEDENT MOISTURE
C 00000365
C C 00000366
C C 00000369
0329 APE=P14*P2*P3
0330 P1=92
0331 P2=93
0332 P3=P16
0333 IF (SNOW.GT.0.0.AND.FROZEN.EQ.0.0) GO TO 1020
0334 IF (PRECIP.LE.0.0) GO TO 1100
0335 IF (FROZEN.EQ.1.0) GO TO 1080
0336 IF (AIREQ.EQ.0.0.AND.PRECIP.EQ.0.0) GO TO 1120
C*** CALCULATE FEEDLOT RUNOFF USING 3 DAY ANTECEDENT MOISTURE CONDITIONS
C** MODIFICATION OF THE SCS METHOD
0337 1020 AM1=AM*PRECIP
0338 PRESIP=PRECIP+SNOW
0339 RG=0.70
0340 IF (MONTH.GT.4.AND.MONTH.GT.10.0) GO TO 1040
0341 IF (AM1.GT.0.75) RG=1.0
0342 IF (AM1.GT.0.75.AND.PRECIP.GT.DORM) PRESIP=GROW
0343 GO TO 1300
0344 1040 IF (AM1.LT.0.501) RG=1.0
0345 IF (SNOW.GT.0.0) RG=1.0
0346 IF (AM1.GT.0.75.AND.PRECIP.GT.DORM) PRESIP=DORM
0347 1060 CS=1000.0/RC=10.0
0348 RUNOFF=(PRECIP-3.2*CS)/(PRECIP+0.8*CS)
0349 RUNOFF=RUNOFF+3.2*CS
0350 SNOW=0.0
0351 IF (RUNOFF.GT.0.06) RUNOFF=RUNOFF+0.06
0352 IF (AM1.GT.0.29*CS.LT.0.0) GO TO 1100
0353 GO TO 1120
0354 1100 RUNOFF=0.0
0355 IF (AIREQ.EQ.0.0) GO TO 1120
0356 1120 RUNOFF=RUNOFF+1.0*AIREQ(3)
C
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.
C*** VOLUME = V - PENVOL*VOL
C 0358 1120 IF (PCONVOL.LT.0.0) GO TO 1160
C
C 0359 V=PENVOL*VOL
C
C*** THE FOLLOWING CALCULATIONS DETERMINE THE SURFACE AREA OF THE STORAGE
C*** VOLUME AS A FUNCTION OF STORAGE VOLUME. AREA IS IN SQUARE FEET
C*** VOLUME IS IN CUBIC FEET. THE STORAGE FACILITY IS SHAPED LIKE AN INVERTED
C*** PARABOLA.
GO TO 1140
IF (NOGT-HMAX) H-HMAX
N2=(W+2.*S)/(L+2.*S)
IF (FROZEN=.F.,11) LAKEVP=.0
KEYF=KEYF+LAKEVP
SEVP=SEVP+2.*(LAKEVP/12)
C**= SEVP IS THE VOLUME OF WATER EXTRACTED FROM THE STORAGE FACILITY BY
C**= FREE SURFACE EVAPOTRANSPIRATION.
C**= THE VOLUMES OF CALculated RUNOFF FROM THE FLOODPLATE AND PRECIPITATION
C**= FALLING ON THE FACILITY ARE ADDED TO THE VOLUME OF WATER IN THE STORAGE
C**= FACILITY (ACRE=IN).
C**= PEVNL-PENVCL=SEVP+SEVP/360
C**= IN ACRE=IN.
C**= THE VOLUME OF WATER REMAINING AT THE END OF THE DAY IS EXPRESSED
C**= OVERFLOWED AND IF SO, THE QUANTITY DISCHARGED
C**= DSC=0
IF (PENVNL-VCLMAX) 1220,1,1
DSC=DSC+VCLMAX
PENVNL-VCLMAX
IF (PENVNL-VCLMAX) 1330,1,1
PENVNL-VCLMAX
1230 PENVNL-VCLMAX=DSCHAG=DSCHAG+
1340 IF (DSCHAG) PEAK=DSCHAG
1350 IF (YEPK) PEAK=PEAK
1360 CONTINUE
C**= THE FOLLOWING STATEMENTS DETERMINE WHETHER THE STORAGE FACILITY HAS
C**= 1220 CONTINUE
O0000426
O0000427
O0000428
O0000429
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O0000459
O0000460
O0000463
O0000464
O0000465
O0000466
O0000469
O0000470
O0000471
3 'INPUTS',3,9X,'OUTPUTS'/21X,'-------------------------',3X,*000000512
4 '-------------------------',9X,'MONTH',*000000913
5X,'PRECIPITATION',6X,'IRRIGATION',3X,'INTERCEPTION',2X,'SURFACE
6UNOFF,3X,'PERCOLATION',8X,'AT',8X,'CHANGE IN SM'
000000915
0447 WRITE(6,1360) (SMAGCT(I,K,J),K=1,8),I=1,13
0449 FORMAT(10X,A,9,F15.2)
0450 CONTINUE
0451 WRITE(6,1340) RW
0452 FORMAT(10X,A,10X,PERCENT OF WASTEWATER CONTROLLED=,F10.2)
0453 WRITE(6,1403) [DISDA]
0454 FORMAT(10X,I1X,POTENTIAL DISPOSAL CASY=,I4)
0455 WRITE(6,1420) [PACK,DSNW]
0456 WRITE(6,1420) [PACK ON DECEMBER 31 = ,F5.2,15X],
0457 'CHANGE IN SNOW STORAGE' = F5.2)
0458 WRITE(6,1440) [PACK]
0459 WRITE(6,1460) [PACK]
0460 FORMAT(10X,A,10X,PERCENT OF MAXIMUM POND VOLUME REQUIRED = ,F7.2)
0461 EVAP=EVAP+LKEVPT
0462 WRITE(6,1480) [LKEVPT]
0463 WRITE(6,1480) [ESTIMATED LAKE EVAPORATION, INCHES = ,F6.2]
0464 CONTINUE
0465 C
0466 C
0467 C
0468 C
0469 C
0470 C
0471 C
0472 C
0473 CM=CM+1
0474 CONT=KASTAW/YEARS
0475 IFAVOL=AVOL/YEARS
0476 PERJS=SPERC/YEARS
0477 IFST=STRAIN/YEARS
0478 DAYS=50/ENOS/YEARS
0479 CHANGE=TPEG/YEARS
0480 RANGE=MT-DAY
0481 WRITE(6,110) NAME,F,CITY,AND,STATE,YSTART,YEND,STORM,LTAREA,L,4,5,00000072
0482 WRITE(6,112) [MAX,WMAX,PSAREA,TAREA,KEPH,RSP,SOIL,DSRATE,PAVLU]
0483 WRITE(6,112) [AVO]--0
0484 WRITE(6,125) [AVO]
0485 WRITE(6,155) [METEOROLOGICAL SUMMARY]
0486 WRITE(6,155) [AVO]
0487 WRITE(6,155) [AVO]
0488 WRITE(6,155) [AVO]
0489 WRITE(6,162) [AVO]
0490 WRITE(6,162) [AVO]
0491 WRITE(6,162) [AVO]
0492 WRITE(6,162) [AVO]
0493 WRITE(6,162) [AVO]
1580 FORMAT('0', '25X', 'AVG. NO. OF DISCHARGES / YEAR HAVING A DISCHARGE >', 'F6.2')
1590 COUNT
1600 FORMAT('0', '25X', 'AVERAGE NO. OF DISCHARGES / YEAR HAVING DISCHARGE <=', 'F6.2')
1610 WRITE(6, 1620) DESCRC
1620 FORMAT('0', '25X', 'AVERAGE DISCHARGE=', 'F6.2, 1X, 'ACRE-INCHES')
1630 WRITE(6, 1640) CCMPL
1640 FORMAT('0', '25X', 'AVERAGE PERCENT OF WASTEWATER CONTROLLED=', 'F6.2')
1650 WRITE(6, 1660) DESCVR
1660 FORMAT('0', '25X', 'TOTAL DISCHARGE VOLUME=', 'F6.2, 1X, 'ACRE-INCHES')
1670 WRITE(6, 1680) CCMPL
1680 FORMAT('0', '25X', 'TOTAL NO. OF DISCHARGES=', 'F4.0')
1690 WRITE(6, 1700) FFCAK
1700 FORMAT('0', '25X', 'MAXIMUM DISCHARGE=', 'F6.2, 1X, 'ACRE-INCHES')
1710 WRITE(6, 1720) IPRVD
1720 FORMAT('0', '25X', 'AVERAGE ANNUAL DEPTH OF WASTEWATER APPLIED=', 'F6.2, 1
1' INCHES OVER ENTIRE DISPOSAL AREA')
1730 WRITE(6, 1740) INCHES
1740 FORMAT('0', '25X', 'AVERAGE ANNUAL DISPOSAL AREA RUNOFF=', 'F6.2, 1 INCHES')
1750 WRITE(6, 1760) INCHES
1760 FORMAT('0', '25X', 'AVERAGE ANNUAL DISPOSAL AREA PERCOLATION=', 'F6.2, 1
1INCHES')
1770 WRITE(6, 1780) INCHES
1780 FORMAT('0', '25X', 'AVERAGE ANNUAL NO. OF DISPOSAL DAYS=', 'F6.1')
1790 STOP
1800 END
STATION: TOPEKA, KANSAS 1973 TO 1973

SIZE OF CRITICAL EVENT 6.10

FEEDLOT AREA 40.00 ACRES

PCND VARIABLES:
(A) BASE DIMENSION—870.00 FEET BY 290.00 FEET
(B) SIDE SLOPE—RLN: RISE = 3.0 : 1
(C) MAXIMUM DEPTH—9.00 FEET
(D) MAXIMUM PCND VOLUME—705.60 ACRE-INCHES
(E) DIRECT RECEIVING AREA (FOR PRECIPITATION) — 7.30 ACRES

DISPOSAL AREA VARIABLES:
(1) DISPOSAL AREA—40.00 ACRES
(2) CRCP—CCRN
(3) SOIL TYPE—5 (SCS) SOIL TYPES
(4) DISPOSAL RATE—0.50 INCHES/DAY ON DISPOSAL DAYS
(5) IRRIGATION MANAGEMENT—IRRIGATION BELOW 0.50 FIELD CAPACITY
### Annual Summary

**9/27/73** - DISCHARGE CF: 2.67 ACRES-IN
**9/29/73** - DISCHARGE CF: 2.67 ACRES-IN
**10/1/73** - DISCHARGE CF: 3.00 ACRES-IN
**10/7/73** - DISCHARGE CF: 2.67 ACRES-IN
**10/14/73** - DISCHARGE CF: 2.67 ACRES-IN
**10/21/73** - DISCHARGE CF: 2.67 ACRES-IN
**10/28/73** - DISCHARGE CF: 2.67 ACRES-IN
**11/1/73** - DISCHARGE CF: 2.67 ACRES-IN
**11/8/73** - DISCHARGE CF: 2.67 ACRES-IN
**11/15/73** - DISCHARGE CF: 2.67 ACRES-IN
**11/22/73** - DISCHARGE CF: 2.67 ACRES-IN
**11/29/73** - DISCHARGE CF: 2.67 ACRES-IN
**12/6/73** - DISCHARGE CF: 2.67 ACRES-IN
**12/13/73** - DISCHARGE CF: 2.67 ACRES-IN
**12/20/73** - DISCHARGE CF: 2.67 ACRES-IN
**12/27/73** - DISCHARGE CF: 2.67 ACRES-IN
**12/30/73** - DISCHARGE CF: 2.67 ACRES-IN
**12/31/73** - DISCHARGE CF: 2.67 ACRES-IN

**WATER ACCOUNT FOR STORAGE FACILITY (IN INCHES OVER DISPOSAL AREA) — 1973**

<table>
<thead>
<tr>
<th>MONTH</th>
<th>PRECIPITATION</th>
<th>FEEDLOT RUNOFF</th>
<th>NC. DISPOSAL DAYS</th>
<th>DISPOSAL VOL.</th>
<th>SURFACE FVAP.</th>
<th>DISCHARGE</th>
<th>CHG. IN VOL.</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAN.</td>
<td>0.45</td>
<td>0.75</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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</tr>
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<td>0.00</td>
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<td>0.00</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>4.27</td>
</tr>
<tr>
<td>APR.</td>
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<td>1.15</td>
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<td>0.00</td>
<td>0.00</td>
<td>1.45</td>
</tr>
<tr>
<td>MAY</td>
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<td>1.39</td>
<td>0.00</td>
<td>0.00</td>
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<td>0.00</td>
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</tr>
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<td>JUNE</td>
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<td>1.73</td>
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<td>0.00</td>
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<td>0.00</td>
<td>1.18</td>
</tr>
<tr>
<td>JULY</td>
<td>1.95</td>
<td>6.90</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>4.95</td>
</tr>
<tr>
<td>AUG.</td>
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<td>0.30</td>
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<td>0.00</td>
<td>2.93</td>
</tr>
<tr>
<td>SEPT</td>
<td>2.00</td>
<td>6.22</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.65</td>
</tr>
<tr>
<td>OCT.</td>
<td>0.34</td>
<td>2.03</td>
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<td>0.00</td>
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<td>0.00</td>
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<tr>
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</tr>
<tr>
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<td>0.00</td>
<td>0.00</td>
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<tr>
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<td>23.00</td>
<td>11.00</td>
<td>7.99</td>
<td>5.46</td>
<td>17.64</td>
</tr>
</tbody>
</table>

**PLT. NO. 1**

**CROP—Corn**

**SOIL TYPE—s**

**DISPOSAL AREA—10.00 ACRES**

**WATER BALANCE (INCHES) IN THE DISPOSAL AREA—1973**

<table>
<thead>
<tr>
<th>MONTH</th>
<th>PRECIPITATION</th>
<th>IRIGATION</th>
<th>INTERC.</th>
<th>SURFACE</th>
<th>PERC.</th>
<th>PERT.</th>
<th>CHANGE IN SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAN.</td>
<td>0.45</td>
<td>0.50</td>
<td>0.26</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.17</td>
</tr>
<tr>
<td>FEB.</td>
<td>1.71</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.17</td>
</tr>
<tr>
<td>MAR.</td>
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<td>0.00</td>
<td>1.77</td>
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<td>0.00</td>
<td>0.00</td>
<td>-0.43</td>
</tr>
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<td>0.00</td>
<td>0.00</td>
<td>0.21</td>
<td>0.00</td>
<td>0.00</td>
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</tr>
<tr>
<td>MAY</td>
<td>4.37</td>
<td>2.00</td>
<td>0.06</td>
<td>1.28</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.26</td>
</tr>
<tr>
<td>JUNE</td>
<td>2.66</td>
<td>2.00</td>
<td>0.38</td>
<td>1.22</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.33</td>
</tr>
<tr>
<td>JULY</td>
<td>10.16</td>
<td>0.00</td>
<td>0.00</td>
<td>1.49</td>
<td>0.00</td>
<td>0.00</td>
<td>-1.51</td>
</tr>
<tr>
<td>AUG.</td>
<td>2.83</td>
<td>4.00</td>
<td>1.33</td>
<td>0.66</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.51</td>
</tr>
<tr>
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<td>1.33</td>
<td>5.99</td>
<td>1.09</td>
<td>3.88</td>
<td>2.37</td>
</tr>
</tbody>
</table>
**PLCT NO. 4**

**CROP--CORN**

**SOIL TYPE-- S**

**DISPOSAL AREA-- 10.00 ACRES**

---

**WATER BALANCE (INCHES) IN THE DISPOSAL AREA - 1973**

---

**INPUTS**

<table>
<thead>
<tr>
<th>MONTH</th>
<th>PRECIPITATION (INCHES)</th>
<th>IRRIGATION (INCHES)</th>
<th>INTERCEPTION (INCHES)</th>
<th>SURFACE RUNOFF (INCHES)</th>
<th>PERCOLATION (INCHES)</th>
<th>AEET (INCHES)</th>
<th>CHANGE IN SM (INCHES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAN.</td>
<td>2.67</td>
<td>0.0</td>
<td>0.51</td>
<td>0.09</td>
<td>0.0</td>
<td>0.34</td>
<td>1.7</td>
</tr>
<tr>
<td>FEB.</td>
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<td>0.50</td>
<td>0.39</td>
<td>0.0</td>
<td>0.74</td>
<td>0.17</td>
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<tr>
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<td>0.0</td>
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<td>0.34</td>
<td>0.35</td>
<td>1.44</td>
<td>2.14</td>
<td>-0.18</td>
</tr>
<tr>
<td>MAY</td>
<td>4.37</td>
<td>0.0</td>
<td>0.34</td>
<td>1.20</td>
<td>0.76</td>
<td>0.26</td>
<td>-0.26</td>
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<tr>
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<td>1.22</td>
<td>0.73</td>
<td>2.89</td>
<td>-0.40</td>
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<td>4.00</td>
<td>1.27</td>
<td>6.53</td>
<td>0.36</td>
</tr>
<tr>
<td>AUG.</td>
<td>2.73</td>
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<td>0.43</td>
<td>0.17</td>
<td>0.0</td>
<td>5.63</td>
<td>-1.93</td>
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<tr>
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<td>12.71</td>
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<td>1.21</td>
<td>9.99</td>
<td>1.68</td>
<td>3.83</td>
<td>1.88</td>
</tr>
<tr>
<td>OCT.</td>
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<td>0.29</td>
<td>2.28</td>
<td>1.03</td>
<td>1.77</td>
<td>-0.60</td>
</tr>
<tr>
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<td>2.00</td>
<td>0.20</td>
<td>0.77</td>
<td>1.25</td>
<td>1.08</td>
<td>0.74</td>
</tr>
<tr>
<td>DEC.</td>
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<td>0.0</td>
<td>0.26</td>
<td>1.13</td>
<td>0.37</td>
<td>0.35</td>
<td>-0.25</td>
</tr>
<tr>
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<td>8.66</td>
<td>19.06</td>
<td>11.42</td>
<td>27.62</td>
<td>4.41</td>
</tr>
</tbody>
</table>

**PERCENT OF WASTEWATER CONTROLLED = 87.31**

**POTENTIAL DISPOSAL DAYS = 23**

**PACK ON DECEMBER 31 = 0.43**

**CHANGE IN SNOW STORAGE = 0.43**

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

**PERCENT OF MAXIMUM POND VOLUME REQUIRED = 100.00**

**ESTIMATED LAKE EVAPORATION, INCHES = 47.47**
STATION: TOPEKA, KANSAS 1973 TC 1973

SIZE OF CRITICAL EVENT 6.10

FEEDLOT AREA 40.00 ACRES

PCND VARIABLES:
(1) BASE DIMENSION— 870.00 FEET BY 200.00 FEET
(2) SIDE SLOPE— RUN: RISE = 3.0 : 1
(3) MAXIMUM DEPTH— 9.00 FEET
(4) MAXIMUM PCND VOLUME— 705.60 ACRE-INCHES
(5) DIRECT RECEIVING AREA (FOR PRECIPITATION) — 7.30 ACRES

DISPOSAL AREA VARIABLES:
(1) DISPOSAL AREA— 40.00 ACRES
(2) CROP— CORN
(3) SOIL TYPE— 5 (SCS SOIL TYPES)
(4) DISPOSAL RATE— 0.50 INCHES/DAY ON DISPOSAL DAYS
(5) IRRIGATION MANAGEMENT— IRRIGATION BELOW 0.50 FIELD CAPACITY

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

METEOROLOGICAL SUMMARY

AVERAGE ANNUAL LAKE EVAPORATION = 47.47 INCHES
AVERAGE ANNUAL PRECIPITATION = 60.64 INCHES
PRECIPITATION RANGE = 0.0 INCHES (FROM A LOW OF 60.89 INCHES TO A HIGH OF 60.89 INCHES)

SUMMARY OF PONG OPERATIONS

NO. OF YEARS HAVING A DISCHARGE =
AVERAGE NO. OF DISCHARGES / YEAR HAVING A DISCHARGE = 15.00
AVERAGE DISCHARGE = 14.39 ACRE-INCHES
AVERAGE PERCENT OF WASTEWATER CONTROLLED = 87.31
TOTAL DISCHARGE VOLUME = 219.43 ACRE-INCHES
TOTAL NO. OF DISCHARGES = 15
MAXIMUM DISCHARGE = 110.47 ACRE-INCHES
AVERAGE ANNUAL DEPTH OF WASTEWATER APPLIED = 11.50 INCHES OVER ENTIRE DISPOSAL AREA

SUMMARY OF DISPOSAL PLOTS

AVERAGE ANNUAL DISPOSAL AREA RUNOFF = 19.60 INCHES
AVERAGE ANNUAL DISPOSAL AREA PERCOLATION = 11.26 INCHES
AVERAGE ANNUAL NO. OF DISPOSAL DAYS = 28.0
APPLICATION OF A COMPUTER MODEL IN DESIGNING KANSAS FEEDLOT WASTE CONTROL SYSTEMS

by

Michael J. Peterson

B.S., Kansas State University, 1975

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1977
ABSTRACT

With the use of continuous watershed models, Kansas stations were tested to evaluate and design feedlot runoff control systems. The control systems consisted of a pond and disposal area for controlling feedlot runoff pollution. The testing was in three phases: 1) control was achieved by evaporation from the pond, 2) control was achieved by irrigation disposal from the pond to a single disposal area, 3) multiple disposal areas were compared to a single area for irrigation disposal. From these tests, design of the control systems are possible given the necessary data concerning the control systems and the location (meteorological).