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A WATER MANAGEMENT MODEL

FOR SHALLOW WATER TABLE SOILS

by

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ABSTRACT
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A study was conducted to develop and test a water management model, DRAINMOD, for shallow water table soils. The objective was to develop a model for soils that normally require artificial drainage, either surface or subsurface, for efficient crop production. The model has the capability of simulating on a day-to-day, hour-by-hour basis the water table position, soil water content, drainage, ET and surface runoff in terms of climatological data, soil properties, crop parameters, and the water management system design. By simulating the performance of alternative system designs over several years of record, an optimum water management system can be designed.

The basis of the model is a soil water balance in the soil profile. It is composed of a number of separate components, incorporated as subroutines to evaluate various mechanisms of water movement and storage in the soil profile. These components include methods to evaluate infiltration, subsurface drainage, surface drainage, potential evapotranspiration (ET), actual ET, subirrigation and soil-water distribution. Approximate methods were used for each component so that the required inputs would be simplified and consistant with available data. The model was constructed so that improved methods can easily be substituted for existing components as they become available.

The model is given in full in an Appendix to the report. Documentation includes a program listing with definition of terms, a description of each subroutine and examples of input data and computer output. Suggestions for improving various components of the model are given in the Recommendations section.

Tests of the validity of DRAINMOD were conducted on three field sites with a total of five water management treatments over a five year period of record. Each site had subsurface and surface drainage systems with provisions for water table control or subirrigation. Rainfall and

water table depths were recorded continuously on each site and the observed water table elevations were compared to predicted day end values for the duration of the experiments. Soil property input data were measured for each site using field and laboratory procedures. Soil property data for five additional soils were also obtained and are predicted in the report.

Comparison of predicted and measured water table elevations were in excellent agreement with standard errors of estimate of the daily water table depths ranging from 7.5 to 19.6 cm. The average deviations between predicted and observed water table depths for 21 plot years of data (approximately 7400 pairs of daily predicted and measured values were compared) was 8.1 cm.

Application of the model was demonstrated with four examples. The first example consisted of an evaluation of alternative designs for combination surface-subsurface drainage systems for two soils. The use of controlled drainage and subirrigation was considered in the second example. DRAINMOD can also be used to determine hydraulic loading capacities for systems for land application of waste water, and an example was given to demonstrate this use of the model. Finally, an example was given to show how DRAINMOD can be used to determine the effects of rooting depth limitations on the number of days and the frequency that a crop suffers from drought stress.

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SUMMARY AND CONCLUSIONS

This report describes the development and testing of a computer simulation model to characterize the operation of drainage and water table control systems on shallow water table soils. The model, DRAINMOD, was developed for design and evaluation of multicomponent water management systems which may include facilities for subsurface drainage, surface drainage, subirrigation or controlled drainage and irrigation of wastewaters onto land. The model is based on a water balance in the soil profile. It uses climatological data to predict, on a day-to-day, hour-by-hour basis, the response of the water table and the soil water regime above it, to various combinations of surface and subsurface water management. By simulating the performance of alternative systems over several years of record an optimum water management system can be designed on a probabilistic basis. DRAINMOD is composed of a number of separate components, incorporated as subroutines, to evaluate the various mechanisms of water movement and storage in the soil profile. These components include methods to evaluate infiltration, subsurface drainage, surface drainage, potential evapotranspiration (ET), actual ET, subirrigation and the soil water distribution. In order to simplify the required inputs and to make them consistent with available data, approximate methods were used for each component. The model was constructed so that improved methods can be easily substituted for existing components as they become available.

The validity of DRAINMOD was tested using data from three experimental sites collected over a five year duration. Each site involved field scale drainage systems with provisions for subirrigation and controlled drainage. The experiments included five different treatments and provided a total of 21 plot years of data. Rainfall and water table elevations were measured continuously on each site and the observed water table elevations were compared to predicted daily values for the duration of the experiments. Numerous other field and laboratory measurements were made on each soil to determine input soil property data. Input soil property data were also measured for five additional soils and will be used in the application of the model.

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The computer program is documented in Appendix A of the report. This Appendix includes a program listing with definition of terms, a description of each subroutine and examples of input data and computer output.

Based on the results of the study and field tests of DRAINMOD it is concluded that the model can be used to design and evaluate water management systems for shallow water table soils. There are a number of improvements that can be made in the model and further tests under different soil and climatological conditions are needed. These needs are covered more specifically in the Recommendations section. Nevertheless, the model is judged to be sufficiently reliable for immediate use and its application for design and evaluation is encouraged. Although research efforts to improve the model will continue, the best test of its utility and the most efficient means of identifying and improving its weak points lies in its application. It is anticipated that modifications to the model, both in terms of the model components and in the required input data, will result from application to real world situations which are frequently complicated by a lack of adequate input data.

RECOMMENDATIONS

Recommendations resulting from this project fall into two cate-
gories: recommendations for the implementation of the model to the
design and evaluation of water management systems; and recommendations
for further research to improve components of the model and to test
its reliability for different water management systems and under dif-
ferent climatological and soil conditions.

Implementation of the model first requires that it be transmitted
to the users complete with documentation and input data needed for its
application. The model has been described to potential users through
professional meetings, work shops and journal articles. This report
will provide the needed documentation. A major need in this area is in-
tensive use of the model in practice. This would involve production
scale use of DRAINMOD in the design and evaluation of drainage and water
table control systems. This is envisioned as a research-extension
activity in which extension personnel would work with the land owner,
and agencies such as the Soil Conservation Service to gather the needed
input data, and make alternative designs for the water management system.
The performance of proposed designs would be simulated using DRAINMOD
and modifications made to obtain the optimum system for a given set of
design requirements. Experience gained in this application would allow
rapid improvement of the model and streamlining of the procedures for
obtaining input data. It would also provide a data base that would be
applicable for the same and similar soil types in other locations.

Another need in this same general category is for design charts
such as those given in Figures 47-52 for a range of soils and locations.
While these charts cannot be used directly, except on the soil for which
they were derived, they could provide a basis for a rough or first-cut
design. In cases where specific input data are not available such appro-
ximations may be better than present alternatives.

At the end of nearly every research project there are recommenda-
tions for continued research in the subject matter to further test the
results or to refine methods developed in the research. This project is
no different in that respect and there are numerous areas where both the

accuracy of the model and efficiency of its use can be improved by further research and development. Perhaps the most obvious need is for further testing under different soil and climatological conditions. Tests are underway using more than 10 years of data collected near Sandusky, Ohio (Schwab, et al., 1973, 1975). Preliminary results look good for the tight soils of this location. Plans are now being made to also test the model using the data from other locations in the U.S.

Infiltration is predicted in the present version of DRAINMOD with the Greem-Ampt equation using input parameters that are selected as a function of the initial water table depth. While this equation has been found to be sufficiently flexible for most field conditions, there is no doubt that the equation parameters depend on the stage of surface cover and tillage, both of which affect the condition of the surface. The effect of crusting due to rainfall impact on an unprotected or partially protected surface as well as breaking up of crusts due to cultivation could be considered in the model and reflected in the Green-Ampt equation parameters. Here again the determination of input data to characterize all of the different combinations of initial conditions will pose a problem in practical application, but this can possibly be overcome with some well directed research. Presently, infiltration is calculated based on rainfall rates assumed to be constant for one-hour intervals. Actually rainfall is not usually constant but may occur in short bursts of high intensity followed by low intensities during the hour. It may be desirable to assume different rainfall rate-time distributions within each hour in order to more precisely determine when rainfall excesses will occur. Additional studies need to be conducted on this subject.

Improvements can also be made in the component of the model that evaluates subsurface drainage and subirrigation fluxes. The present version uses the Hooghoudt equation to evaluate flux in terms of water table elevations at the drain and at a point midway between the drains. Layers are considered by evaluating an equivalent horizontal conductivity and convergence near the drains is accounted for by defining an equivalent depth to the impermeable layer. Recent methods developed by

van Beers (1976) for steady state drainage under rainfall conditions
will accommodate layered soils and correct for convergence near the
drains directly. These methods need to be worked into the model and
tested to determine if their use will improve the overall performance
of DRAINMOD.

Although the saturated hydraulic conductivity is assumed to be
constant, we know that it changes with water temperature, primarily
as a result of viscosity changes. Thus the conductivity is usually
higher during the summer months than during the winter. The model
could be programed to consider the effect of soil water temperature
changes on K and thus on drainage flux. A predictive method could be
used to calculate soil temperatures at a given depth in terms of average
air temperature and soil thermal properties. Maximum and minimum air
temperatures, which are used to predict ET, may also be used to estimate
soil temperature changes.

Freezing conditions are not currently considered in the model.
Errors caused by the omission are reflected for early spring conditions
in tests of DRAINMOD currently being conducted with data from NW Ohio.
Frozen soils will have a big effect on both infiltration and drainage;
more work is needed on this subject.

In discussing the results from Aurora (Chapter 5) we noted errors
in the predicted water table that were caused by a failure of DRAINMOD
to consider the time lag of water table response at the beginning of the
subirrigation process. Methods for determining time lag in terms of the
soil properties, drain spacing, etc. have been worked out (Skaggs, 1974).
Such methods have not been employed in the model because of the complex-
ity of programing and the relatively infrequent occurrence of the situa-
tion. However, this capability should be added to the model to improve
its accuracy during transition periods between drainage and subirrigation.

Further work is also needed to better describe water removal from
and development of the dry zone. In the present version of DRAINMOD it
is assumed that, as long as water exists in the root zone at water con-
tents above some limiting value, $\theta_{\ell\ell}$, it may be used by the plant to com-

pletely satisfy ET demands. It would be more reasonable to assume (after Lagace, 1973) that the availability of water is reduced as the soil water content decreases. This would involve reducing actual ET based on the soil water content after the water content in the root zone decreases below some threshold value.

Trafficable conditions are now based on whether the drained volume (air volume) in the soil profile is greater than a given limit, which is determined from rather subjective field measurements. Further work needs to be done to define trafficable conditions in terms of more basic soil properties and to determine how both the water content and distribution affects those properties. Methods developed by Wendt, et al. (1976) may be used to strengthen this part of the simulation procedure.

Presently, DRAINMOD determines the total number of trafficable days in a given time period. In the actual farm operation, it may be more important to know the frequency of trafficable conditions for several days at a time, and the effect of the drainage system on that frequency. In order to consider the total system in this regard, it may be desirable to couple DRAINMOD with a machinery management model to determine the optimum combination of farm machinery and drainage systems for a given situation.

One of the inputs to DRAINMOD is the relationship between effective root depth and time. While this function can be approximated from data in the literature, it obviously depends heavily on the water management system, as discussed in Chapter 2. One method that could be used to characterize the interrelationships between the soil water regime and root depth is to use a root model such as the one developed by Lambert and Baker (1979). However the input and computer time requirements for such models are large and are not generally compatible with DRAINMOD. Work is needed to either modify present root models or to develop new models that would allow prediction of effective root depth in terms of soil water stresses (both too wet and too dry), nutrients, temperatures, etc.

A logical extension of the above would be to couple DRAINMOD with a plant growth model which would also include the capability of predicting root growth and development. This would permit the direct evaluation of the effect of a water management system on crop production without resorting to mechanisms such as SEW_{30}. With the present stage of development of crop models such an extension seems feasible and further research in this direction should be given high priority.

Various models have been developed (e.g. the ARM and NPS models developed for EPA) to predict nutrient and pesticide runoff from agricultural watersheds. In most cases these models have been developed for upland conditions where subsurface drainage as considered herein is of less importance than the surface hydrology. Because of the interest in nutrient outflow from drainage systems, better methods are needed to characterize nutrient transformations and movement in high water table situations. It is suggested that DRAINMOD might serve as a base for development of a water quality model for high water table soils. A first cut might be to couple DRAINMOD with the water quality part of one of the existing models. However, considering the differences in boundary conditions, a more basic approach may be necessary. When developed and tested the resulting model would allow evaluation of proposed methods for reducing nutrient outflows from drainage systems.

ACKNOWLEDGEMENTS

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CHAPTER 1
INTRODUCTION

The design of efficient agricultural water management systems is becoming more and more critical as competitive uses for our water resources increase, and as installation and operational costs climb. In humid regions, artificial drainage is necessary to permit farming of some of the nation's most productive soils. Drainage is needed to provide trafficable conditions for seedbed preparation and planting in the spring and to insure a suitable environment for plant growth during the growing season. At the same time excessive drainage is undesirable as it reduces soil water available to growing plants and leaches fertilizer nutrients, carrying them to receiving streams where they act as pollutants. In some cases, water table control or subirrigation can be used to maintain a relatively high water table during the growing season thereby supplying irrigation water for crop growth as well as preventing excessive drainage.

The design and operation of each component of a water management system should be dependent on soil properties, topography, climate, crops grown and trafficability requirements. Further, the design of one component should depend on the other components. For example, a field with good surface drainage will require less intensive subsurface drainage than it would if surface drainage is poor. This has been clearly demonstrated in both field studies of crop response (Schwab, et al., 1974) and by theoretical methods (Skaggs, 1974). The relative importance of water management components varies with climate, so, in humid regions, a well designed drainage system may be critical in some years yet provide essentially no benefits in others. Thus, methods for designing and evaluating multicomponent water management systems should be capable of identifying sequences of weather conditions that are critical to crop production and of describing the performance of the system during those periods.

The purpose of this report is to present the results of a study to develop and test a water management model for soils with high water tables. The model, which is called DRAINMOD, is a computer

simulation program that characterizes the response of the soil water regime to various combinations of surface and subsurface water management. It can be used to predict the response of the water table and the soil water above the water table to rainfall, evapotranspiration (ET), given degrees of surface and subsurface drainage, and the use of water table control or subirrigation practices. Surface irrigation can also be considered and the model has been used to analyze sites for land disposal of waste water. Climatological data are used in the model to simulate the performance of a given water management system over several years of record. In this way optimum water management can be designed on a probabilistic basis as initially proposed for subsurface drainage by van Schilfgaarde (1965) and subsequently used by Young and Ligon (1972) and Wiser, et al. (1974).

This report begins with a description of each of the model components. Then results of field experiments to test the validity of the model for multi-component water management systems are given. Finally, examples of the use of the model for the design of drainage and water table control systems, determining permissible hydraulic loading rates for land disposal of waste water and evaluation of the effect of rooting depth limitations on number and frequency of days that a growing crop is stressed due to dry conditions, are presented.

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CHAPTER 2

THE MODEL

Background

A schematic of the type of water management system considered is
given in Figure 1. The soil is nearly flat and has an impermeable
layer at a relatively shallow depth. Subsurface drainage is provided
by drain tubes or parallel ditches at a distance d, above the imperme-
able layer and spaced a distance, L, apart. When rainfall occurs,
water infiltrates at the surface and percolates through the profile
raising the water table and increasing the subsurface drainage rate.
If the rainfall rate is greater than the capacity of the soil to infil-
trate, water begins to collect on the surface. When good surface
drainage is provided so that the surface is smooth and on grade, most
of the surface water will be available for runoff. However, if sur-

RAINFALL OR ET

DEPRESSION STORAGE S

SOIL SURFACE

DRAINAGE

SUBIRRIGATION

L

b

d

RESTRICTIVE LAYER
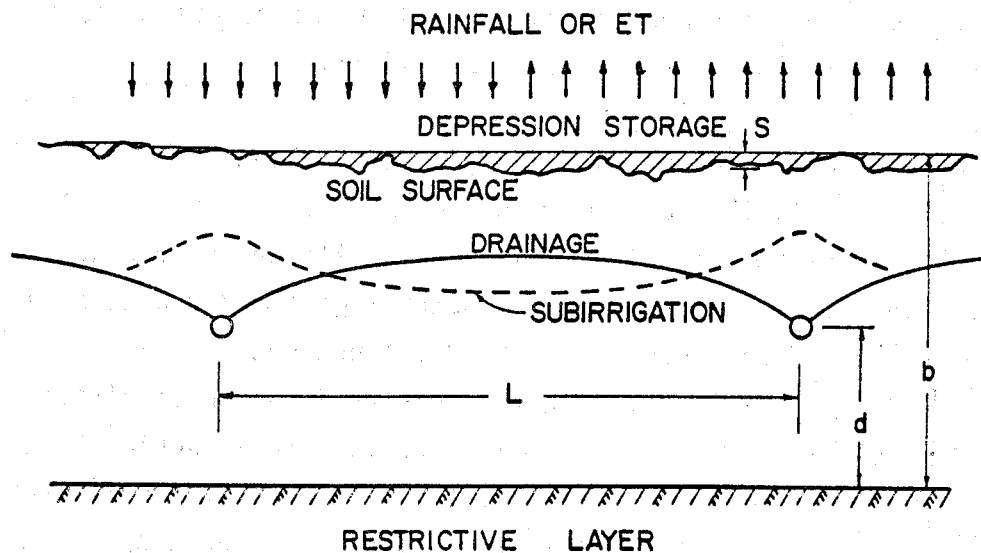
Figure 1. Schematic of water management system with subsurface
drains that may be used for drainage or subirrigation.

face drainage is poor, a certain amount of water must be stored in depressions before runoff can begin. After rainfall ceases, infiltration continues until the water stored in surface depressions is infiltrated into the soil. Thus, poor surface drainage effectively lengthens the infiltration event for a given storm permitting more water to infiltrate and a larger rise in the water table than would occur if depression storage did not exist.

The rate water is drained from the profile depends on the hydraulic conductivity of the soil, the drain depth and spacing, the effective profile depth, and the depth of water in the drains. When the water level is raised in the drainage ditches, for purposes of supplying water to the root zone of the crop, the drainage rate will be reduced and water may move from the drains into the soil profile giving the shape shown by the broken curve in Figure 1. It was shown in a previous study (Skaggs, 1974) that a high water table reduces the amount of storage available for infiltrating rainfall and may result in frequent conditions of excessive soil water if the system is not properly designed and managed. Water may also be removed from the profile by ET, and by deep seepage, both of which must be considered in the calculations if the soil water regime is to be modeled successfully.

Model Development

Two important criteria were adopted in the development of the computer model. First, the model must be capable of describing all aspects of water movement and storage in the profile so as to characterize, as accurately as possible, the soil water regime and drainage rates with time. And second, the model must be developed such that the computer time necessary to simulate long term events is not prohibitive. The movement of water in soil is a complex process and it would be an easy matter to become so involved with getting exact solutions to every possible situation that the final answer would never be obtained. The guiding principle in the model development was therefore to assemble the linkage between various components of the system, allowing the specifics to be incorporated as subroutines, so that they can readily

be modified when better methods are developed.

The basis for the computer model is a water balance for the soil profile (Figure 2). The rates of infiltration, drainage, and evapotranspiration, and the distribution of soil water in the profile can be computed by obtaining numerical solutions to nonlinear differential equations (e.g., Freeze, 1971). However these methods would require prohibitive amounts of computer time for long term simulations and thus could not be used in the model. Instead, approximate methods were used to characterize the water movement processes. In order to insure that the approximate methods provided reliable estimates, they were compared to exact methods for a range of soils and boundary conditions. Further, the reliability of the total model was tested using field experiments.
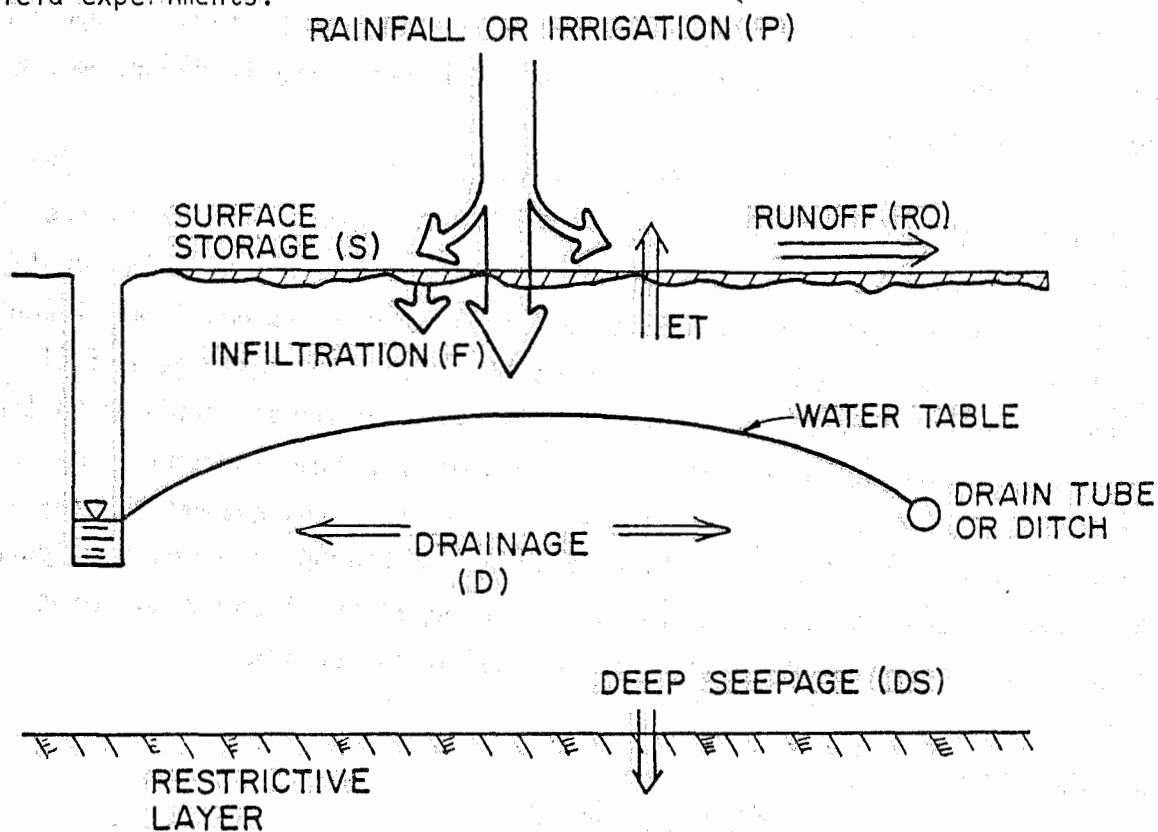
Figure 2. Schematic of water management system with drainage to ditches or drain tubes. Components evaluated in the water balance are shown on the diagram.

The basic relationship in the model is a water balance for a thin section of soil of unit surface area which extends from the impermeable layer to the surface and is located midway between adjacent drains. The water balance for a time increment of Δt may be expressed as,

$$\Delta V_a = D + ET + DS - F \qquad (1)$$

where ΔV_a is the change in the air volume (cm), D is drainage (cm) from (or subirrigation into) the section, ET is evapotranspiration (cm), DS is deep seepage (cm) and F is infiltration (cm) entering the section in Δt.

The terms on the right-hand side of equation 1 are computed in terms of the water table elevation, soil water content, soil properties, site and drainage system parameters, crop and stage of growth, and atmospheric conditions. The amount of runoff and storage on the surface is computed from a water balance at the soil surface for each time increment which may be written as,

$$P = F + \Delta S + RO \qquad (2)$$

where P is the precipitation (cm), F is infiltration (cm), ΔS is the change in volume of water stored on the surface (cm), and RO is runoff (cm) during time Δt. The basic time increment used in equations 1 and 2 is 1 hour. However when rainfall does not occur and drainage and ET rates are slow such that the water table position moves slowly with time, equation 1 is based on Δt of 1 day. Conversely, time increments of 0.05 hour or less are used to compute F when rainfall rates exceed the infiltration capacity. A general Flow Chart for DRAINMOD is given in Figure 3. Methods used to evaluate the terms in equations 1 and 2 and other model components are discussed in the following sections.

Precipitation

Model Components

Precipitation records are one of the major inputs of DRAINMOD. The accuracy of the model prediction for infiltration, runoff and surface storage is dependent on the complete description of rainfall. Therefore, a short time increment for rainfall input data will allow
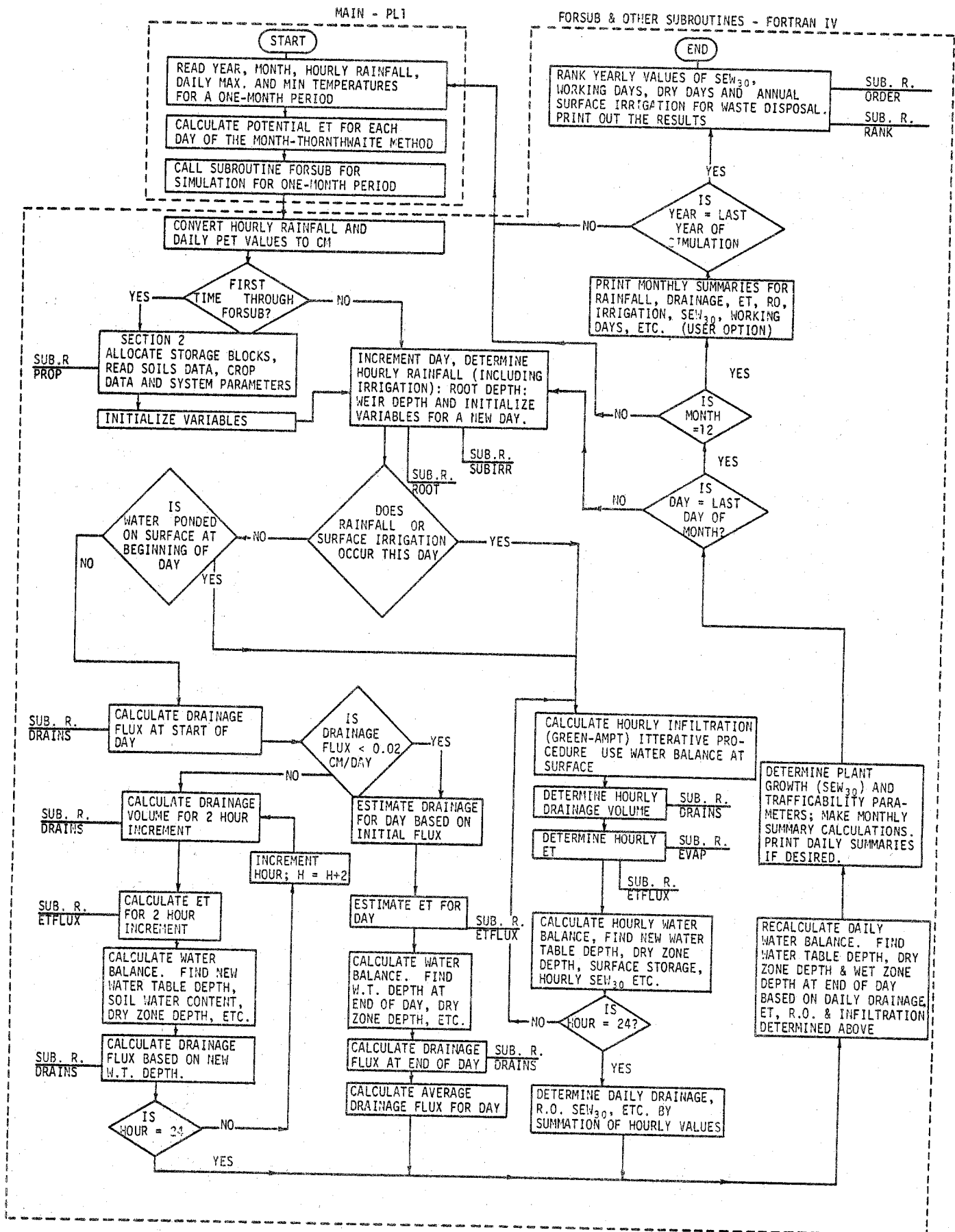
Figure 3. An abbreviated general flow chart for DRAINMOD.

better estimates of these model components than will less frequent data. A basic time increment of one hour was selected for use in the model because of the availability of hourly rainfall data. While data for shorter time increments are available for a few locations, hourly rainfall data are readily available for many locations in the U.S.

Hourly rainfall records are stored in the computer based HISARS (Wiser, 1972, 1975) for several locations in North Carolina and these records are automatically accessed as inputs to the model. Hourly data for other locations in the U.S. can be obtained from the National Weather Service at Asheville, N.C.

Infiltration

Infiltration of water at the soil surface is a complex process which has been studied extensively during the past two decades. A recent review of infiltration and methods for quantifying infiltration rates was presented by Skaggs, et al. (1979). Philip (1969), Hilel (1971), Morel-Seytoux (1973) and Hadas, et al. (1973) have also presented reviews of the infiltration processes. Infiltration is affected by soil factors such as hydraulic conductivity, initial water content, surface compaction, depth of profile, and water table depth; plant factors such as extent of cover and depth of root zone; and rainfall factors such as intensity, duration, and time distribution of rainfall.

Methods for characterizing the infiltration process have concentrated on the effects of soil factors and have generally assumed the soil system to be a fixed or undeformable matrix with well defined hydraulic conductivity and soil water characteristic functions. Under these assumptions and the additional assumption that there is negligible resistance to the movement of displaced air, the Richards equation may be taken as the governing relationship for the process. For vertical water movement, the Richards equation may be written as,

$$C(h) \frac{\partial h}{\partial t} = \frac{\partial}{\partial z} [K(h)\frac{\partial h}{\partial z}] - \frac{\partial K(h)}{\partial z} \qquad (3)$$

where h is the soil water pressure head, z is the distance below the soil surface, t is time, K(h) is the hydraulic conductivity function and C(h) is the water capacity function which is obtained from the

soil water characteristic. The effects of rainfall rate and time distribution, initial soil water conditions, and water table depth are incorporated as boundary and initial conditions in the solution of equation 3.

Although the Richards equation provides a rather comprehensive method of determining the effects of many interactive factors on infiltration, input and computational requirements prohibits its use in DRAINMOD. The hydraulic conductivity function required in the Richards equation is difficult to measure and is available in the literature for only a few soils. Furthermore, equation 3 is nonlinear and for the general case, must be solved by numerical methods requiring time increments in the order of a few seconds. The computer time required by such solutions would clearly be prohibitive for long term simulations covering several years of record. Nevertheless, these solutions can be used to evaluate approximate methods and, in some cases, to determine parameter values required in these methods.

Approximate equations for predicting the infiltration have been proposed by Green and Ampt (1911), Horton (1939), Philip (1957) and Holton, et al. (1967), among others. Of these, the Green-Ampt equation appears to be the most flexible and is used to characterize the infiltration component in DRAINMOD. The Green-Ampt equation was originally derived for deep homogeneous profiles with a uniform initial water content. The equation may be written as,

$$f = K_s + K_s M_d S_f/F \qquad (4)$$

where f is the infiltration rate, F is accumulative infiltration, K_s is the hydraulic conductivity of the transmission zone, M_d is the difference between final and initial volumetric water contents ($M_d = \theta_o - \theta_i$), and S_f is the effective suction at the wetting front. For a given soil with a given initial water content equation 4 may be written as,

$$f = A/F + B \qquad (5)$$

where A and B are parameters that depend on the soil properties, initial water content and distribution, and surface conditions such as cover, crusting, etc.

In addition to uniform profiles for which it was originally de-
rived, the Green-Ampt equation has been used with good results for
profiles that become denser with depth (Childs and Bybordi, 1969) and
for soils with partially sealed surfaces (Hillel and Gardner, 1970).
Bouwer (1969) showed that it may also be used for nonuniform initial
water contents.

Mein and Larson (1973) used the Green-Ampt equation to predict
infiltration from steady rainfall. Their results were in good agree-
ment with rates obtained from solutions to the Richards equation for
a wide variety of soil types and application rates. Mein and Larson's
results imply that, for uniform deep soils with constant initial water
contents, the infiltration rate may be expressed in terms of cumula-
tive infiltration, F, alone, regardless of the application rate. This
is implicity assumed in the Green-Ampt equation and in the parametric
model proposed by Smith (1972). Reeves and Miller (1975) extended
this assumption to the case of erratic rainfall where the unsteady
application rate dropped below infiltration capacity for a period of
time followed by a high intensity application. Their investigations
showed that the infiltration capacity could be approximated as a
simple function of F regardless of the application rate versus time
history. These results are extremely important for modeling efforts
of the type discussed herein. If the infiltration relationship is
independent of application rate, the only input parameters required are
those pertaining to the necessary range of initial conditions. On the
other hand, a set of parameters covering the possible range in applica-
tion rates would be required for each initial condition if the infil-
tration relationship depends on application rate.

A frequent initial condition for shallow water table soils is an
unsaturated profile in equilibrium with the water table. Solutions
for the infiltration rate - time relationship for a profile initially
in equilibrium with a water table 100 cm deep are given in Figure 4
for a sandy loam soil. The solutions were obtained by solving the
Richards equation for rainfall rates varying from 2 to 10 cm/h and
for a shallow ponded surface. Note that infiltration rate is dependent

on both time and the application rate. However, when infiltration rate is plotted versus cumulative infiltration, $F = \int_0^t f \, dt$, (Figure 5) the relationship is nearly independent of the application rate. This is consistant with Mein and Larson's (1973) results discussed above for deep soils with uniform initial water contents.

It should be noted that resistance to air movement was neglected in predicting the infiltration relationships given in Figures 4 and 5. Such effects can be quite significant for shallow water tables where air may be entrapped between the water table and the advancing wetting front (McWhorter, 1971, 1976). Morel-Seytoux and Khanji (1974) showed that the Green-Ampt equation retained its original form when the effects of air movement were considered for deep soils with uniform initial water contents. The equation parameters were simply modified to include the effects of air movement.

Infiltration relationships for a range of water table depths are plotted in Figure 6 for the sandy loam considered above. Although these curves were determined from solutions to the Richards equation, similar relationships could have been measured experimentally. The parameters A and B in equation 5 may be determined by using regression methods to fit the equation to the observed infiltration data. The resultant parameter values will reflect the effects of air movement as well as other factors which would have otherwise been neglected. Infiltration predictions based on such measurements will usually be more reliable than if the predictions are obtained from basic soil property measurements.

The model requires inputs for infiltration in the form of a table of A and B versus water table depth. When rainfall occurs, A and B values are interpolated from the table for the appropriate water table depth at the beginning of the rainfall event. An iteration procedure is used with equation 5 to determine the cumulative infiltration at the end of hourly time intervals. When the rainfall rate exceeds the infiltration capacity as given by equation 5, equation 2 is applied to conduct a water balance at the surface for Δt increments of 3 min. (0.05 h).
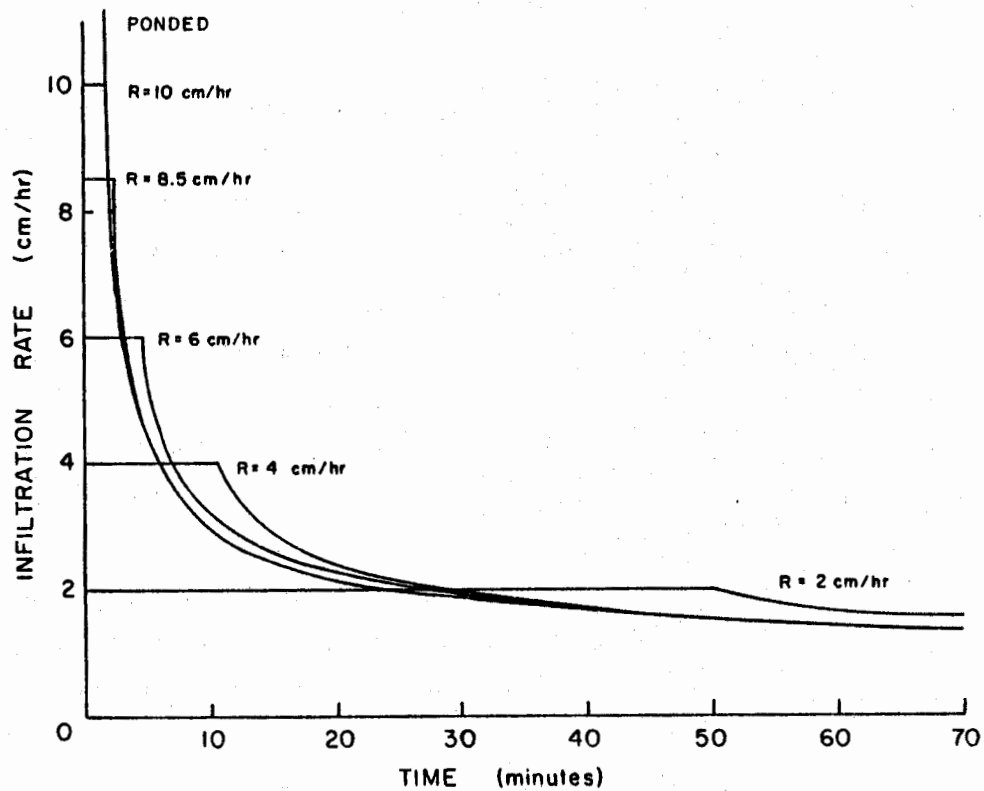
Figure 4.   Infiltration rate versus time for a sandy loam soil initially drained to equilibrium to a water table 1.0 m deep. Note that the infiltration-time relationships are dependent on the rainfall rate.
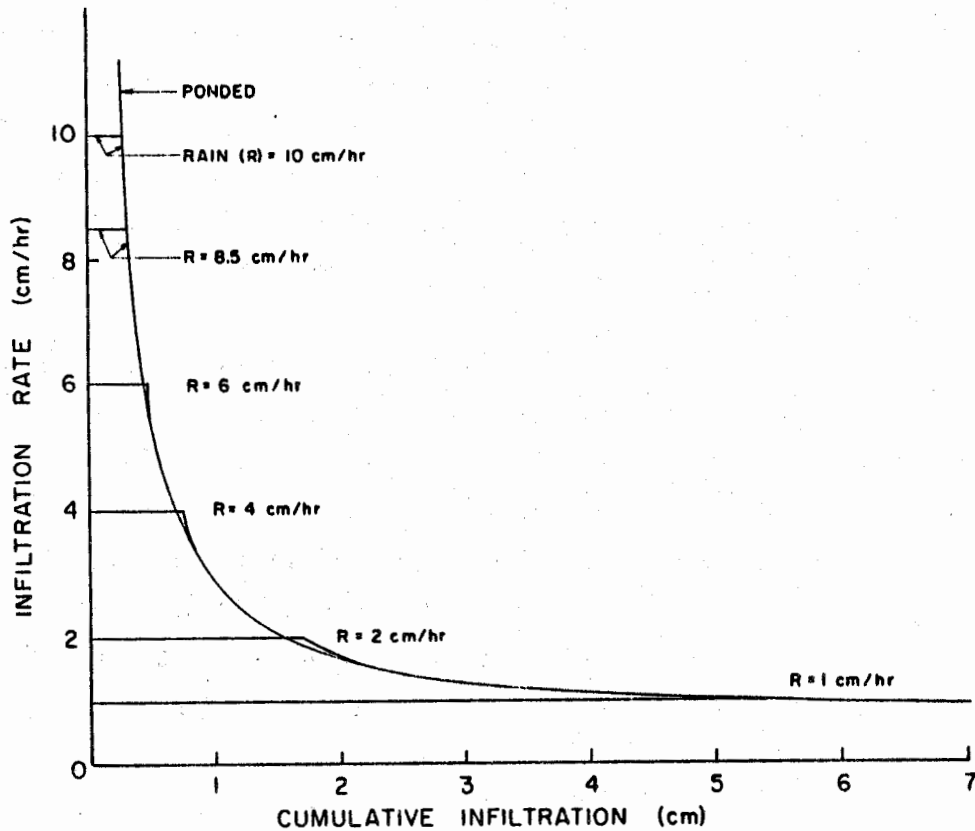
Figure 5.   Infiltration rate - cumulative infiltration relationships as affected by rainfall rate for the same conditions as Figure 4.
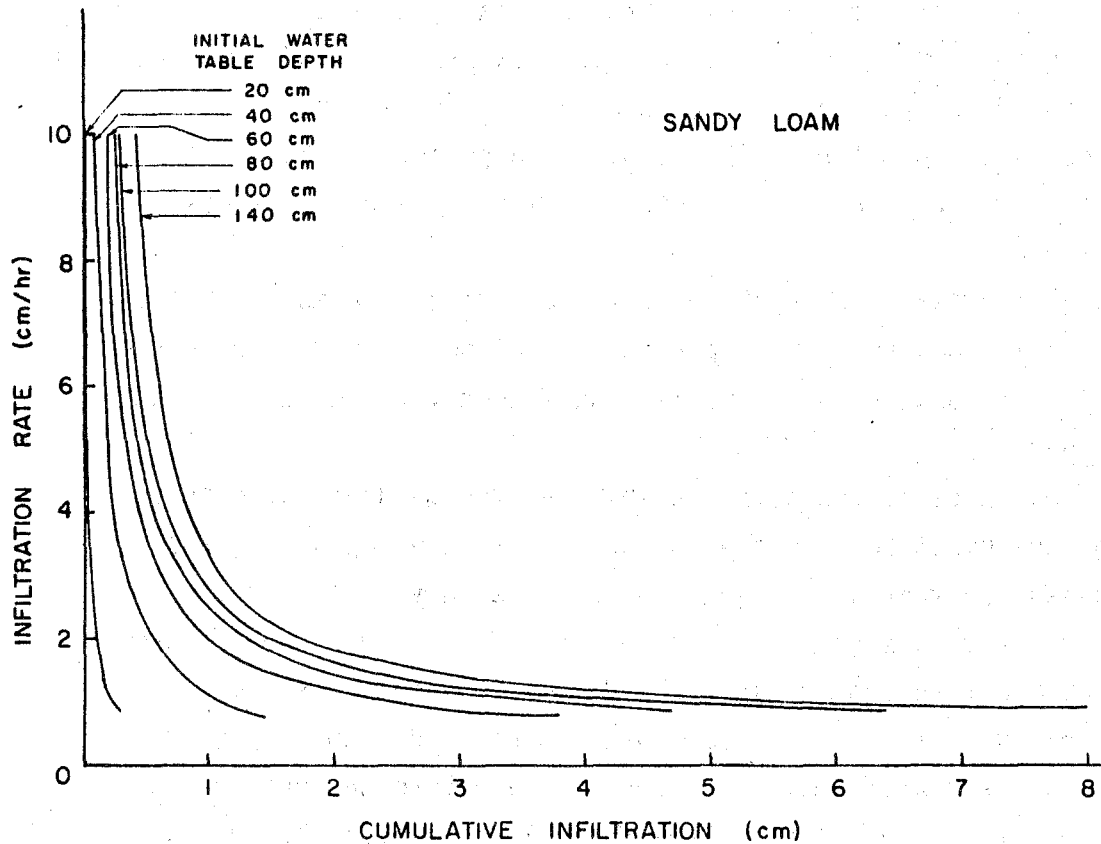
Figure 6. Infiltration relationships for the sandy loam soil of Figure 4 initially drained to equilibrium at various water table depths.

Rainfall in excess of infiltration is accumulated as surface storage. When the surface storage depth exceeds the maximum storage depth for a given field, the additional excess is allotted to surface runoff. These values are accumulated so that, at the end of the hour, infiltration and runoff as well as the present depth of surface storage are predicted. Hourly rainfall data are used in the program so the same procedure is repeated for the next hour using the recorded rainfall for that period. Infiltration is accumulated from hour to hour and used in equation 5 until rainfall terminates and all water stored on the surface has infiltrated. Likewise, the same A and B values are

used for as long as the rainfall event continues. An exception is
when the water table rises to the surface, at which point A is set to
A = 0 and B is set equal to the sum of the drainage, ET and deep seep-
age rates. An infiltration event is assumed to terminate and new A and
B values obtained for succeeding events when no rainfall or surface
water has been available for infiltration for a period of at least 2
hours. This time increment was selected arbitrarily and can be easily
changed in the program.

Although it is assumed in the present version of the model that the
A and B matrix is constant, it is possible to allow it to vary with time
or to be dependent on events that affect surface cover, compaction, etc.

Surface Drainage

Surface drainage is characterized by the average depth of depres-
sion storage that must be satisfied before runoff can begin. In most
cases it is assumed that depression storage is evenly distributed over
the field. Depression storage may be further broken down into a micro
component representing storage in small depressions due to surface
structure and cover, and a macro component which is due to larger sur-
face depressions and which may be altered by land forming, grading,
etc. A field study conducted by Gayle and Skaggs (1978) showed that
the micro-storage component varies from about 0.1 cm for soil surfaces
that have been smoothed by weathering (impacting rainfall and wind) to
several centimeters for rough plowed land. Macro-storage values for
eastern N.C. fields varied from nearly 0 for fields that have been land
formed and smoothed or that are naturally on grade to >3 cm for fields
with numerous pot holes and depressions or which have inadequate sur-
face outlets. Surface storage could be considered as a time dependent
function or to be dependent on other events such as rainfall and the
time sequence of tillage operations. Therefore, the variation in the micro-
storage component during the year can be simulated. However, it is
assumed to be constant in the present version of the model.

A second storage component that must be considered is the "film"
or depth of surface water that is accumulated, in addition to the
depression storage, before runoff from the surface begins and during

the runoff process. This volume is referred to as surface detention storage and depends on the rate of runoff, slope, and hydraulic roughness of the surface. It is neglected in the present version of the model which assumes that runoff moves immediately from the surface to the outlet. Actually water that eventually runs off from one section of the field is temporarily stored as surface detention and may be infiltrated or stored at a location downslope as it moves from the field. However the flow paths are relatively short and this volume is assumed to be small for the field size units normally considered in this model.

Subusrface Drainage

The rate of subsurface water movement into drain tubes or ditches depends on the hydraulic conductivity of the soil, drain spacing and depth, profile depth and water table elevation. Water moves toward drains in both the saturated and unsaturated zones and can best be quantified by solving the Richards equation for two-dimensional flow. Solutions have been obtained for drainage ditches (Skaggs and Tang, 1976), drainage in layered soils (Tang and Skaggs, 1978), and for drain tubes of various sizes (Skaggs and Tang, 1978). Input and computational requirements prohibit the use of these numerical methods in DRAINMOD, as was the case for infiltration discussed previously. However, numerical solutions provide a very useful means of evaluating approximate methods of computing drainage flux.

The method used in DRAINMOD to calculate drainage rates is based on the assumption that lateral water movement occurs mainly in the saturated region. The effective horizontal saturated hydraulic conductivity is used and the flux is evaluated in terms of the water table elevation midway between the drains and the water level or hydraulic head in the drains. Several methods are available for estimating the drain flux including the use of numerical solutions to the Boussinesq equation. However, Hooghoudt's steady state equation, as used by Bouwer and van Schilfgaarde (1963), was selected for use in DRAINMOD. Because this equation is used for both drainage and subirrigation flux, a brief derivation is given below.

Consider steady drainage due to constant rainfall at rate, R, as shown schematically in Figure 7. Making the Dupuit-Forchheimer (D-F) assumptions and considering flow in the saturated zone only, the flux per unit width can be expressed as:

$$Q = - K h \frac{dh}{dx} \qquad (6)$$

where K is the horizontal or lateral saturated hydraulic conductivity and h is the height of the water table above the restrictive layer. From conservation of mass we know that the flux at any point x is equal to the total rainfall between x and the midpoint, x = L/2.

$$-Kh \frac{dh}{dx} = - R (L/2 - x) \qquad (7)$$

where the negative sign on the right hand side of equation 7 is due to the fact that flow to the drain at x = o is in the -x direction. Separating variables and intergrating equation 7 subject to the boundary conditions h = d at x = o and h = d + m at x = L/2 yields
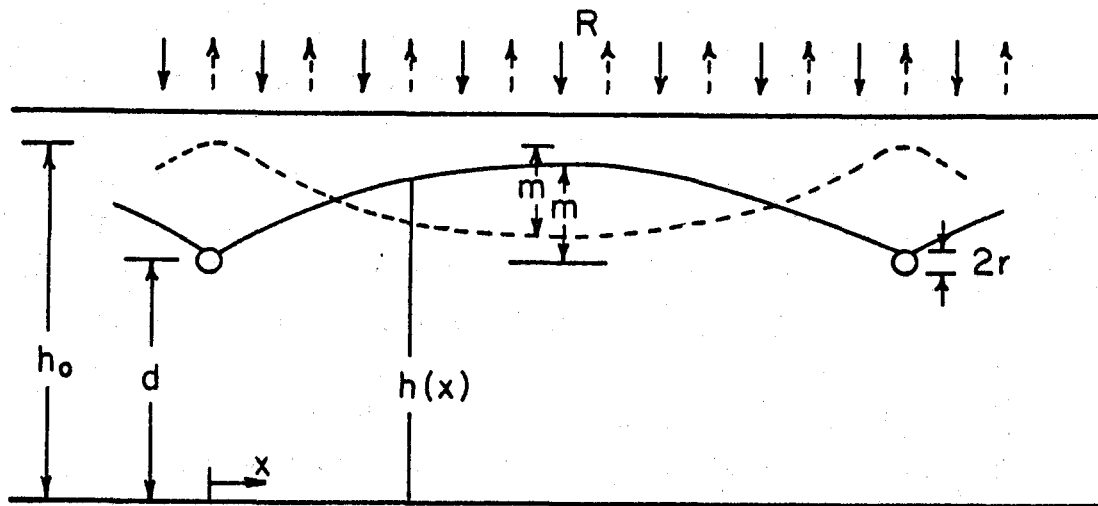
Figure 7. Schematic of water table drawdown to and subirrigation from parallel drain tubes.

an expression for R in terms of the water table elevation at the mid-point as,

$$R = \frac{4K\ (2\ md\ +\ m^2)}{L^2} \tag{8}$$

Although drainage is not a steady state process in most cases, a good approximation of the drainage flux can be obtained from equation 8. That is, the flux resulting from a midpoint water table elevation of m may be approximated as equal to the steady rainfall rate which would cause the same equilibrium m value. Then the equation for drainage flux may be written as,

$$q = \frac{8\ K\ d_e m\ +\ 4\ K\ m^2}{C\ L^2}, \tag{9}$$

where q is the flux in cm/hr, m is the midpoint water table height above the drain, K is the effective lateral hydraulic conductivity and L is the distance between drains. Bouwer and van Schilfgaarde (1963) considered C to be equal to the ratio of the average flux between the drains to the flux midway between the drains. While it is possible to vary C depending on the water table elevation, it is assumed to be unity in the present version of the model.

The equivalent depth, d_e, was substituted for d in equation 8 in order to correct the convergence near the drains. The D-F assumptions used in deriving equation 9 imply that equipotential lines are vertical and streamlines horizontal within the saturated zone. Numerical solutions for the hydraulic head (potential) distribution and water table position are plotted in Figure 8 for four different drains: a conventional 114 mm O.D. drain tube, a wide open 114 mm tube, an open ditch, and a drain tube surrounded by a square envelope, 0.5 m x 0.5 m in cross-section. The solutions were obtained by solving the two-dimensional Richards equation which requires no simplifying assumptions. These solutions show that, except for the region close to the drain, the equipotential lines in the saturated zone are nearly vertical. Thus, the D-F assumptions would appear reasonable for this case providing convergence near the drain can be accounted for.

Hooghoudt (van Schilfgaarde, 1974) characterized flow to cylinderical drains by considering radial flow in the region near the drains
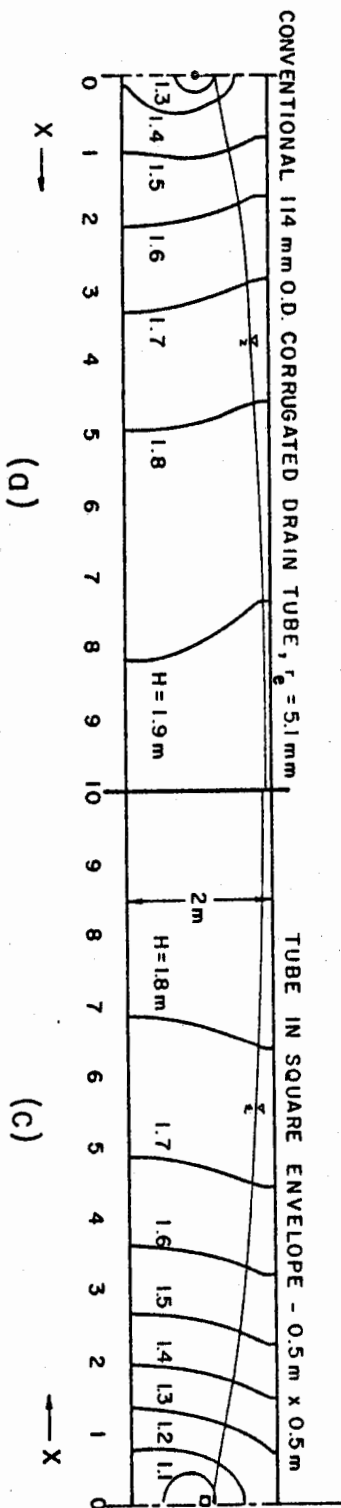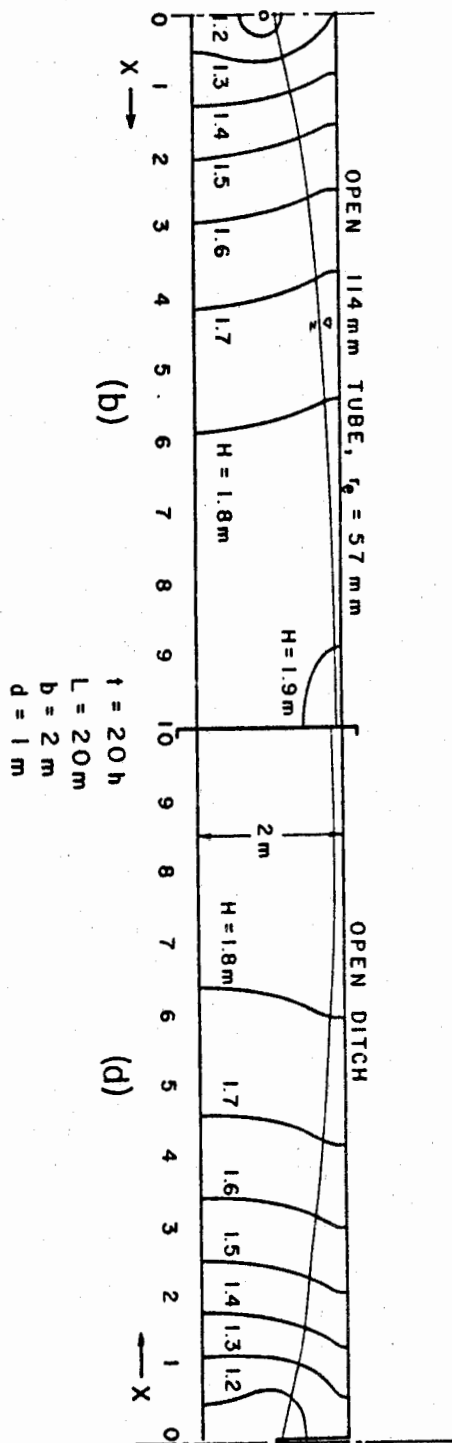
Figure 8. Water table position and hydraulic head, H, distribution in a Panoche soil after 20 hours of drainage to (a) conventional 114 mm (4-inch) drain tubes; (b) wide open (no walls) 114 mm diameter drain tubes; (c) a drain tube in a square envelope 0.5 m x 0.5 m; and (d) an open ditch 0.5 m wide. The drain spacings in all cases were 20 m. (After Skaggs and Tang, 1978).

and applying the D-F assumptions to the region away from the drains. The Hooghoudt analysis has been widely used to determine an equivalent depth, d_e, which, when substituted for d in Figure 7 will tend to correct drainage fluxes predicted by equation 9 for convergence near the drain. Moody (1967) examined Hooghoudt's solutions and presented the following equations from which d_e can be obtained.

For $0 < d/L < 0.3$

$$d_e = \frac{d}{1 + \frac{d}{L} \{\frac{8}{\pi} \ln (\frac{d}{r}) - \alpha\}} \qquad (10)$$

in which

$$\alpha = 3.55 - \frac{1.6d}{L} + 2 (\frac{d}{L})^2 \qquad (11)$$

and for $d/L > 0.3$

$$d_e = \frac{L\pi}{8 \{\ln (\frac{L}{r}) - 1.15\}} \qquad (12)$$

in which r = drain tube radius. Usually α can be approximated as $\alpha = 3.4$ with negligible error for design purposes.

For real, rather than completely open drain tubes, there is an additional loss of hydraulic head due to convergence as water approaches the finite number of openings in the tube. The effect of various opening sizes and configurations can be approximated by defining an effective drain tube radius, r_e, such that a completely open drain tube with radius r_e will offer the same resistance to inflow as a real tube with radius r. Dennis and Trafford (1975) used Kirkham's (1949) equation for drainage from a ponded surface and measured drain discharge rates in a laboratory soil tank to define effective drain tube radii. Bravo and Schwab (1977) used an electric analog model to determine the effect of openings on radial flow to corrugated drain tubes. Their data was used by Skaggs (1978) to define r_e for the 114-mm (4.5-in.) O.D. tubing that they used (standard 4-in. (100-mm) corrugated tubing has an outside diameter of approximately 4.5 in.). The same methods are used to determine r_e and then d_e which is an input to the model.

The above discussion treats the soil as a homogeneous media with saturated conductivity K. Most soils are actually layered with each

layer having a different K value. Since subsurface water movement to drain is primarily in the lateral direction, the effective hydraulic conductivity in the lateral direction is used in Equation 9. Referring to Figure 9 the equivalent conductivity is calculated using the equation,

$$K_e = \frac{K_1 d_1 + K_2 D_2 + K_3 D_3 + K_4 D_4}{d_1 + D_2 + D_3 + D_4} \qquad (13)$$

Because the thickness of the saturated zone in the upper layers is dependent on the water table position, K_e is determined prior to every flux calculation using the value of d_1 which depends on the water table position. If the water table is below layer 1, $d_1 = 0$ and a similarly defined d_2 is substituted for D_2 in equation 13.
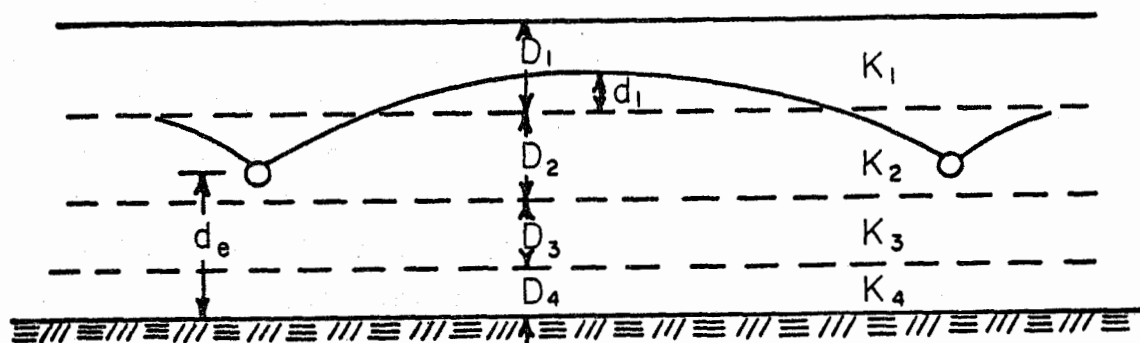
Figure 9. Equivalent lateral hydraulic conductivity is determined for soil profiles with up to 5 layers.

Other methods for calculating the drain flux which considers convergence to the drains and layered profiles have been summarized by van Beers (1976). The most general is the Hooghoudt-Ernst equation which does not require a separate calculation for d_e. However, it is necessary to determine a geometric factor from a graphical solution for some layered systems. The modified Hooghoudt-Ernst

equation is also discussed by van Beers (1976) and could be easily employed in DRAINMOD.

Subirrigation

When subirrigation is used, water is raised in the drainage outlet so as to maintain a pressure head at the drain of h_o (refer to the broken curve in Figure 7). If the boundary condition $h = h_o$ at $x = 0$ is used in solving equation 7, the equation corresponding to equation 9 for flux is,

$$q = \frac{4K}{L^2} (2\, h_o\, m + m^2) \tag{14}$$

where m is always defined as water table elevation midway between the drains minus the equivalent water table elevation at the drain, h_o, in this case. Thus for subirrigation, m is negative as is the flux. Convergence losses at the drain are treated in the same manner as in drainage by setting h_o equal to the sum of d_e and the water level elevation above the center of the drains.

When controlled drainage is used, a weir is set at a given elevation in the drainage outlet. The actual water level in the drain is not fixed as it is with subirrigation, but depends on size of the outlet, previous drainage, etc. If the water table elevation in the field is higher than the water level in the drain, drainage will occur and the water level in the drain will increase. If it rises to the weir level, additional drainage water will spill over the weir and leave the system. When the water table in the field is lower than that in the drain, water will move into the field at a rate given by equation 14 raising the water table in the field or supplying ET demands while reducing the water level in the drain. The amount of water stored in the drainage outlet and the water level in the outlet during subirrigation or controlled drainage is computed at each time increment by a DRAINMOD subroutine called YDITCH. This subroutine uses the geometry of the outlet, weir setting and drainage or subirrigation flux to determine the water level in the outlet at all times.

Evapotranspiration

The determination of evapotranspiration (ET) is a two-step pro-

cess in the model. First the daily potential evapotranspiration (ET) is calculated in terms of atmospheric data and is distributed on an hourly basis. The PET represents the maximum amount of water that will leave the soil system by evapotranspiration when there is a sufficient supply of soil water. The present version of the model distributes the PET at a uniform rate for the 12 hours between 6:00 AM and 6:00 PM. In case of rainfall, hourly PET is set equal to zero for any hour in which rainfall occurs. After PET is calculated, checks are made to determine if ET is limited by soil water conditions. If soil water conditions are not limiting, ET is set equal to PET. When PET is higher than the amount of water that can be supplied from the soil system, ET is set equal to the smaller amount. Methods used for determining PET and the rate that water can be supplied from the soil water system are discussed below.

Potential ET depends on climatological factors which include net radiation, temperature, humidity and wind velocity. Evapotranspiration can be directly measured with lysimeters or from water balance-soil water depletion methods. However, such measurements are rarely available for a given time and location and most PET values are obtained from climatological data using one of the many prediction methods. Methods for predicting PET in humid regions were reviewed by McGuinness and Borden (1972) and Mohammad (1978). A summary of some of the methods including required input climatological data is given in Table 1. Perhaps the most reliable method is the one developed by Penman (1948, 1956) which is based on an energy balance at the surface. The method requires net radiation, relative humidity, temperature, and wind speed as input data. Additional methods that could be used include, among others, those by Jensen et al.(1963), Stephens and Stewart (1963), Turc (1961) and van Bavel (1961). However all of these equations require daily solar or net radiation as input data and these data are available for only very few locations. Because we are interested in conducting simulations in many locations in N.C. as well as throughout the humid regions of the U.S., it is necessary to estimate ET based on readily available input data.

Table 1. Summary of PET prediction methods for humid regions.

Method	Climatological Factors													Formula Used
	TC	TA	RH	RI	H	U	e_s	e_d	DL	RT	S	PT	PD	
Penman			✓		✓	✓	✓	✓					✓	$PET = (\Delta H + E_a \gamma)/(\Delta + \gamma)$ in mm/day
Jensen-Haise		✓		✓										$PET = [0.014(TA) - 0.37]RI(0.000673)$ in in/day
Stephens & Stewart		✓		✓										$PET = (0.0082\ TA - 0.19)(RI/1500)$ in in/day
Turc	✓			✓										$PET = 0.40\ TC(RI + 50)/(TC + 15)$ in in/day
Grassi	✓			✓										$PET = KC_{RS}\ C_T\ C_{crc}\ F$ in in/day
Thornthwaite	✓													$PET = 1.6\ (10\ TC/I)^a$ in cm/month
Blany-Criddle		✓							✓					$PET = (0.0173\ TA - 0.314)KC \times TA(DL/4465.5)$ in in/day
Hamon											✓	✓		$PET = C\ S^2\ PT/100$ in in/day
Papadakis							✓	✓						$PET = 0.5625\ (e_a - e_{d-2})$ in cm/month
Makkink	✓			✓										$PET = 0.61\ RI[\Delta/(\Delta + \gamma)] - 0.12$ in mm/month
Christiansen		✓	✓			✓				✓	✓			$PET = 0.473\ R_T\ C_T\ C_W\ C_H\ C_S\ C_E\ C_M$ in in/day
van Bavel					✓	✓	✓	✓					✓	$PET = [(\Delta/\gamma)(H/L) + BV\ PD]/[(\Delta/\gamma) + 1]$ in in/day

PET = Potential evapotranspiration
TC = Mean air temperature in ^oC
TA = Mean air temperature in ^oF
RH = Relative humidity
RI = Solar radiation in langleys
H = Net radiation in langleys
U = Wind speed at a height of 2 meters
e_s = Saturated vapor pressure of the air in mm mercury
e_d = Actual vapor pressure of the air in mm mercury
DL = Day length in hours

RT = Solar radiation at the top of the atmosphere in inches of evaporation equivalent
S = Possible hours of sunshine in units of 12 hours
PT = Saturated vapor density
PD = Vapor pressure deficit in mm
K = Constant (0.537)
C_{crc} = Plant cover coefficient (for meadow is 1.0)
F = Constant (for alfalfa is 1.09)
KC = Crop growth stage coefficient
C = Constant (0.55)
C_E = Coefficient for the elevation of the site
C_M = Monthly vegetative coefficient

The method selected for use in the model was the empirical method developed by Thornthwaite (1948). He expressed the monthly PET as,

$$e_j = c \, \bar{T}_j^{\,a} \qquad (15)$$

where e_j is the PET for month j and $\bar{T}_j$ is the monthly mean temperature ($^{\circ}$C), c and a are constants which depend on location and temperatures. The coefficients a and c are calculated from the annual heat index, I, which is the sum of the monthly heat indexes, i_j, given by the equation,

$$i_j = (\bar{T}_j/5)^{1.514} \qquad (16)$$

$$I = \sum_{j=1}^{12} i_j \qquad (17)$$

The heat index is computed from temperature records and the monthly PET calculated from equation 15. Then the monthly PET value is corrected for number of days in the month and the number of hours between sunrise and sunset in the day by adjusting for the month and latitude. Daily values may be obtained from the monthly PET by using the daily mean temperature according to the methods given by Thornthwaite and Mather (1957).

The PET is computed in the main program of DRAINMOD from recorded daily maximum and minimum temperature values. The heat index must be determined and entered, along with the latitude of the site, separately. Adjustments for day length and number of days in the month are made in the program based on latitude and date. This version of the main program also inputs hourly rainfall from climatological records and is used for long term simulations. Another version of the main program was developed to input climatological data obtained in experiments to test the model. In this case the daily PET values were calculated separately and read into the model from cards. In this case any method could be used to determine PET although the Thornthwaite method was still used for our tests.

Mohammad (1978) compared six methods for predicting PET for eastern N.C. conditions. His study was closely associated with our experiments to test DRAINMOD and he used data from some of the same

research sites to evaluate the prediction methods. Mohammad found that the PET values predicted by the Thornthwaite method were somewhat higher and those predicted from pan evaporation measurements and lower than predictions from the Penman method. Considering the difference in input requirements, the Thornthwaite method appears to provide a reasonable estimate of PET.

Each ET calculation involves a check to determine if soil water conditions are limiting. When the water table is near the surface or when the upper layers of the soil profile have a high water content ET will be equal to PET. However, for deep water tables and drier conditions, ET may be limited by the rate that water can be taken up by plant roots. Gardner (1975) analyzed the factors controlling steady evaporation from soils with shallow water tables by solving the governing equations for unsaturated upward water movement. For soils with a given functional relationship between unsaturated hydraulic conductivity and pressure head, $K = K(h)$, Gardner presented simplified expressions for the maximum evaporation rate in terms of water table depth and the conductivity function parameters. For steady unsaturated flow, the upward flux is constant everywhere and the governing equation may be written as,

$$\frac{d}{dz} [K(h) \frac{dh}{dz} - K(h)] = 0 \tag{18}$$

Where h is the soil water pressure head and z is measured downward from the surface (Figure 10). For any given water table depth, the rate of upward water movement will increase with soil water suction (-h) at the surface. Therefore the maximum evaporation rate for a given water table depth can be approximated by solving equation 18 subject to a large negative h value, say h = -1000 cm, at the surface (z = 0) and h = 0 at z = d, the water table depth. Numerical solutions to equation 18 can be obtained for layered soils and for functional or tabulated K(h) relationships. By obtaining solutions for a range of water table depths, the relationship between maximum rate of upward water movement and water table depth can be developed. Such a relationship is shown in Figure 11 for the Wagram loamy sand studied by Wells and Skaggs (1976).
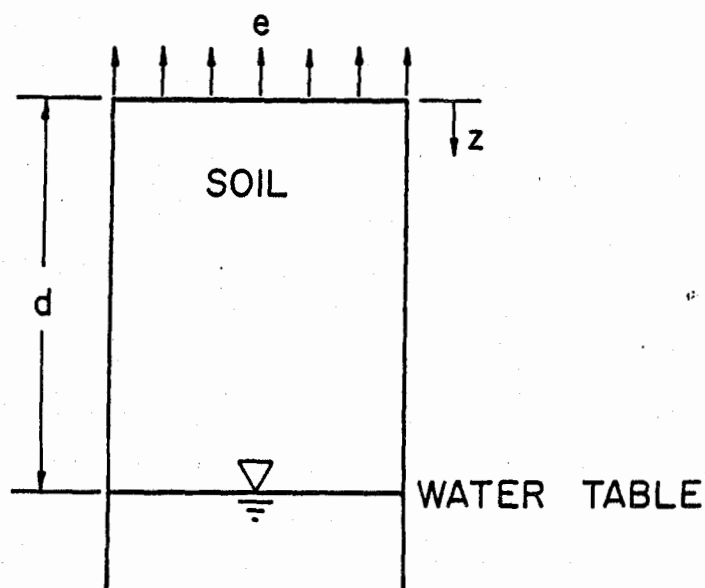
Figure 10. Schematic for upward water movement from a water table due to evaporation.

Relationships such as that shown in Figure 11 are read as inputs to the model in tabular form. Then if the PET is 5 mm/day, the ET demand could be satisfied directly from the water table for water table depths less than about 0.64 m. For deeper water tables, ET for that day would be less than 5 mm or the difference would have to be extracted from root zone storage. The root depth will be discussed in a later section. However, it should be pointed out that the roots are assumed to be concentrated within an effective root depth, and that the surface boundary condition may be shifted to the bottom of the root zone as indicated by the abscissa label in Figure 11.

Methods used for determining whether ET is limited by soil water conditions can best be described by an example. Assume that for the Wagram soil shown in Figure 11, the water table at the begin-

ning of day x is 0.91 m; the root zone depth is 10 cm and PET for day x is 5 mm. From Figure 11, we find that 1 mm of the PET demand will be supplied from the water table, leaving a 4 mm deficit. This deficit can be supplied by water stored in the root zone if it has not already been used up. Here it is assumed that the plant roots will extract water down to some lower limit water content, $\theta_{\ell\ell}$; the wilting point water content has been used for $\theta_{\ell\ell}$ but a larger value can be substituted if desired. For convenience this water is assumed to be removed from a layer of soil starting at the surface and creating a dry zone which has a maximum depth equal to the rooting depth. Taking
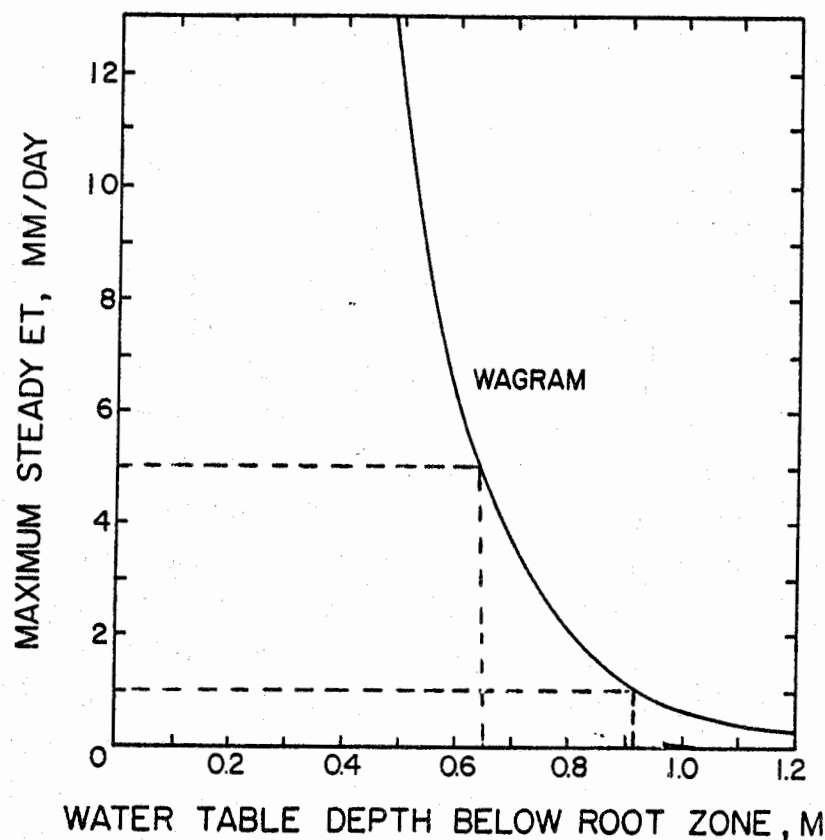

Figure 11. Relationship between maximum rate of upward water movement versus water table depth below the root zone for a Wagram loamy sand.

a value of $\theta_{\ell\ell}$ of 0.15 and a saturated water content, θ_s, of 0.35 the 4 mm deficit would dry out a layer of thickness 0.4 cm/(0.35 - 0.15) = 2 cm. Thus the dry zone depth at the end of day x would be increased by 2 cm. Further, the total water table depth would be increased by 2 cm in addition to the increase resulting from the upward movement of the 1 mm of water. Under these conditions, ET for day x will be equal to the PET of 5 mm. When the dry zone depth becomes equal to the rooting depth, ET is limited by soil water conditions and is set equal to the upward water movement. For example, if the dry zone at the beginning of day x was already 10 cm deep, the ET for day x would be limited to the rate of upward water movement of 1 mm rather than 5 mm. The amount of storage volume in the dry zone is accumulated separately from the rest of the unsaturated zone. It is accounted for on a day to day, hour to hour basis and is assumed to be the first volume filled when rainfall or irrigation occurs.

One problem with the use of the methods discussed above for calculating ET is the difficulty of obtaining reliable K(h) data needed to determine the relationship given in Figure 11 for many field soils. This is particularly true for multilayered soils. A more approximate method was developed and may be used as an option in the model by estimating a single critical or limiting depth parameter. When this option is used it is assumed that the potential ET rate will be supplied from the water table until the distance between the root zone and the water table becomes greater than the limiting depth. After the distance between the root zone and the water table reaches the limiting depth, it is assumed that water will be extracted from the root zone at a rate still equal to the potential ET rate until the root zone water content reaches $\theta_{\ell\ell}$ in the same manner as was explained above when PET was greater than the rate of upward water movement. Thus water is removed from the root zone from the surface downward until the depth of the resulting dry zone is equal to the rooting depth. Then ET is assumed equal to zero. This option is considered more approximate than the alternative method and should be used only when the relationship between maximum upward flux and water table depth cannot be obtained.

Soil Water Distribution

The basic water balance equation for the soil profile (equation 1) does not require knowledge of the distribution of the water within the profile. However, the methods used to evaluate the individual compo-nents such as drainage and ET depend on the position of the water table and the soil water distribution in the unsaturated zone. One of the key variables that is determined at the end of every water balance calculation in DRAINMOD is the water table depth. The soil water con-tent below the water table is assumed to be essentially saturated; actu-ally it is slightly less than the saturated value due to residual en-trapped air in soils with fluctuating water tables. In some earlier models the water content in the unsaturated zone was assumed to be con-stant and equal to the saturated value less the drainable porosity. However, recent work (Skaggs and Tang, 1976, 1978) has shown that, ex-cept for the region close to drains, the pressure head distribution a-bove the water table during drainage may be assumed nearly hydrostatic for many field scale drainage systems. The soil water distribution under these conditions is the same as in a column of soil drained to equilibrium with a static water table. This is due to the fact that, in most cases in fields with artificial drains, the water table draw-down is slow and the unsaturated zone in a sense "keeps up" with the saturated zone. This implies that vertical hydraulic gradients are small. This is supported by the nearly vertical equipotential (H) lines in Figure 8 and by Figure 12 which shows plots of pressure head versus depth at the drain, quarter and midpoints for drainage to open ditches spaced 20 m apart in a Panoche soil. The pressure head at the quarter and midpoints increase with depth in a 1:1 fashion indicating that the unsaturated zone is essentially drained to equilibrium with the water table (located where pressure head = 0) at all times after drainage begins.

The assumption of a hydrostatic condition above the water table during drainage will generally hold for conditions in which the D-F assumptions are valid. This will be true for situations where the ratio of the drain spacing to profile depth is large but may cause
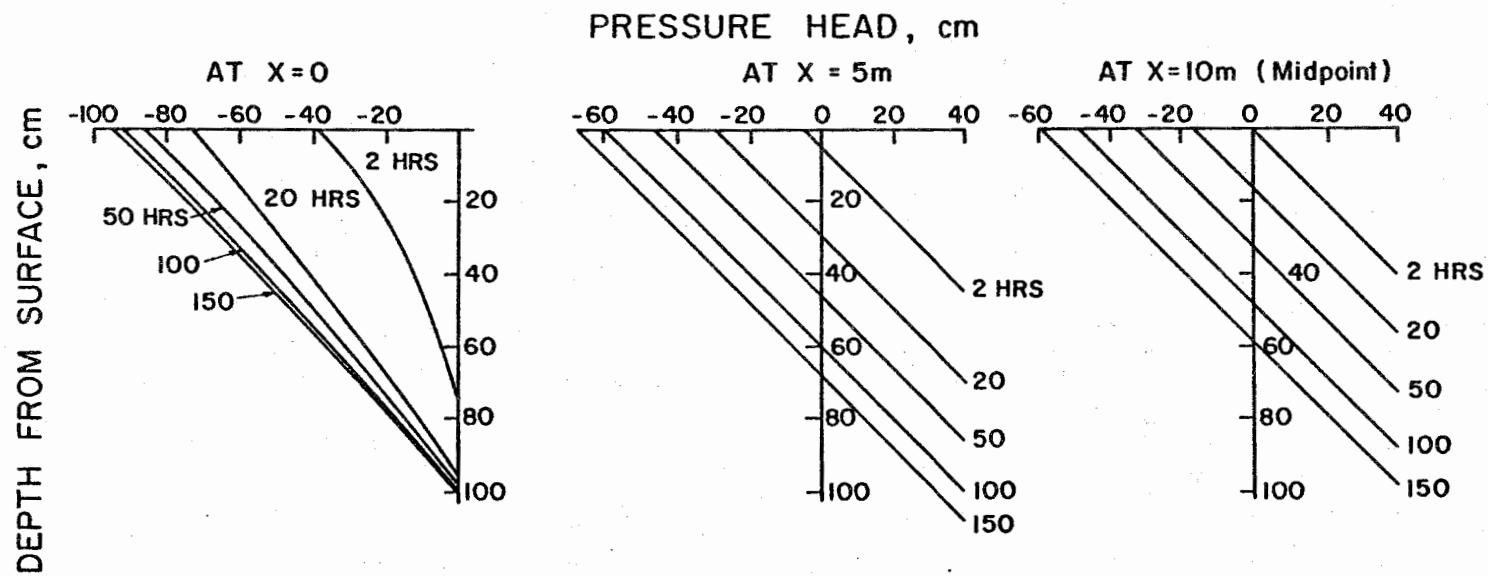
Figure 12. Pressure head distribution with depth at midpoint, quarter point and next to the drain for various times after drainage begins for a Panoche loam soil (after Skaggs and Tang, 1976).

30

errors for deep profiles with narrow drain spacings.

Water is also removed from the profile by ET which results in water table drawdown and changes in the water content of the unsaturated zone. In this case the vertical hydraulic gradient in the unsaturated zone is in the upward direction. However when the water table is near the surface, the vertical gradient will be small and the water content distribution still close to the equilibrium distribution. Solutions for the water content distribution in a vertical column of soil under simultaneous drainage and evaporation are given in Figures 13 and 14. The solutions to the Richards' equation for saturated and unsaturated flow were obtained using numerical methods described in an earlier paper (Skaggs, 1974). The water table was
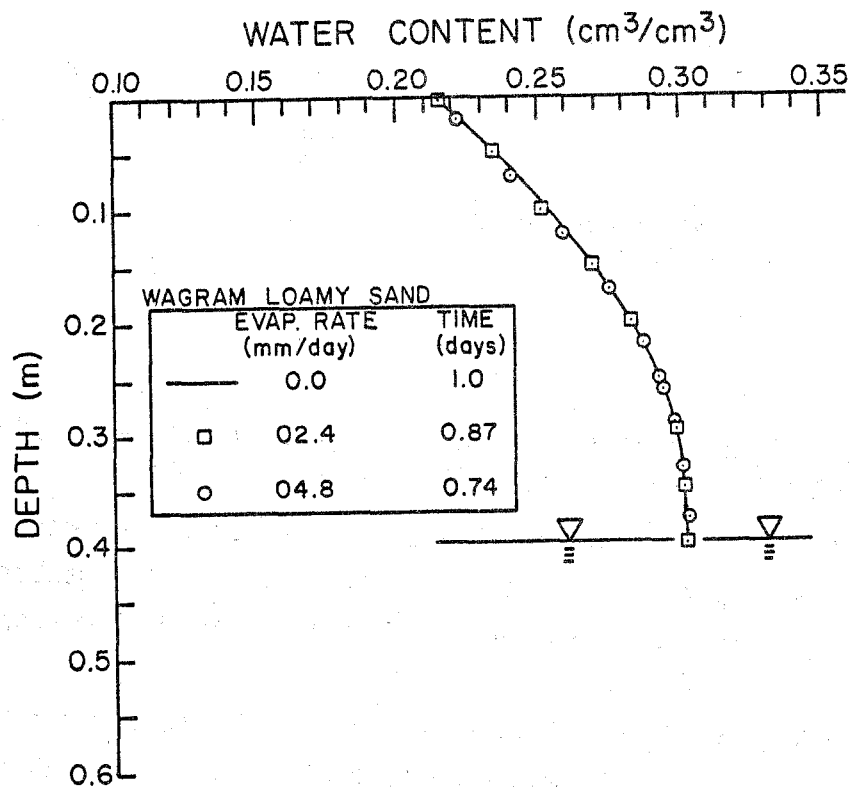

Figure 13. Soil water content distribution for a 0.4 m water table depth. The water table was initially at the surface and was drawn down by drainage and evaporation. Solutions are shown for three evaporation rates.
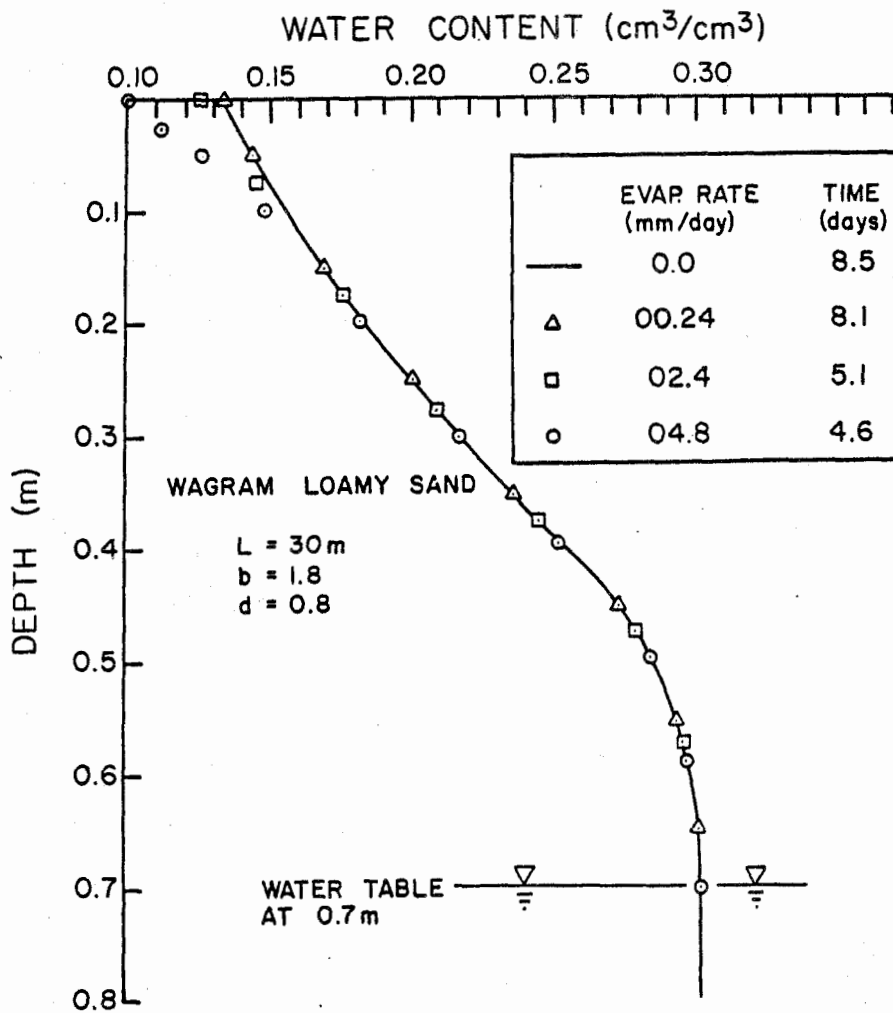
Figure 14.   Soil water distribution for a water table depth of 0.7 m
             for various drainage and evaporation rates.

initially at the surface of the soil column and solutions were obtain-
ed for various evaporation rates and a drainage rate at the bottom of
the column equal to that resulting from drains spaced 30 m apart and
1 m deep.

The results in Figure 13 indicate that, when the water table is
0.4 m from the surface, the water content distribution for this soil
is independent of evaporation rates less than 4.8 mm/day. When the
rate of evaporation from the surface was 0.0 the water table fell to

the 0.4 m depth after 1 day of drainage; whereas, it reached the same depth in 0.74 days when the evaporation rate was 4.8 mm/day. However, the water content distribution above the water table was the same for both cases; it was also the same for the intermediate evaporation rate of 2.4 mm/day. Figure 14 shows the distribution when the water table reached a depth of 0.7 m. Again the soil water distribution was independent of the evaporation rate except for the region close to the surface at the high evaporation rate (4.8 mm/day). The distribution for no evaporation is exactly the same as that which would result from the profile draining to equilibrium with a water table 0.7 m deep. Thus the "drained to equilibrium" assumption appears to provide a good approximation of the soil water distribution for this soil for both drainage and evaporation when the water table depth is relatively shallow. Even when the water table is very deep the soil water distribution for some distance above the water table will be approximately equal to the "equilibrium" distribution.

The zone directly above the water table is called the wet zone and the water content distribution is assumed to be independent of the means in which water was removed from the profile. Thus the air volume, or the volume of water leaving the profile by drainage, ET and deep seepage, may be plotted as a function of water table depth as shown in Figure 15. Assuming hysteresis can be neglected, Figure 15 would allow the water table depth to be determined simply from the volume of water that enters or is removed from the profile over an arbitrary period of time. For example, if the water table in the Wagram loamy sand of Figure 15 is initially at a depth of 0.6 m, the air volume above the water table would be V_a = 33 mm. Then if drainage and ET remove 10 mm of water during the following day the total V_a will be 43 mm and the depth of the wet zone, which is equal to the water table depth in this case, 0.66 m (from Figure 15). Subsequent infiltration of 25 mm would reduce the air volume to 18 mm and the water table depth to 0.48 m.

The maximum water table depth for which the approximation of a drained to equilibrium water content distribution will hold depends on
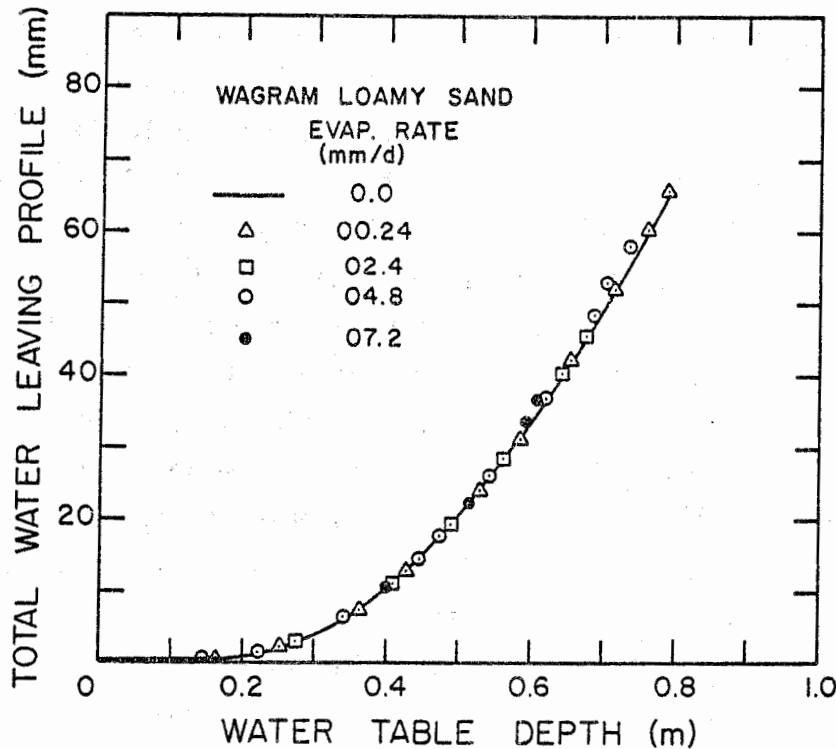
Figure 15. Volume of water leaving profile (cm^3/cm^2) by drainage
and evaporation versus water table depth. Solutions
for five evaporation rates are given.

the hydraulic conductivity functions of the profile layers and the
ET rate. The maximum depth will increase with the hydraulic conduc-
tivity of the soil and decrease with the ET rate.   Because the
unsaturated hydraulic conductivity decreases rapidly with water con-
tent, large upward gradients may develop near the surface, or near
the bottom of the root zone, when the soil water distribution de-
parts from the equilibrium profile. At this point, the upward flux
cannot be sustained for much deeper water table depths and additional
water necessary to supply the ET demand would be extracted from
storage in the root zone creating a dry zone as discussed in the ET
section. This is shown schematically in Figure 16.
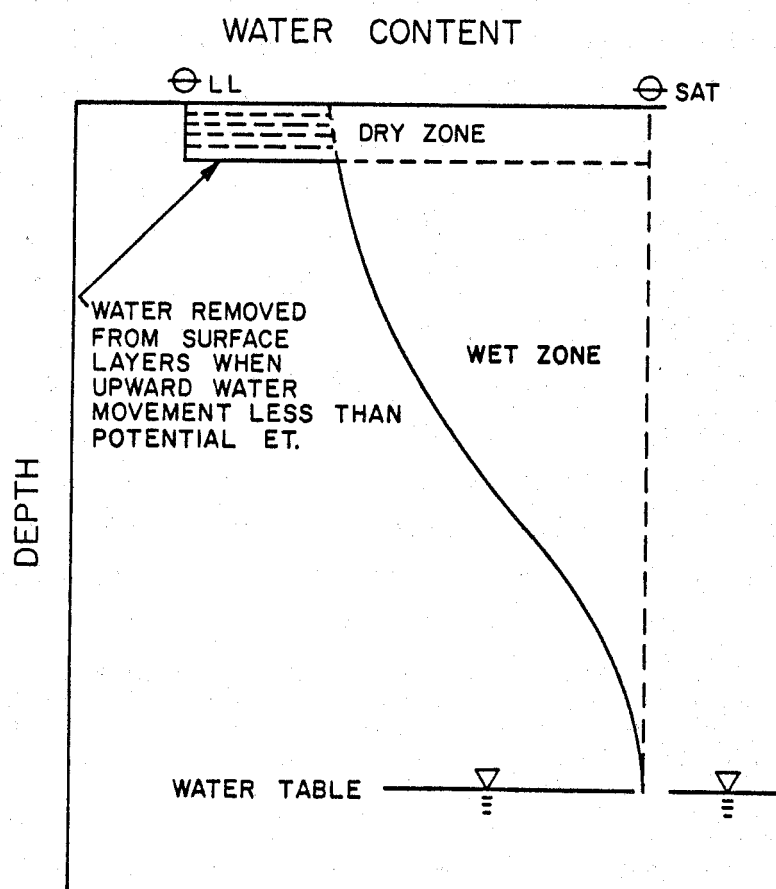
Figure 16. Schematic of soil water distribution when a dry zone
is created near the surface.

For purposes of calculation in DRAINMOD, the soil water is
assumed to be distributed in two zones - a wet zone extending from
the water table up to the root zone and possibly through the root
zone to the surface, and a dry zone. The water content distribu-
tion in the wet zone is assumed to be that of a drained to equili-
brium profile. When the maximum rate of upward water movement,
determined as a function of the water table depth, is not suffi-
cient to supply the ET demand, water is removed from root zone

storage creating a dry zone as discussed in the ET section. The depth of the wet zone may continue to increase due to drainage and some upward water movement. At the same time the dry zone with a constant water content of $\theta_{\ell\ell}$ may continue to increase to a maximum depth equal to that of the root zone. The water table depth is calculated as the sum of the depths of the wet and dry zones. When rainfall occurs the storage volume in the dry zone, if one exists, is satisfied before any change in the wet zone is allowed. However the depth to the water table will decrease by virtue of the reduction of the dry zone depth.

The assumptions made concerning soil water distribution may cause errors during periods of relatively dry conditions in soils with deep water tables and low K in the subsurface layers. Deep water tables may result from vertical seepage into an underlying aquifer or because of deep subsurface drains. For such conditions, the soil water at the top of the wet zone just beneath the root zone may be depleted by slow upward movement and by roots extending beyond the assumed depth of the concentrated root mass. Such conditions may cause the water content at the top of the wet zone to significantly depart from the drained to equilibrium distribution. However this will not cause a problem for wet conditions and for most shallow water table soils for which the model was derived.

Rooting Depth

The effective rooting depth is used in the model to define the zone from which water can be removed as necessary to supply ET demands. Rooting depth is read into the model as a function of Julian date. Since the simulation process is usually continuous for several years, an effective depth is defined for all periods. When the soil is fallow the effective depth is defined as the depth of the thin layer that will dry out at the surface. When a second crop or a cover crop is grown its respective rooting depth function is also included. The rooting depth function is read in as a table of effective rooting depth versus Julian date. The rooting depth for days other than those listed in the table is obtained by interpolation.

This method of treating the rooting depth is at best an approximation. The depth and distribution of plant roots is affected by many factors in addition to crop species and date after planting. These factors include physical barriers such as hardpans and plow pans, chemical barriers, fertilizer distribution, tillage treatments and others as reviewed in detail by Allmaras et al. (1973) and Danielson (1967). One of the most important factors influencing root growth and distribution is soil water. This includes both depth and fluctuation of the water table as well as the distribution of soil water during dry periods. Since the purpose of the model is to predict the water table position and soil water content, a model which includes the complex plant growth processes would be required to accurately characterize the change of the root zone with time. Such models have been developed for very specific situations but their use is limited by input data and computational requirements.

The variation of root zone depths with time after planting may be approximated for some crops from experimental data reported in the literature. Studies of the depth and distribution of corn roots under field conditions were reported by Mengel and Barber (1974). Their data were collected on a silt loam soil which was drained, with drains placed 1 m deep and 20 m apart. They observed little evidence of root growth limitation by moisture or aeration stresses. The data of Mengel and Barber are plotted in Figure 17 for root zone depth versus time. Numbers on the curves indicate percentage of the total root length found at depths less than the value plotted. The broken sections of the curves were approximated by assuming that the effective root depth increases slowly for the first 20 days after planting, then more rapidly until the beginning of their measurements on day 30. The data of Mengel and Barber (1974) for the year 1971 showed the total root length reached a maximum 80 days after planting at about the silking stage, remained constant until day 94 then decreased until harvest at day 132. However the percentage of roots less than a given depth remained relatively constant after about 80 days as shown in Figure 17.
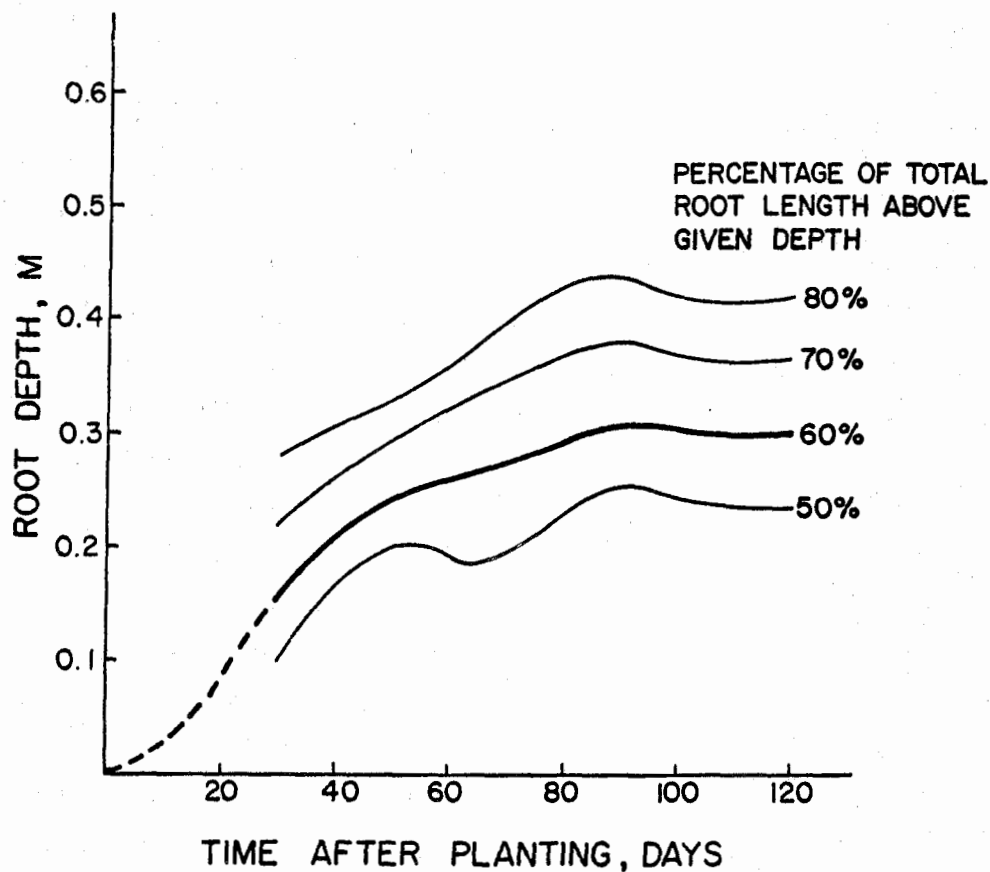
Figure 17. Relationships for depth above which 50, 60, 70, and 80
percent of the total root length exists versus time
after planting for corn. From data given by Mengel
and Barber (1974).

A similar study on the root distribution in corn was conducted
by Foth (1962). Distribution plots based on root weights are given
in Figure 18. The major differences between these results and those
of Mengel and Barber were the shorter growing season (85 day versus
120 day corn) and smaller root depths, than those given in Figure 17.
The total root dry weight is also plotted versus time in Figure 18.
Foth found that root growth for plants less than 0.3 to 0.4 m reached
a maximum by end of the vegetative growth stage 45 to 50 days after
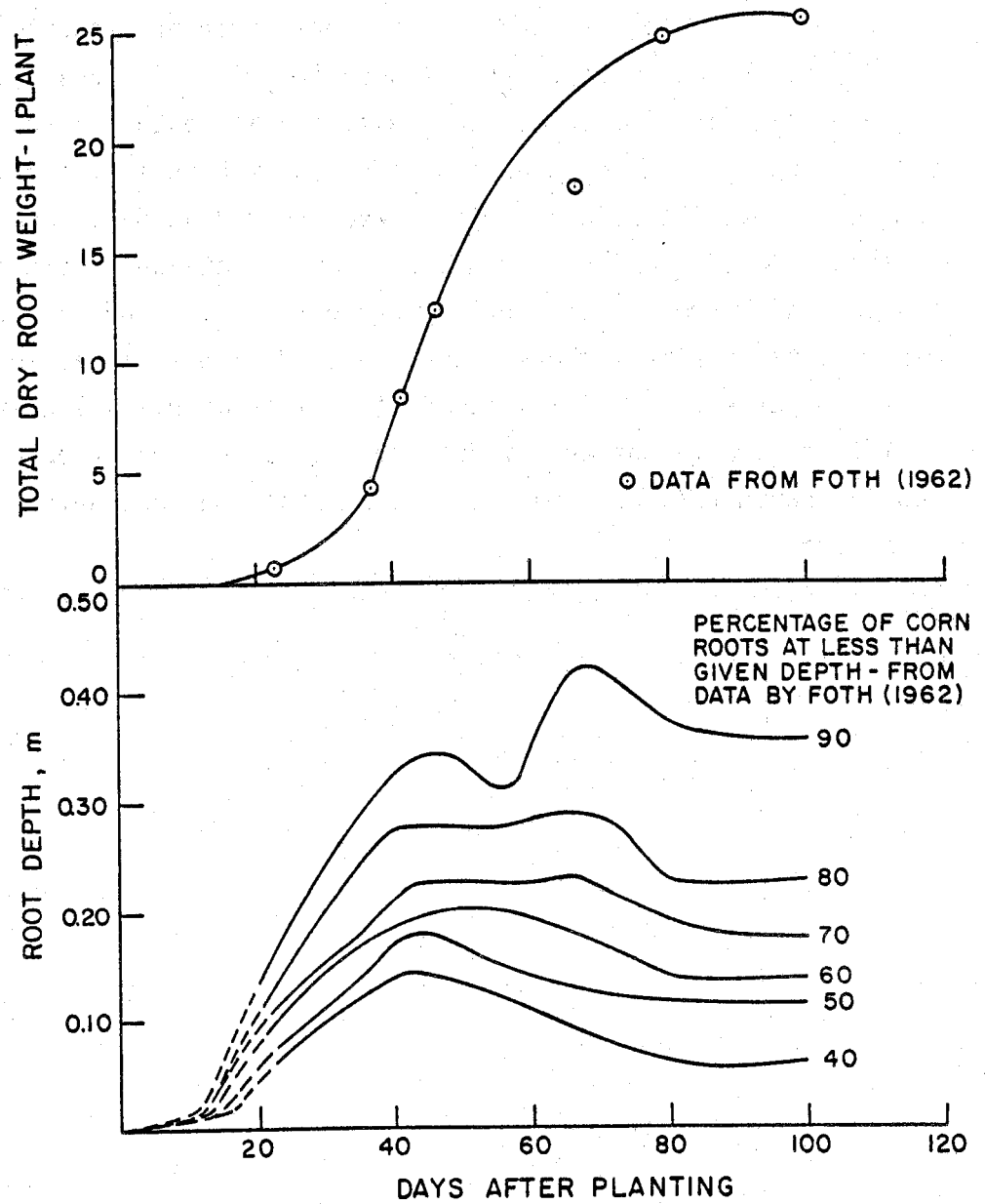
Figure 18. Root depths and total dry root weight versus times after planting for corn. From data given by Foth (1962).

planting. After that date there was a more rapid increase of roots at deeper depths.

Relationships such as those given in Figures 17 and 18 for the change of root zone depth with time are not available for many crops. Values for a constant effective root zone depth are reported in the literature for many crops and are used in irrigation design. Blood-worth et al. (1958) reported root distribution data for several mature crops. Based on the results given in Figure 17 and 18 it is suggested that the relationship between root zone depth and time can be approximated from the maximum effective root zone depth as follows. Assume a slow growth rate during seed germination and root establish-ment the first 2 to 4 weeks after planting with a linear increase to 10 to 15 percent of the maximum depth. Then assume a linear increase from that time to the end of the vegetative growth period when the rooting depth reaches a maximum and remains constant until the crop is mature.

CHAPTER 3
WATER MANAGEMENT SYSTEM OBJECTIVES

Agricultural water management systems may be installed to satisfy a variety of objectives. In most cases the overall objective is to eliminate water related factors that limit crop production or to reduce those factors to an acceptable level. In the final analysis, the acceptable level depends on the cost of the required water management system in relation to the benefits that will result from its installation. Such benefits vary from year to year with both weather and economic conditions and are difficult to quantify because of the complex interrelationships of crop production processes. The selection or design of an optimum water management system for a given situation may also depend on the land owner. Some owners are willing to operate at a greater level of risk than others, so an acceptable level of drainage protection, for example, may be less for one owner than for another.

More specific objectives of a water management system are easier to quantify and generally form the basis for system selection and design. For example, drainage systems in humid regions are usually installed to satisfy two functions: a) to provide trafficable conditions for seedbed preparation in the spring and harvest in the fall, and b) to insure suitable soil water conditions for the crop during the growing season. There may be a number of drainage system designs that will satisfy these objectives. For example a system with good surface drainage and poor subsurface drainage may be adequate while a system with poor surface drainage and good subsurface drainage may serve the same purpose. Whether or not a given system will satisfy the objective depends on the location, crop and soil properties. DRAINMOD can be used to simulate the performance of a given system design and evaluate the appropriate objective functions for a long period of climatological record. By making multiple simulations, the least expensive system that will satisfy the water management objectives can be chosen.

Four objective functions are routinely computed in DRAINMOD and may be used for evaluating the adequacy of a given system design. These objective functions are:

1. Number of working days - this is used to characterize the
    ability of the water management system to insure traffic-
    able conditions during specified periods.

2. SEW_{30} - stands for sum of excess water at depths less than
    30 cm and provides a measure of excessive soil water condi-
    tions during the growing season.

3. Number of dry days during growing season - quantifies the
    length of time when have deficient soil water conditions.

4. Irrigation volume - when a water management system is de-
    signed for land disposal of waste water, the objective
    function is the allowable amount of irrigation for a
    specified time interval.

Working Day

A day is defined as a working day if the air volume (drained
volume) in the profile exceeds some limiting value, AMIN; if the rain-
fall occurring that day is less than a minimum value, ROUTA; and if a
minimum number of days, ROUTT, have elasped since that amount of rain-
fall occurred. It should be noted that ROUTA and ROUTT are assumed to
be independent of AMIN and of the drainage system. For example if
conditions are very dry with say an air volume of 150 mm in the profile
a 30 mm rainfall might still postpone field operations for 1 or 2 days
even though the soil would normally be trafficable with an air volume
of less than 150 - 30 = 120 mm. This is due to the fact that the
surface wets up during rainfall and remains too wet for field opera-
tions until sufficient time for redistribution of the soil water has
elapsed. Values for these limiting parameters are read into the model
for two time periods which are specified by the beginning and ending
Julian dates. The starting and stopping working hours (SWKHR and EWKHA)
are also read in for each period and are used to compute partial working
days. For example, let's assume that SWKHR = 0600 and EWKHR = 1800
(i.e., the working day is 12 hours long) for a given period. Then if
rain in excess of ROUTA occurs at 1400 hours field work would be ter-
minated at that point; and (1400 - 0600)/12 = 0.67 working days would
be computed and stored for that day. The parameters AMIN, ROUTA, etc.
are dependent on the soil and on the field operation to be conducted.

These parameters have been obtained experimentally for some soils and are presented in a subsequent section.

SEW_{30}

The concept of SEW_{30} was discussed by Wesseling (1974) and Bouwer (1974). It was originally defined by Sieben (1964) to evaluate the influence of high fluctuating water tables during the winter on cereal crops. It is used herein to quantify excessive soil water conditions during the growing season and may be expressed as,

$$SEW_{30} = \sum_{i=1}^{n} (30 - x_i) \qquad (19)$$

where x_i is the water table depth on day i, with $i = 1$ being the first day and n the number of days in the growing season. Negative terms inside the summation are neglected.

Use of the SEW concept assumes that the effect on crop production of a 5 cm water table depth for a one day duration is the same as that of a 25 cm depth for five days. This seems unlikely as pointed out by Wesseling (1974). The severity of crop injury due to high water tables depends on the growth stage and time of year (Williamson and Kriz, 1970) as well as height of water table and time of exposure which determine the SEW_{30} values. Probably a better method of evaluating the quality of drainage during the growing season is the stress day index (SDI) concept advanced by Hiler (1969). This objective function was used by Ravelo (1977). He used the model presented herein to evaluate alternative drainage system designs based on predicted excess water damage to grain sorghum. The crop susceptibility factors were defined for 3 growth stages from published experimental data (Howell et al., 1976) and SEW_{30} was used as the stress-day factor. This procedure allowed association of the amount of damage and the level of the stress-day-index. The slight modifications of the model necessary to use the stress-day-index are given by Ravalo (1977). However the crop susceptibility factors are not available for other crops, so the SEW_{30} value is used here as the objective function for quantifying excessive soil water conditions.

Although the SEW concept has a number of weaknesses, it still provides a convenient method of approximating the quality of drainage. Sieben found that yields decreased for SEW_{30} values greater than 100 to 200 cm-days. However, his values were calculated for the entire year rather than just for the growing season as given here. Unless otherwise specified it will be assumed that drainage is adequate to protect crops from excess water if the SEW_{30} value is less than 100 cm-days. More research is needed to better define the relationship between drainage and crop response.

Dry Days

A dry day is defined as a day in which ET is limited by soil water conditions. When the water table is at a shallow depth, water removed from the root zone by ET is replenished by upward movement from the wetter zones near the water table. After the water table is drawn down to a certain depth, the ET demand can no longer be sustained by upward movement alone and the root zone water will be depleted. ET will continue at a rate governed by atmospheric conditions until the soil water content in the root zone reaches some lower limit, $\theta_{\ell\ell}$, as discussed previously. When this condition occurs, ET will be limited to the rate water can move upward to the root zone from the vicinity of the water table. Days on which this condition exists are presumed detrimental to optimum crop production and are counted as "dry days". Thus the three parameters, working days, SEW_{30}, and dry days are used to quantify the performance of alternative agricultural water management systems. Ideally a system should insure a given number of working days during the season when the crops are to be planted; SEW_{30} values below a given maximum to prevent crop damage by excessive soil water; and a minimum number of dry days during the growing season.

Wastewater Irrigation Volume

DRAINMOD was also developed with the option to evaluate hydraulic loading limitations of land disposal of wastewater. Wastewater application to the surface may be scheduled at a specified interval, INTDAY, during a given period. If the drained volume in the profile is less

than a given amount, REQDAR, irrigation of waste water will be skipped until after the next interval. If rainfall in excess of AMTRN occurs prior to time of scheduled irrigation, the event is postponed to the next day. When land application systems are hydraulically rather than nutrient limited, the objective is to apply as much wastewater as possible without surface runoff. Maximum application reduces the land area required for the system as well as the size of the irrigation system required. Thus the objective function for evaluating a system design and irrigation scheme is the amount of wastewater that can be applied per unit area. This function is evaluated on an annual basis to determine the size of the required system, and on a month to month basis to assess the wastewater storage capacity that may be required during wet months.

CHAPTER 4

SIMULATION OF WATER MANAGEMENT SYSTEMS - PROCEDURE

This section discusses the procedure for using DRAINMOD to simulate the performance of a water management system. An example drainage system design is considered. The required input data are identified and discussed and a representative example of the program output is presented. Other examples of the use of DRAINMOD for evaluation and design are given in a later section. The purpose of this chapter is to identify the required inputs and to demonstrate the form of the simulation output.

Example - A combination surface-subsurface drainage system

The soil chosen for this example is a Wagram loamy sand located near Wilson, N.C. This soil type is usually well drained in nature and does not require artificial drainage. In this case, however, it is flat and is underlain by a very slowly permeably layer at a 1.8 m depth. Corn is to be grown on a continuous basis. The seedbed is to be prepared after about March 15 and corn planted by April 15; the harvest period is September 1 to October 15. The purpose of the drainage system is to provide trafficable conditions in the spring and during the fall harvest season, and to prevent excessive soil water conditions during the growing season. The simulation will tell us whether or not the given design will accomplish this purpose and how often it may be expected to fail.

Input Data

All of the input data for this example are given in Appendix A as card images arranged in the order that they are fed into the computer. The sources of these data and more details concerning the inputs are discussed below.

Soil Property Inputs

The relationships between drainage volume (or effective air volume above the water table) and water table depth were determined from large field cores as discussed by Skaggs et al. (1978), and are plotted along with similar relationships for other soils in Figure 23. The relation-

ship between maximum rate of upward water movement to supply ET requirements and depth of the water table below the root zone was obtained by numerically solving equation 18 as discussed in Chapter 2 and is given in Figure 11 for the Wagram soil. The hydraulic properties required for the numerical solutions were previously reported for the Wagram soil (Wells and Skaggs, 1976). A summary of the other soil property inputs is given in Table 2.

Crop Input Data

The growing season for corn is approximately 120 days from April 15 to about August 15. The effective root zone depth is assumed to be dependent on time after planting and is arbitrarily taken as that given by the 60 percent curve from the data of Mengel and Barber, Figure 16. Soil water from a shallow surface layer will be removed (i.e., dried out to some lower limit water content) by evaporation even when the land is fallow. Therefore an effective root zone depth of 3 cm was assumed for the periods before and after the growing season. Other crop related input data are given in Table 2.

Drainage System Input Parameters

The drainage system consists of subsurface 102 mm (4 inch) drains spaced 45 m apart and 1 m deep. The surface drainage is only fair with some shallow depressions and an average surface storage depth of 12.5 mm. Convergence near the drain is accounted for by defining an equivalent depth from the drain to the impermeable layer according to the methods given by Hooghoudt (van Schilfgaarde, 1974). Methods given elsewhere Skaggs (1978), were used to find an effective radius of a completely open drain tube from data presented by Bravo and Schwab (1975), and then to determine the equivalent depth using equations given by Moody (1966). Input parameters describing the drainage system are summarized in Table 3.

Climatological Input Data

Hourly precipitation and daily temperature data were obtained for Wilson, N.C. from HISARS. Inputs identifying the station and specifying the heat index for ET calculations were given on the EXECUTE JCL card. These inputs are given in Table 4.

Table 2. Summary of soil property and crop related input data for Wagram loamy sand.

Parameter	Program Variable Name	Value
Depth to restricting layer	DEPTH	180 cm
Hydraulic conductivity	CONK	6 cm/hr (uniform)
Volumetric water content at lower limit (wilting point)	WP	0.05
Initial water table depth	IDTWT	0.0 cm
Minimum soil air volume required for tillage operations during:		
first work period (spring)	AMIN1	3.7 cm
second work period (harvest)	AMIN2	3.0 cm
Minimum rain to stop field operations:		
spring seedbed prep.	ROUTA1	1.2 cm
fall harvest	ROUTA2	0.5 cm
Minimum time after rain before can till:		
spring seedbed prep.	ROUTT1	1 day
fall harvest	ROUTT2	1 day
Working period for seedbed prep.:		
starting day	BWKDY1	74
ending day	EWKDY1	104
Working period for harvest:		
starting day	BWKDY2	240
ending day	EWKDY2	270
Working hours during spring:		
starting time	SWKHR1	0800
ending time	EWKHR1	2000
Working hours during harvest:		
starting time	SWKHR2	0800
ending time	EWKHR2	1800
Growing season - Starting Date	ISEWMS/ISEWDS	4/15
Ending Date	ISDWME/ISEWDE	8/15
Depth on which SEW calculations are based	SEWX	30 cm

Parameters for Green-Ampt infiltration equation:	W.T. Depth	$A(hr^{-1})$	$B(cm\ hr^{-1})$
	0 cm	0	0
	50	3.0	1.0
	100	5.5	2.0
	150	8.7	3.0
	200	11.5	3.0
	500	25.0	3.0

Table 3. Summary of drainage system input parameters.

Parameter	Program Variable Name	Value
Drain spacing	SDRAIN	45 m
Drain depth	DDRAIN	1 m
Equivalent depth to impermeable layer	HDRAIN	0.68 m
*Equivalent profile depth	DEPTH	1.68 m
Maximum depth of surface storage	STMAX	0.25 cm
Drain radius	**	57 mm
Effective drain radius	**	5.1 mm

*The equivalent profile depth is the sum of DDRAIN and HDRAIN and is used as input for the variable DEPTH rather than the actual profile depth in Table 1.

**These variables are not inputs to DRAINMOD but are used to calculate HDRAIN.

Table 4. Inputs for calling climatological data from HISARS and ET calculations.

Parameter	Program Variable Name	Value
Station ID for precipitation	ID1	319476
Station ID for daily temperatures	ID2	319476
Latitude for temperature station	LATT	35^0 47'
Heat Index	HET	75.0
Year and month simulation starts	START	1952-01
Year and month simulation ends	END	1971-12

Other Input Data

Irrigation is not considered in the example given here. However, input data for irrigation must be specified; values are selected such that no irrigation water will be applied. An example of the irrigation inputs required for simulating the use of the above system for application of waste water is given in Appendix A.

Simulation Results

Sample results of the simulation are shown in Table 5, daily
summaries for the month of July 1959 and Table 6 for monthly summaries
for 1959, a relatively wet year with a total of 1553 mm of rainfall.
The results in Table 5 give the total daily rainfall, infiltration
(INFIL), ET, cumulative drainage (DRAIN), runoff, total water leaving
the field through the outlet drain (WLOSS) and the amount of irrigated
water (DMTSI). In addition, soil water conditions at the <u>end</u> of the
day are given by values for air volume in the wet zone (AIR VOL), total
drained volume (TVOL), depth of dry zone (DDZ), depth of wet zone
(WETZ), depth of the water table (DTWT), depth of water stored on the
surface at the end of the day (STOR), depth of water in the outlet
(YD) and the equivalent depth of water stored in drainage outlet
(DRNSTO). The SEW_{30} value is also given for each day. The monthly
summaries give the totals of rainfall, infiltration, drainage, ET,
working days, dry days, water lost from the field through the drainage
outlet, SEW_{30}, depth of water pumped for subirrigation (PUMP), total
irrigation (MIR), number of irrigation events (MCN) and the number of
scheduled irrigation events postponed (MPT) for each month. Sample out-
put results for a year (1961) with a smaller amount of rainfall are
given in the output section of Appendix A. Also given in Appendix A is
an example of simulation output when this water management system is
used for disposal of waste water at a planned sprinkler irrigation rate
of 2.5 cm/week.

The simulation was conducted for a 20 year period (1952-1971). The
summary and ranking of the objective functions which is printed out at
the end of the simulation is given in Table 7.

Table 5. An example of computer output for daily summaries - Wagram soil, July, 1959. All values given in cm.

1959   7

DAY	RAIN	INFIL	ET	DRAIN	AIR VOL	TVOL	DDZ	WETZ	DTWT	STOR	RUNOFF	WLOSS	YD	DRNSTO	SEW	DMTSI
1	2.90	2.90	0.52	0.0	12.75	16.88	16.40	99.82	116.22	0.0	0.00	0.00	0.0	0.00	0.0	0.0
2	0.38	0.38	0.61	0.0	12.79	17.11	17.15	99.95	117.10	0.0	0.00	0.0	0.0	0.00	0.0	0.0
3	0.13	0.13	0.41	0.0	12.82	17.39	18.14	100.07	118.21	0.0	0.0	0.00	0.0	0.00	0.0	0.0
4	0.0	0.0	0.42	0.0	12.89	17.81	19.53	100.27	119.80	0.0	0.0	0.0	0.0	0.00	0.0	0.0
5	0.0	0.0	0.46	0.0	12.96	18.27	21.05	100.48	121.53	0.0	0.0	0.0	0.0	0.00	0.0	0.0
6	1.19	1.19	0.53	0.0	13.00	17.60	18.26	100.59	118.85	0.0	0.00	0.00	0.0	0.0	0.0	0.0
7	0.0	0.0	0.53	0.0	13.07	18.13	20.08	100.79	120.88	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.47	0.0	13.14	18.61	21.68	100.99	122.68	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.71	0.71	0.31	0.0	13.18	18.21	19.96	101.10	121.06	0.0	0.00	0.0	0.0	0.00	0.0	0.0
10	2.24	2.24	0.34	0.0	13.21	16.31	12.30	101.20	113.50	0.0	0.00	0.00	0.0	0.0	0.0	0.0
11	3.53	3.53	0.28	0.0	13.06	13.06	0.0	100.77	100.77	0.0	0.00	0.00	0.0	0.0	0.0	0.0
12	2.26	2.26	0.30	0.01	11.11	11.11	0.0	94.06	94.06	0.0	0.0	0.01	0.0	0.0	0.0	0.0
13	8.00	7.72	0.20	0.12	3.70	3.70	0.0	65.00	65.00	0.0	0.28	0.39	0.0	0.0	0.0	0.0
14	1.70	1.70	0.22	0.19	2.41	2.41	0.0	57.20	57.20	0.0	0.00	0.19	0.0	0.0	0.0	0.0
15	3.68	2.95	0.20	0.34	0.00	0.00	0.0	0.00	0.00	0.11	0.63	0.97	0.0	0.0	7.50	0.0
16	5.03	0.45	0.42	0.55	0.53	0.53	0.0	30.91	30.91	0.22	4.47	5.03	0.0	0.0	15.70	0.0
17	0.53	0.75	0.42	0.40	0.59	0.59	0.0	33.14	33.14	0.0	0.00	0.40	0.0	0.0	1.32	0.0
18	0.15	0.15	0.48	0.32	1.24	1.24	0.0	47.41	47.41	0.0	0.00	0.32	0.0	0.0	0.0	0.0
19	0.53	0.53	0.47	0.27	1.45	1.45	0.0	50.37	50.37	0.0	0.00	0.27	0.0	0.0	0.0	0.0
20	1.14	1.14	0.41	0.28	1.00	1.00	0.0	43.35	43.35	0.0	0.0	0.28	0.0	0.0	0.0	0.0
21	0.51	0.51	0.37	0.39	1.16	1.16	0.0	46.01	46.01	0.0	0.00	0.30	0.0	0.0	0.0	0.0
22	0.0	0.0	0.57	0.26	1.99	1.99	0.0	54.19	54.19	0.0	0.0	0.26	0.0	0.0	0.0	0.0
23	0.0	0.0	0.56	0.22	2.77	2.77	0.0	59.80	59.80	0.0	0.0	0.22	0.0	0.0	0.0	0.0
24	0.0	0.0	0.56	0.19	3.53	3.53	0.0	64.03	64.03	0.0	0.0	0.19	0.0	0.0	0.0	0.0
25	2.62	2.62	0.56	0.17	1.64	1.64	0.0	51.74	51.74	0.0	0.0	0.17	0.0	0.0	0.0	0.0
26	3.20	2.46	0.46	0.36	0.00	0.00	0.0	0.00	0.00	0.08	0.65	1.01	0.0	0.0	9.26	0.0
27	4.95	0.20	0.47	0.47	0.74	0.74	0.0	38.02	38.02	0.21	4.63	5.10	0.0	0.0	8.71	0.0
28	0.10	0.31	0.43	0.33	1.19	1.19	0.0	46.49	46.49	0.0	0.00	0.33	0.0	0.0	0.0	0.0
29	0.10	0.10	0.46	0.26	1.81	1.81	0.0	52.91	52.91	0.0	0.00	0.26	0.0	0.0	0.0	0.0
30	0.74	0.74	0.58	0.23	1.88	1.88	0.0	53.43	53.43	0.0	0.00	0.23	0.0	0.0	0.0	0.0
31	0.05	0.05	0.48	0.23	2.54	2.54	0.0	58.15	58.15	0.0	0.00	0.23	0.0	0.0	0.0	0.0

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Table 6. An example of computer output for monthly summaries - Wagram soil, 1959.

MONTHLY VOLUMES IN CENTIMETERS FOR YEAR 1959

MONTH	RAINFALL	INFILTRATION	RUNOFF	DRAINAGE	ET	DRY DAYS	WRK DAYS	FLOOD DAYS	WATER LOSS	SEW
1	5.97	5.97	0.00	5.48	1.19	0.0	0.0	5.48	0.0	0.0
2	10.59	9.25	1.34	6.71	1.45	0.0	3.00	8.05	0.0	0.0
3	12.17	10.69	1.48	7.39	2.48	0.0	4.00	8.87	0.0	0.0
4	18.77	13.53	5.24	8.94	6.53	5.46	9.00	14.17	40.81	0.0
5	4.93	4.93	0.00	1.81	11.02	1.58	0.0	1.82	0.0	0.0
6	6.93	6.93	0.00	0.16	13.72	0.0	0.0	0.17	42.50	0.0
7	46.38	35.72	10.66	5.51	13.49	0.0	5.00	16.17	0.0	0.0
8	12.88	12.88	0.00	2.86	15.18	0.0	0.0	2.87	0.0	0.0
9	6.53	6.53	0.00	1.55	7.80	0.0	0.0	1.55	0.0	0.0
10	17.12	17.12	0.00	4.05	5.39	0.0	0.0	4.05	0.0	0.0
11	6.10	6.10	0.00	5.23	2.61	0.0	0.0	5.23	0.0	0.0
12	6.93	6.93	0.00	5.18	1.29	0.0	0.0	5.18	0.0	0.0
TOTALS	155.30	136.58	18.72	54.85	82.15	7.04	21.00	73.61	83.31	0.0

Table 7. Example of computer output of yearly summaries and ranking of objective functions - work days, SEW$_{30}$, dry days and yearly irrigation.

RANK	WORK DAYS	YEAR	SEW	YEAR	DRY DAYS	YEAR	IRRIGATION	YEAR	SEW	YEAR	MIR	YEAR	MCN	PUMP	MPT
1	30.00	1955	97.51	1953	54.00	1954	0.0	1952	0.0	1952	0.0	1952	0	0.0	0
2	30.00	1966	83.31	1959	38.00	1952	0.0	1953	0.0	1953	0.0	1953	0	0.0	0
3	28.00	1967	63.88	1967	32.00	1955	0.0	1934	0.0	1954	0.0	1934	0	0.0	0
4	25.75	1968	62.01	1965	26.00	1957	0.0	1955	0.0	1955	0.0	1955	0	0.0	0
5	18.25	1933	37.39	1960	22.00	1970	0.0	1956	0.0	1956	0.0	1956	0	0.0	0
6	14.28	1969	30.60	1958	20.00	1956	0.0	1957	0.0	1957	0.0	1957	0	0.0	0
7	14.08	1963	0.0	1952	19.00	1964	0.0	1958	0.0	1958	0.0	1958	0	0.0	0
8	13.25	1954	0.0	1954	11.00	1960	0.0	1959	0.0	1959	0.0	1959	0	0.0	0
9	11.99	1952	0.0	1956	8.00	1953	0.0	1960	0.0	1960	0.0	1960	0	0.0	0
10	11.57	1965	0.0	1970	8.00	1962	0.0	1961	0.0	1961	0.0	1961	0	0.0	0
11	11.25	1957	0.0	1957	6.00	1963	0.0	1962	0.0	1962	0.0	1962	0	0.0	0
12	8.61	1936	0.0	1961	5.00	1971	0.0	1963	0.0	1963	0.0	1963	0	0.0	0
13	7.75	1970	0.0	1962	5.00	1958	0.0	1964	0.0	1964	0.0	1964	0	0.0	0
14	7.04	1959	0.0	1963	2.00	1967	0.0	1965	0.0	1965	0.0	1965	0	0.0	0
15	7.00	1971	0.0	1964	2.00	1969	0.0	1966	0.0	1966	0.0	1966	0	0.0	0
16	5.23	1960	0.0	1966	0.0	1959	0.0	1967	0.0	1967	0.0	1967	0	0.0	0
17	4.63	1964	0.0	1968	0.0	1961	0.0	1968	0.0	1968	0.0	1968	0	0.0	0
18	3.92	1961	0.0	1969	0.0	1965	0.0	1969	0.0	1969	0.0	1969	0	0.0	0
19	1.06	1972	0.0	1970	0.0	1966	0.0	1970	0.0	19.0	0.0	19.0	0	0.0	0
20	0.0	1958	0.0	1971	0.0	1968	0.0	1971	0.0	1971	0.0	1971	0	0.0	0
AVERAGE	12.68		18.73		12.90		0.0		0.0		0.0		0	0.0	0

CHAPTER 5
FIELD TESTING OF THE MODEL

The basis of DRAINMOD is an expression for a water balance in the soil profile (equation 1). Individual components of the water balance are evaluated from approximate methods. While most of these methods have been tested individually, to varying degrees, and their limitations documented in the literature, accumulation of errors from the various components could cause large inaccuracies in the composite model. The most direct and meaningful way of testing the reliability of DRAINMOD is to compare model predictions with results measured in field situations. Such experiments not only provide a good test of the reliability of the model but also documents the required model inputs for the sites and soils considered. They also provide a measure of the difficulty and expense of obtaining input values for the model.

Field experiments were installed in four locations to determine soil property and climatological inputs and test the reliability of DRAINMOD. This chapter describes the experiments and presents comparisons between measured and predicted results for a range of site and soil conditions.

Experimental Procedure
Field Sites

Experimental sites were located near Aurora, Plymouth, Laurinburg and Kinston, N.C. so field data representing a good geographical distribution of the Coastal Plains and Tidewater Regions in North Carolina were obtained. The water management systems on all sites have facilities for subsurface drainage and water table control as well as varying degrees of surface drainage. A brief description of each site is given below. Drainage system parameters for each site are given in Table 8. A list of crops grown on the research sites is given in Table 9 and a description of the soil profiles in Appendix B.

Table 8. Drainage system parameters for the experimental sites.

Parameter	Aurora - Austin Farm			Plymouth	Laurinburg	Kinston	
	7.5 m	15 m	30 m			Rains	Goldsboro
Soil type	Lumbee s.l. (some Myatt)		Cape Fear l.	Ogeechee l.	Rains s.l.	Goldsboro s.l.	
Type Drain	clay tile - 4 in.			open ditch	tubing	tubing	clay tile
Drain spacing	7.5 m	15 m	30 m	85 m	48 m	30 m	30 m
Drain depth	0.8 m	0.9 m	1.0 m	0.8 m	1.1 m	1 m	1 m
Drain diameter	102 mm	102 mm	102 mm	open	125 mm	152 mm	102 mm
Effective drain radius	2.5 mm	2.5 mm	2.5 mm	–	7 mm	7 mm	5.1 mm
Depth from drain to restrictive layer	0.5 m	0.5 m	0.7 m	2.2 m	1.4 m	0.4 m	0.4 m
Facilities for water table control a. controlled outlet	yes	yes	yes	yes	yes	yes	yes
b. pump-in capability	yes	yes	yes	yes	limited	no	no

Table 9. Crops grown on research sites; planting and harvesting dates.

Year	Crop	Aurora Plant date	Harvest date	Crop	Plymouth Plant date	Harvest date	Crop	Laurinburg Plant date	Harvest date
1973	potato	3-10*	6-20	corn	4-15*	9-12	-	-	-
	soybean	7-17	11-14						
1974	potato	3-10*	6-17	corn	4-15*	10-4	cotton	4-1*	10-15*
	soybean	7-10	11-27						
1975	corn	4-21	9-10	corn	4-21	9-23	cotton	4-1*	10-15*
	wheat	11-12	-						
1976	wheat	-	6-16	corn	4-15	9-1	cotton	4-4*	11-10*
	soybean	6-17	11-17	wheat	12-1	-			
1977	corn	4-25	9-1*	wheat	-	6-18*	cotton	4-5*	10-25*
				soybean	6-20*	11-20*			

*Approximate dates for planting or harvest.

Aurora. The site near Aurora is located on the H. Carroll Austin farm and is the same site that was used in a previous study to investigate the feasibility of water table control and subirrigation in the Coastal Plains (Skaggs and Kriz, 1972). The water management system consists of tile drains spaced 7.5, 15, and 30 m apart and buried approximately 1 m deep. The soil is primarily Lumbee sandy loam with some Myatt sandy loam and Torhunta sandy loam in the areas of the 7.5 and 15 m spacings. A schematic of the experimental setup is shown in Figure 19. The four drains for each spacing empty into an outlet ditch where a water level control structure is used to raise or lower the water level for subirrigation or drainage. Subirrigation was implemented by pumping additional water into the ditch from a well located near the five acre field. In some years this system was used to control the water table during April - July for growing potatoes and corn; however, it was used as a conventional drainage system during most of the experimental period.

Plymouth. The experimental site near Plymouth is located on the Tidewater Research Station and was also used in the previous water table control study. The soil is a Cape Fear loam and the water management system consists of open lateral ditches spaced 85 m apart. The field was land-formed in about 1969 and has excellent surface drainage. A water level control structure in the outlet ditch permitted the water level in the ditches to be controlled by either collecting field runoff and drainage waters or by pumping into the ditch from an irrigation well. A weir was installed in the outlet structure to raise the water table during the months of May, June, and July in 1974 and 1975 to supply water to the crop. Water was pumped into the outlet and the ditch water maintained for subirrigation purposes for short periods in both years. However the system was operated in a controlled drainage mode without pumping for most of the growing season. Figure 20 shows the weir and the raised water level in the outlet. This field was also used as one treatment in another Water Resources Research Institute sponsored study reported by Gilliam et al. (1978) on controlling the movement of fertilizer nitrates in drainage waters. As a part of this investigation the weir level was raised almost to the surface during the winter months of
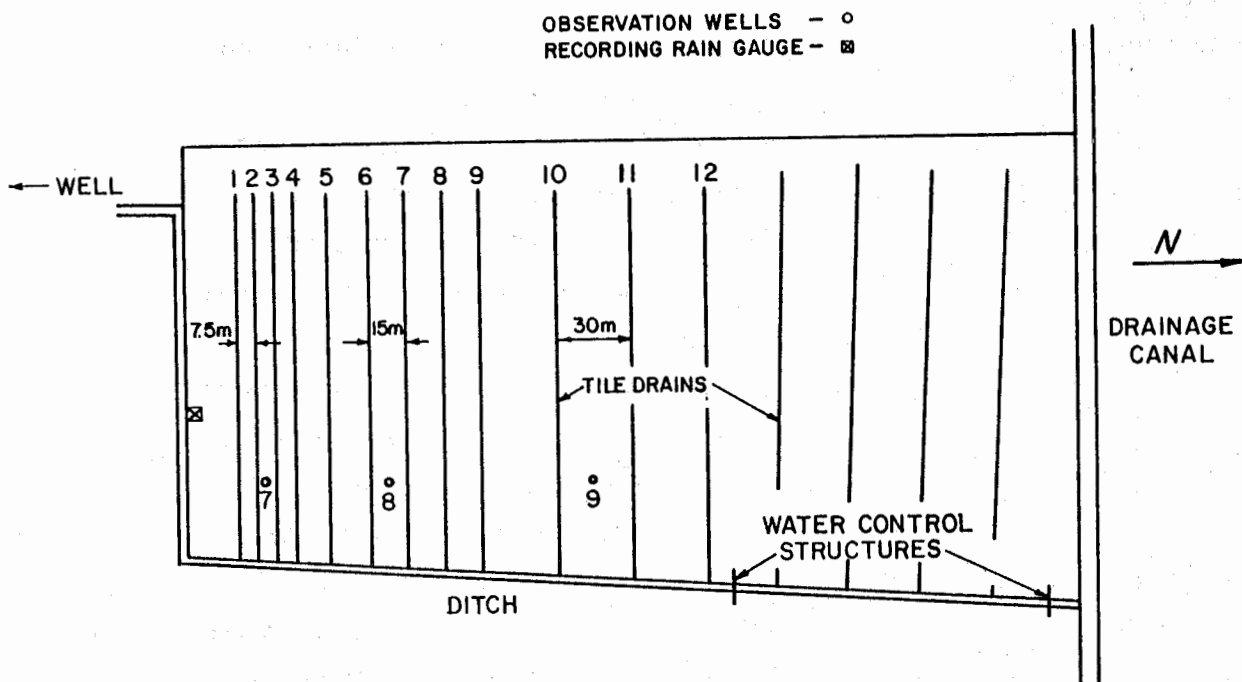
Figure 19. Schematic of experimental setup on the H. Carroll Austin Farm, Aurora, N.C.
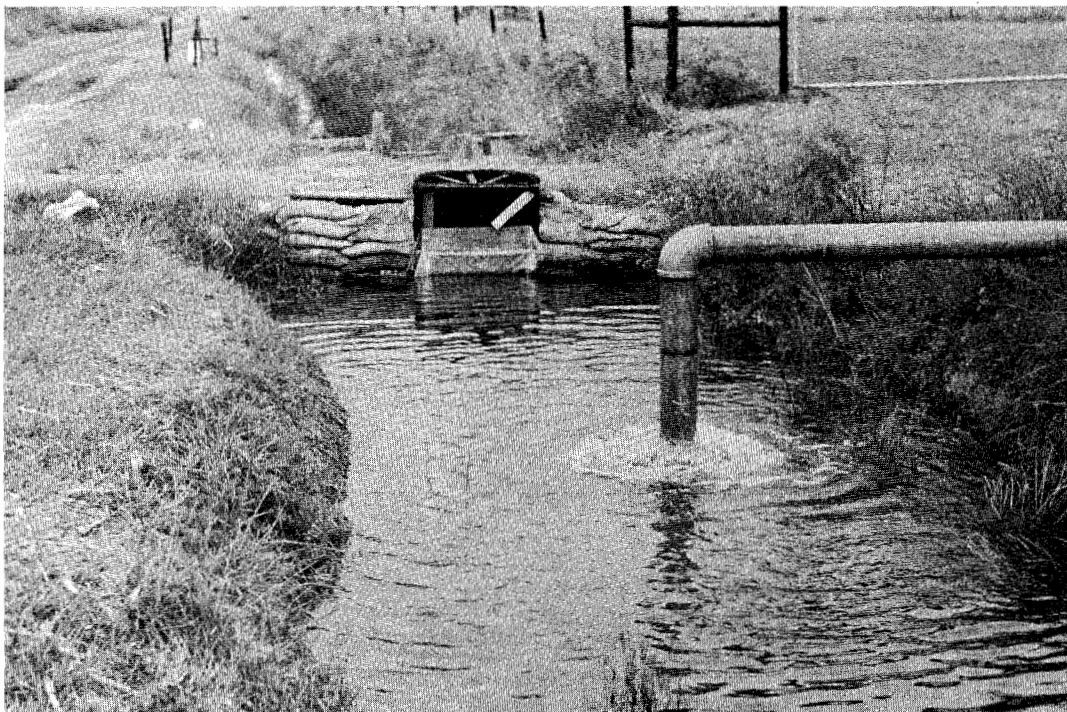
Figure 20. A water level control structure in the outlet ditch at the Tidewater Research Station permitted controlled drainage and subirrigation on the Cape Fear soil.

1973-74 and 1974-75 and the system operated in the controlled drainage mode for purposes of studying the effect of high water tables on the movement and denitrification of fertilizer nitrates.

Laurinburg. Experiments were conducted on a water management system located on the McArne Bay farm of McNair Seed Company near Laurinburg, N.C. The soil was formerly classified as a Portsmouth loam but more detailed analysis indicated primarily Ogeechee with small areas of Coxville in the experimental area. The loam and sandy clay surface layers are underlain at about 1 m by a coarse sand layer which varies in thickness from 0.50 to 1.2 m. Drain tubes are spaced 48 m apart and outlet into a large drainage ditch. The water level in the ditch is controlled by raising or lowering the weir on a water level control structure and holding drainage and runoff water in the ditch. During dry periods water may be pumped from a drainage canal to raise the water in the outlet ditch. This water management system is an integral part of the drainage and irrigation system for an entire Carolina Bay consisting of about 1200 acres.

Kinston. Water management systems on a Rains sandy loam and a Goldsboro sandy loam on the Tobacco Experiment Station at Kinston were studied. Both systems have good surface drainage and have tile drains spaced 30 m apart and buried 1 to 1.2 m deep. Water level control structures were installed on the main tile lines in each system to control the drainage rate and were used in the fertilizer nitrate study by Gilliam et al. (1978) referenced above. Although water table records of sufficient length to test the model were not collected on these sites, short term experiments were conducted and input properties were measured for each soil and may be used for long term simulations.

Field Measurements.

Although the design and management of the water table control systems vary in some respects among the sites discussed above, most of the field measurement procedures were the same for each site. The water table elevation midway between drains was measured in 10 cm diameter observation wells, drilled to the depth of the impermeable layer, and fitted with Leupold and Stevens type F water level recorders

to give a continuous record of the water table position. The same instrument was used to record the water level in the drainage ditches, or, in the case of drain tubes, the water level in the outlet ditch. The unsaturated soil water pressure head distribution was measured with tensiometers for intervals of a few weeks duration during the growing season at the Plymouth and Aurora sites. Tensiometers were placed at 15, 30, 45, 60, 75, and 120 cm depths midway between sub-surface drains.

Tests of short duration were conducted on the Aurora and Plymouth sites to make intensive measurements of soil water conditions during drainage and subirrigation. The water table was raised to near the soil surface by raising the weir levels in the water level control structures and pumping water into the outlet ditches. Piezometers were installed at the tensiometer depths given above at the midpoint and quarter points between drains and used to determine the existance of vertical gradients in the saturated zone of the profile. Then the weir level was lowered and the tensiometers and piezometers read several times daily during the drainage period to test the validity of the linear pressure head distributions assumed in DRAINMOD for the drainage period.

Rainfall was measured on each site with a WeatherMeasure Model P501-1 tipping bucket recording rain gauge with a P521 event recorder. Although this instrument accurately measured the variation of rainfall intensity with time, hourly values were used as inputs to test DRAINMOD. Use of rainfall data on a more frequent basis, say 10 to 15 minutes, was possible and would have probably allowed a better estimation of infiltration and runoff. However, data available from weather station records have a maximum frequency of one hour in most cases. Since these are the data that will be used in simulation, the model was tested using measured rainfall accumulated over one-hour intervals.

Daily maximum and minimum temperatures were obtained from weather stations near each site and the potential ET calculated by the Thornthwaite method. U.S. Weather Bureau standard evaporation pans were installed at each location and modified to record evaporation contin-

uously (Figure 21). Details of the design and operation of the recording pan as well as comparisons between pan measurements and Thornthwaite predictions are given by Mohammad (1978). However, the Thornthwaite method is used to compute PET in the present version of DRAINMOD, so it was also used in testing the validity of the model predictions.

Surface runoff plots were installed to measure surface runoff during rainfall events and to be used in determining the infiltration characteristics of the soils. Sheet metal barriers were installed around the 3 m x 4 m plots and the runoff was diverted to buried reservoirs (Figure 22). Runoff rates were measured and recorded using a tipping bucket apparatus in conjunction with an event recorder. Infiltration tests were conducted by sprinkling water on the surface of the plot at a rate of approximately 120 mm/hr and measuring the runoff rate.

Surface depression storage was characterized by making elevation surveys on a fine meshed grid and by using a surface sealing procedure to determine the storage in small pockets or depressions caused by micro-relief. These measurements were made as a part of a detailed study of surface storage and are described in detail by Gayle and Skaggs (1978).

One of the functions of DRAINMOD is to determine, on a day to day basis, whether conditions are suitable for conducting field operations, as discussed in Chapter 3. This determination is based on soil and weather conditions and requires input data specifying the drained, or air, volume below which conditions are not suitable for field operations. The amount of rainfall necessary to postpone field operations and the length of time after rainfall occurs before operations can continue are also needed inputs to the model. These parameters were approximated for the soils considered in this study by field observations in the spring months of 1975 and 1976. Field conditions on all research sites were monitored by experienced technicians in coordination with the farmer or experiment station personnel. When the soil reached a condition that was just dry enough to plow and prepare seedbed, soil samples were taken from 10 and 20 cm depths at several locations within the field
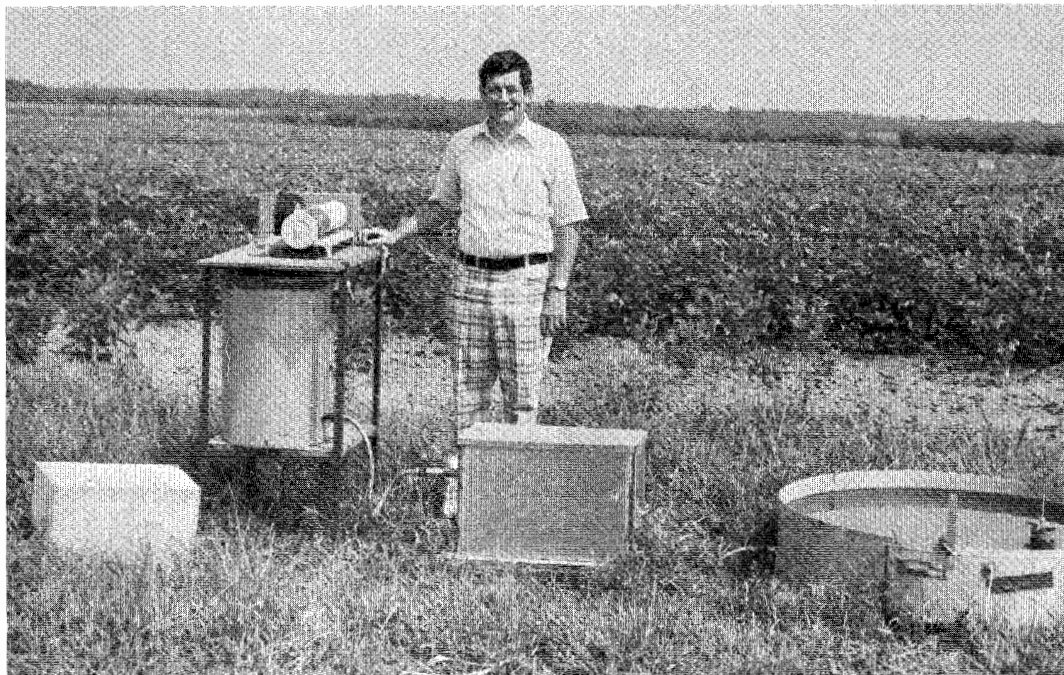
Figure 21. A standard evaporation pan was modified to record pan evaporation directly. A reservoir was set up to supply water to the pan through a float valve as evaporation took place. By recording the water level in the reservoir, evaporation could be determined as a function of time.

Figure 22. Runoff from 3 m X 4 m plots was recorded with a tipping bucket apparatus and an event recorder.

and the volumetric water content determined. Drainage or air volumes
corresponding to the measured water contents were determined from the
soil water characteristics and the drainage volume - water table depth
relationships. The amount of rain necessary to postpone field opera-
tions and the minimum time required after that amount of rainfall before
operations can proceed were also approximated based on the soil type and
experience of the farmer or station manager.

Soil Property Measurements.

The saturated hydraulic conductivity was measured in the field
using the auger hole method (Boast and Kirkham, 1971) and a method based
on water table drawdown (Skaggs, 1976). The unsaturated hydraulic conduc-
tivity function K(h) was estimated using the method of Millington and
Quirk (1960) with a matching factor at saturation. The K(h) function for
the Wagram and top 60 cm of the Lumbee soils were measured experimentally
(Wells and Skaggs, 1976).

Soil water characteristics for each soil horizon down to the drain
depth were determined on small undisturbed core samples using a standard
pressure plate method (Richards, 1965). The relationship between drain-
age volume and water table depth was measured directly on large undis-
turbed soil cores (0.50 m in diameter and approximately 1 m long). The
procedures for extracting the cores and making the measurements are des-
cribed by Skaggs et al. (1978). The cores were attached to gravel filled
bases in the lab and wetted from the bottom by raising a water reservoir
connected to the outlet. After the water table rose to the surface and
remained for at least one day the outlet reservoir was lowered in small
increments and the drainage volume measured at each water table depth.

Results - Soil Properties

Hydraulic Conductivity

The results of the saturated conductivity measurements are summariz-
ed in Table 10. Values obtained from both drawdown and auger hole measure-
ments varied with initial water table depth and from point to point in
the fields so average values are tabulated. The soils on the Aurora,
Plymouth and Laurinburg sites have sandy layers at depths below about 1 m
(Appendix B) which have higher K values than the surface layers. The con-

Table 10. Summary of average hydraulic conductivity values from auger
hole and drawdown measurements.

Site	Method	No. measurement	Average K value
Aurora			
7.5 m	drawdown	17	1.01 cm/hr
	auger hole	9	1.84
15 m	drawdown	19	1.84
	auger hole	9	1.73
30 m	drawdown	19	
	auger hole	10	3.16
Plymouth	drawdown	7	37.2
	auger hole	6	15.3
Laurinburg	drawdown	8	6.3
	auger hole	3	7.8
Kinston			
Goldsboro	auger hole	3	6.5
	large core (		
	(vertical K)	2	1.7
Rains	auger hole	6	4.3
	large core		
	(vertical K)	1	1.8

ductivities of the various profile layers are difficult to determine from
drawdown measurements as the drawdown depends on the conductivities in
all layers below the water table. Likewise measurements from auger holes
that penetrate or closely approach the sandy layer may be expected to
give an intermediate value between the K's of the upper and lower layers.

The soils on the Aurora site are particularly difficult to
characterize because of sandy layers in the surface horizons which are
of varying thickness and sometimes discontinuous. For example, in pre-
vious studies (Wells and Skaggs, 1976), we found the vertical K in 3
large cores of the surface 60 cm of Lumbee to be greater than 10 cm/hr
yet only 1.2 cm/hr in a 4th core from the same general area of the field.
Measurements from other cores greater than 1 m deep and analysis of the
K determinations from auger hole and drawdown measurements according to
initial water table depth indicates that the surface 0.75 to 1 m of the
Aurora soils have an effective lateral K of about 1 cm/hr. In some field

locations the effective K of the surface zone is higher, and there are high K layers within this zone in nearly all locations. However drawdown and auger hole measurements indicate that the effective K falls within the range of 0.75 to 1.5 cm/hr for the surface layer. Values tend to be near the higher end of the range for the Lumbee soils where the spacing is 30 m and somewhat lower for the soils in the 7.5 and 15 m spacing. The K value of the deeper sandy layer is about 3 cm/hr.

Analysis of the K values with respect to initial water table depth and soil profile layering resulted in the values given in Table 11 for conductivities at each site. The effective lateral K of the profile when the water table is near the surface was calculated from the conductivities of the two layers and may be compared to the values in Table 10.

Table 11. Summary of K values of profile layers used as input to DRAINMOD.

Site	Layer Depth (m)	K (cm/hr)	Equivalent K* for profile (cm/hr)
Aurora			
7.5 m	0 - 1.0 **	1.0 cm/hr	
	1.0 - 1.08	3.0	1.14 cm/hr
15 m	0 - 1.0 **	1.0	
	1.0 - 1.23	3.0	1.37
30 m	0 - 1.0 **	1.0	
	1.0 - 1.58	3.0	1.73
Plymouth	0 - 1.1 **	15.0	
	1.1 - 2.82	45.0	34.0
Laurinburg	0 - 1.20	0.75	3.5
	1.20- 2.40	6.3	
Kinston			
Goldsboro	0 - 1.4	6.5	6.5
Rains	0 - 1.1	4.3	3.6
	1.1 - 1.4	1.0	3.6

*This value is calculated for lateral flow (parallel to the layers) with the water table at the surface.
**Effective depths of the profiles when corrected for convergence near the drain.

The conductivity inputs to DRAINMOD are the values given for individual layers in Table 11. It should be noted that the values given for the drawdown method in Table 10 are averages obtained for a range of initial water table depths. Generally the values for Aurora and Plymouth increased with initial water table depth. Likewise the equivalent conductivities obtained from the layer values given in Table 11 will increase with depth because of the higher conductivity of the bottom layer.

Soil Water Characteristic and Drainage Volume - Water Table Depth Relationships

Soil water characteristic data (drainage branch) are tabulated in Table 12 for the soils considered in this study. Data are also presented for two additional soils, a Wagram loamy sand, and a Portsmouth sandy loam; the latter soil is located on the Tidewater Experiment Station at Plymouth. Wilting point water contents are also included in the soil water characteristic data. The main use of the soil water characteristic in DRAINMOD is to calculate the relationship between drainage volume and water table depth. However these relationships were measured directly from large field cores for all soils on the experimental sites except for the Ogeechee soil on the Laurinburg site. The measured drainage volume - water table depth relationships are plotted in Figure 23. Relationships for water table depths greater than the core depth were calculated from the soil water characteristics. The entire relationship was calculated for the soil on the Laurinburg site as large cores were not collected from this location.

Infiltration Parameters

Coefficients of the Green-Ampt infiltration equation were determined from infiltration measurements on the surface runoff plots and on large undisturbed field cores. Some runoff plot infiltration measurements were made by sprinkling water at a known rate on the plot and subtracting the measured runoff rate from the application rate. Other infiltration measurements were determined from runoff caused by natural rainfall events. Measurements on field cores were made by ponding water on the surface of the same large cores used to determine the drainage volume -

Table 12. Drainage branch of the soil water characteristics for the soils considered in this study. Values given in table are volumetric water contents.

Soil	Soil water pressure head (cm of water)													Wilting point (15 bars)
	0	-10	-20	-30	-40	-50	-60	-70	-80	-100	-150	-200	-500	
Lumbee s.l. - Aurora (0 - 0.6 m)	0.342	0.335	0.322	0.305	0.290	0.280	0.270	0.265	0.256	0.250	0.210	0.190		0.12
Cape Fear l. - Plymouth														
(0.15 m)	0.482	0.444	0.429	0.418	0.410	0.402	0.396	0.392	0.388	0.381	0.372	0.368		0.22
(0.5 m)	0.462	0.444	0.329	0.422	0.417	0.412	0.409	0.405	0.401	0.394	0.378	0.367		
Ogeechee l. - Laurinburg														
(0.3 m)	0.450	0.433	0.420	0.410	0.405	0.402	0.398	0.397	0.391	0.385	0.372	0.365	0.340	0.24
(0.75 m)	0.425	0.398	0.383	0.368	0.358	0.347	0.335	0.331	0.326	0.320	0.312	0.307	0.293	
Goldsboro s.l. - Kinston														
(0.15 m)	0.364	0.354	0.340	0.322	0.300	0.272	0.253	0.242	0.234	0.224	0.192	0.186		0.06
(0.40 m)	0.370	0.360	0.350	0.340	0.326	0.312	0.303	0.297	0.294	0.288	0.282	0.280		
Rains s.l. - Kinston														
(0.15 m)	0.370	0.300	0.282	0.272	0.266	0.258	0.254	0.248	0.244	0.238	0.228	0.224		0.09
(0.40 m)	0.368	0.326	0.302	0.286	0.275	0.267	0.261	0.256	0.251	0.244	0.231	0.222		
Wagram l.s. (0-0.9 m)	0.302	0.299	0.285	0.254	0.218	0.184	0.154	0.132	0.117	0.103	0.087	0.072	0.051	0.03
Portsmouth s.l. - Plymouth														
(0.15 m)	0.390	0.363	0.354	0.346	0.340	0.334	0.328	0.324	0.319	0.312	0.304	0.296		0.13
(0.40 m)	0.400	0.382	0.370	0.361	0.354	0.348	0.342	0.338	0.336	0.334	0.331	0.328		
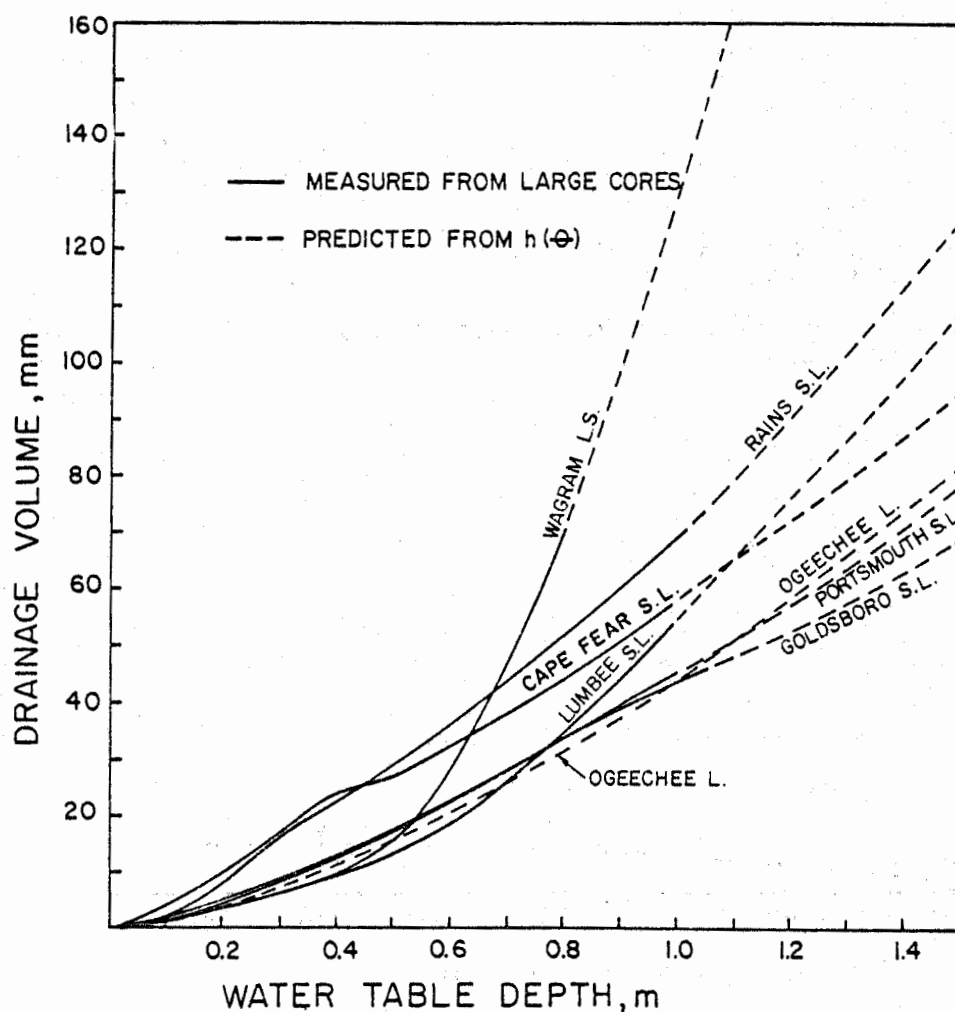
Figure 23. Drainage volume or air volume (cm^3/cm^2) as a function of water table depth for soils considered in this study.

water table depth relationships. Finally, additional measurements were made using guarded ring infiltrometers. Coefficients A and B of the Green-Ampt equation were determined from each measured relationship and plotted versus the initial water table depth (e.g. Figure 24 for Lumbee sandy loam). When a dry zone existed at the soil surface an equivalent initial water table depth was defined such that the air volume corresponding to the equivalent depth is equal to the total air volume in the profile including the dry zone. Values of the coefficients A and B corresponding to selected initial water table depths were obtained from
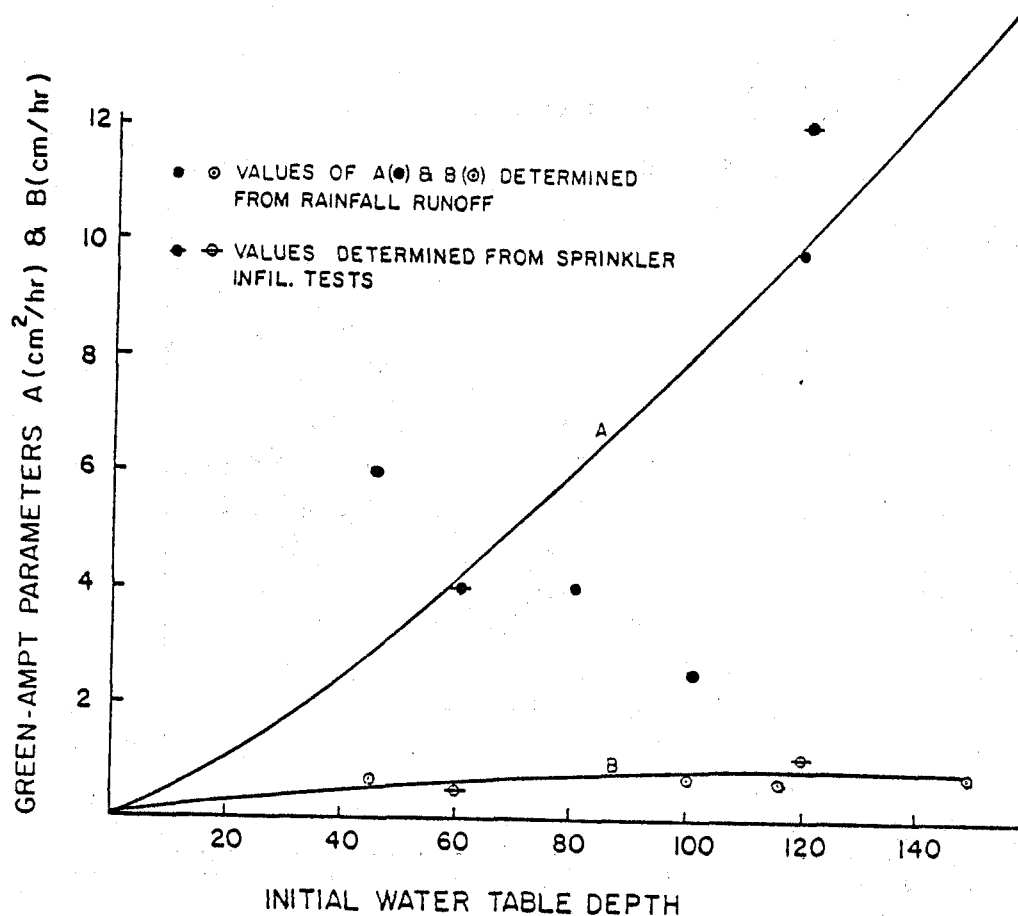
Figure 24. Green-Ampt parameters A and B versus water table depth for the Lumbee sandy loam soil on the Aurora site.

the plots and used as inputs to the computer program. These values are tabulated in Table 13 for the experimental sites. In the simulation process, DRAINMOD selects coefficients by interpolation from the table based on the initial equivalent water table depth.

Upward Water Movement

Relationships between maximum rate of upward water movement and water table depth were defined for each soil by numerically solving equation 18 for vertical unsaturated water movement due to ET at the surface. The surface boundary condition was assumed to be h = -1000 cm. The relationships are plotted in Figure 25.
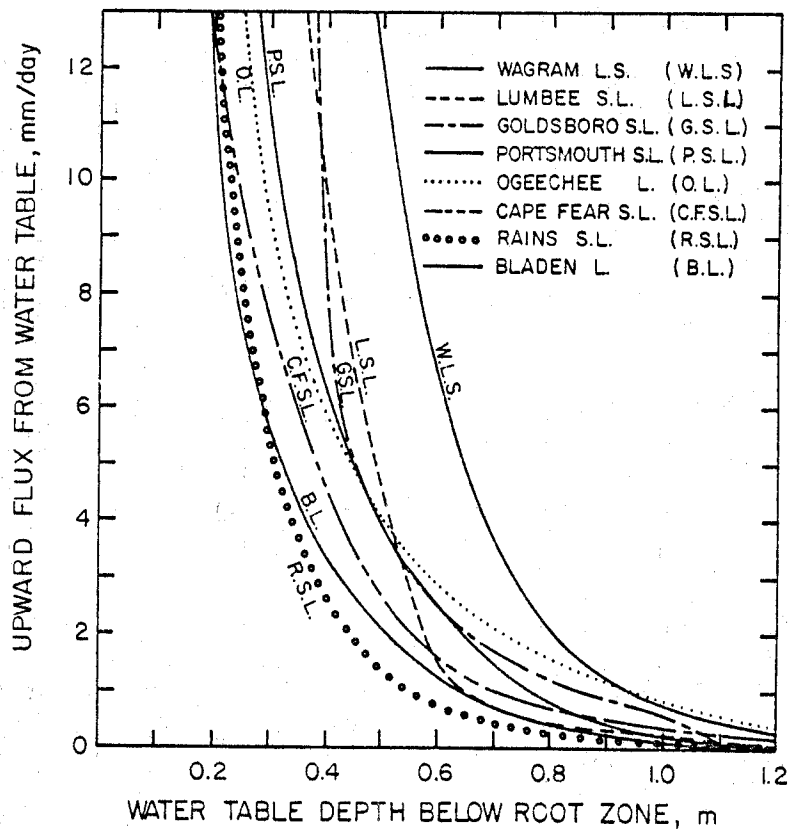
Figure 25.   Effect of water table depth on steady upward flux from
               the water table.

Trafficability parameters

Trafficability parameters for the soils considered in this study
are listed in Table 14.   These data are not used to test the model but
are important inputs for long term simulations for the given soils.   The
parameters given were determined for plowing and seedbed preparation in
the spring.   No attempt was made to determine the parameter values for
the harvest season.   Generally the maximum allowable soil water content
for field operations would be higher and the required drained (air)
volume lower during the harvest season than for seedbed preparation.

Root Depths

The crop root depths were estimated from the planting and harvesting
dates given in Table 9.   The plots given in Figure 17 were used as a
guide to determine the rooting depth for corn.   The maximum effective

Table 13. Estimates of coefficients for the Green-Ampt infiltration equation as a function of initial equivalent water table depths.

Soil	Equivalent water table depth (m)*											
	0		0.50		1.0		1.5		2.0		5.0	
	A	B	A	B	A	B	A	B	A	B	A	B
Cape Fear	0	0	0.8	0.5	6.6	0.8	9.5	1.0	11.0	1.0	13.0	1.0
Lumbee	0	0	3.3	0.3	8.0	0.8	15	1.0	20	1.0	20	1.0
Ogeeche	0	0	2.0	0.75	4.0	1.0	6.0	2.0	8.6	2.6	30	2.6
Goldsboro	0	0	1.2	0.75	2.7	1.25	4.4	2.0	5.3	2.0	26.0	2.0
Rains	0	0	1.2	0.50	3.0	0.75	6.0	1.0	9.2	1.0	25.0	1.0
Wagram	0	0	3.0	1.0	5.5	2.0	8.7	3.0	11.5	3.0	25	3.0
Portsmouth	0	0	1.2	0.75	6.5	1.2	10.0	1.5	12.0	1.5	15.0	1.5
Bladen	0	0	0.82	0.15	1.3	0.15	1.5	0.15	1.8	0.15	2.1	0.15

*Equivalent water table depth is the drained to equilibrium water table depth corresponding to a given amount of air volume in the profile. For example if the water table depth was 1.0 m but a dry zone exists so that the profile contains 10 cm³ of air per cm² of surface area, the equivalent water table depth is the drained to equilibrium depth that would have 10 cm of air.

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Table 14. Trafficability parameters for plowing and seedbed preparation.

Soil	Maximum water content-plow layer (cm³/cm³)	AMIN* (mm)	ROUTA** (mm)	ROUTT*** (days)
Cape Fear 1.	0.395	33	12	2
Lumbee s.1.	0.265	28	15	1
Ogeechee 1.	0.39	34	12	2
Goldsboro s.1.	0.23	32	15	1
Rains s.1.	0.25	39	12	2
Wagram 1.s.	0.15	35	15	1
Bladen s.1.	0.40	30	10	2
Portsmouth s.1.	0.32	30	12	2

*AMIN = the minimum air volume (or drained volume) for plowing and seedbed preparation. That is, it would be too wet to prepare seedbeds if the drained volume is less than AMIN.

**ROUTA = the amount of rain necessary to postpone field work.

***ROUTT = the time necessary for soil water redistribution before field work can be restarted after it has been postponed by rainfall in excess of ROUTT.

rooting depth for corn was assumed to be 30 cm while 25 cm was assumed for potatoes, soybeans and wheat. The rooting depths for each site are tabulated as a function of Julian date for each year in Appendix C.

Climatological Data

Hourly precipitation data measured on each experimental site are given in Appendix D for the duration of the study. Daily maximum and minimum temperatures were obtained from published U.S. Weather Bureau records for stations at Aurora, Plymouth and Laurinburg. The Plymouth weather records were collected on the Tidewater Experiment Station while the weather stations at Aurora and Laurinburg were within a few km of the experimental sites.

Water Level in Drainage Outlet

The drainage outlets in the field experiments at Aurora, Plymouth and Laurinburg all received water from large areas outside of the

experimental areas. As a result it was not possible to predict the water level in the drainage outlet. The water level in the outlet was measured continuously and the average daily value was used as an input to test DRAINMOD. That is, the measured water level in the ditch was read in rather than predicted from subroutine YDITCH in the model. The daily values for each year of the tests are tabulated in Appendix D for sites at Plymouth and Laurinburg. The outlet water levels are plotted for the Aurora site in Figures 41-45.

Measured Versus Predicted Water Table Elevations

Water table elevations predicted by DRAINMOD are compared to measured values in the plots given on the following pages. The measured and predicted water table elevations at the end of each day were plotted automatically by the computer for a series of one-year test periods. The agreement between predicted and measured values was quantified by calculating a standard error for each test period defined as follows,

$$s = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - Y_i')^2)}{n}} \qquad (20)$$

where s is the standard error, n is the number of days in the test period (year), Y_i is the measured water table elevation above a datum at the end of each day and Y_i' is the predicted water table elevation. The average deviation (a.d.) was also computed for each test period as,

$$a.d. = \sum_{i=1}^{n}|Y_i - Y_i'|/n \qquad (21)$$

where the symbols are the same as defined above.

It should be emphasized that the plots given on the following pages are not the results of a data fitting exercise.. In every case the agreement between measured and predicted results could be improved by changing one or more of the model inputs. However the values required to optimize the fit could not be determined *a priori* so juggling the various inputs to improve the agreement with observed data would not provide a meaningful test of the model reliability. Instead, each input parameter was determined independently as discussed in previous sections

of this report. In a few cases the parameters will be varied to deter-
mine the sensitivity of the model to errors in parameter determinations.
However, comparison of predicted results with values measured in the
field using independently measured input parameters is the only true
test of the reliability of the model. This is the method used herein
to determine the suitability of DRAINMOD for application to design and
analysis of water management systems.

Plymouth

Predicted and observed water table elevations from the Tidewater
Experiment Station near Plymouth are given in Figures 26 through 30. The
agreement between predicted and observed results is very good with stan-
dard errors of estimate (s values) ranging from 8.6 cm (1977) to 9.8 cm
(1975). The agreement is particularly good during periods when the water
level in the drainage ditch is raised by controlled drainage or subirri-
gation. This is due to the high conductivity of the profile, especially
the sandy layer below a depth of approximately 1.1 m, which permits the
water table to respond quickly to changes in the observed ditch water
level. The net effect is that the high K values makes the water table
more sensitive to ditch water levels than to some of the other input para-
meters such as those used in predicting infiltration, upward water move-
ment and ET. Controlled drainage was used during most of 1974, the first
60 days of 1975, and for a two month period from Dec., 1976 to Jan., 1977.
Subirrigation was also used for short periods in 1973 and 1975 by pumping
water into the drainage outlet from a deep well. However, for most of
1973, 1975, 1976 and 1977, the system was operated as a conventional
drainage system and still gave excellent agreement between measured and
predicted results.

Aurora

Water table elevations are plotted for the 7.5 m drain spacing at
Aurora in Figures 31 (1973) through 35 (1977). Results are plotted for
the same years for the 15 m spacing in Figures 36 through 40 and for
the 30 m spacing in Figures 41 through 45. The standard errors of
estimate (s) are given on each plot and summarized, along with corres-

PLYMOUTH▦
L = 85 m
YEAR 1973

——————— CALCULATED
·················· OBSERVED

S = 10.4 cm

SURFACE

DRAIN EL.

JULIAN DATE
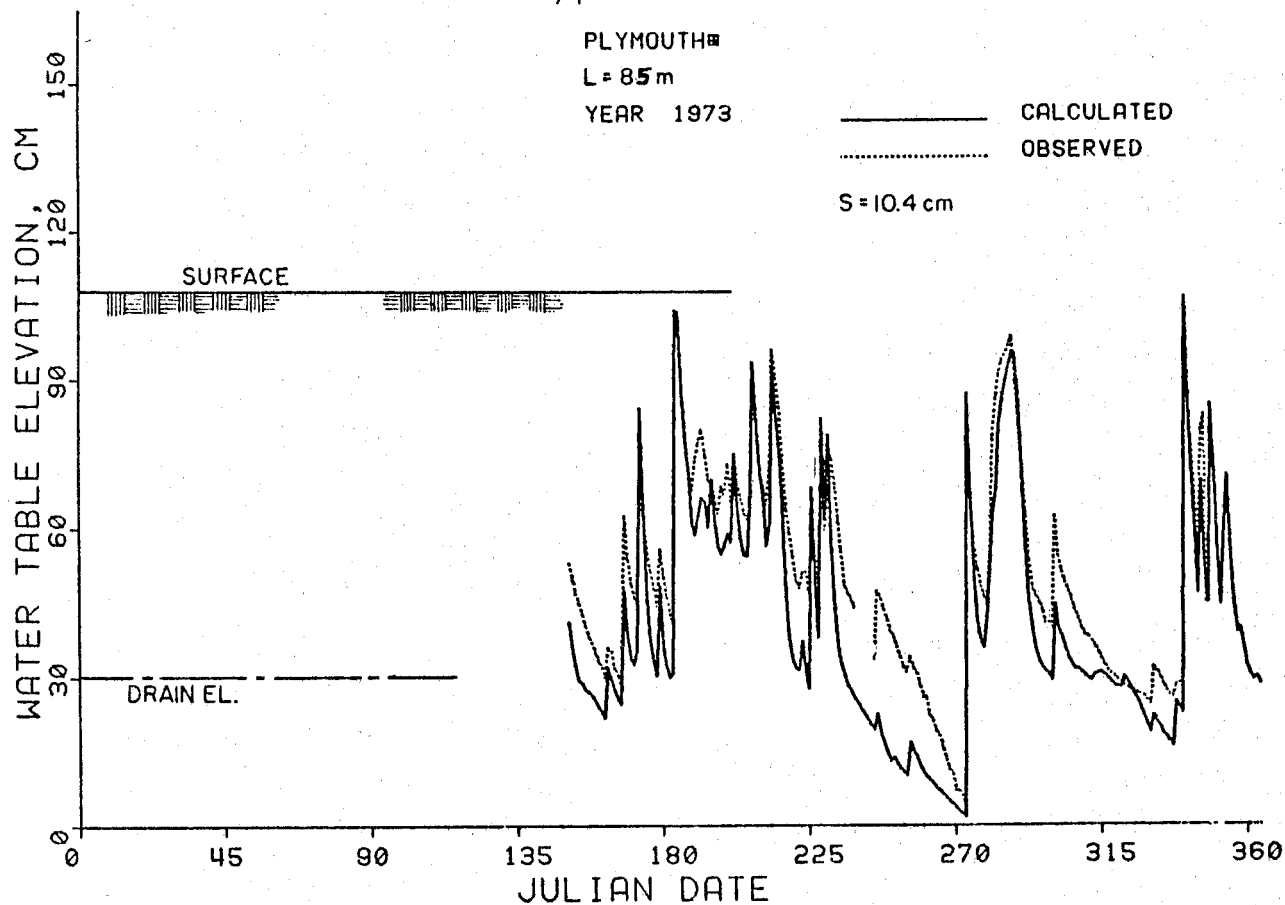
Figure 26. Observed and predicted water table elevations midway between drains space 85 m apart on the Plymouth site during 1973.

PLYMOUTH▦
L = 85 m
YEAR 1975

——————— CALCULATED
·················· OBSERVED

S = 9.8 cm

SURFACE

DRAIN EL.

JULIAN DATE
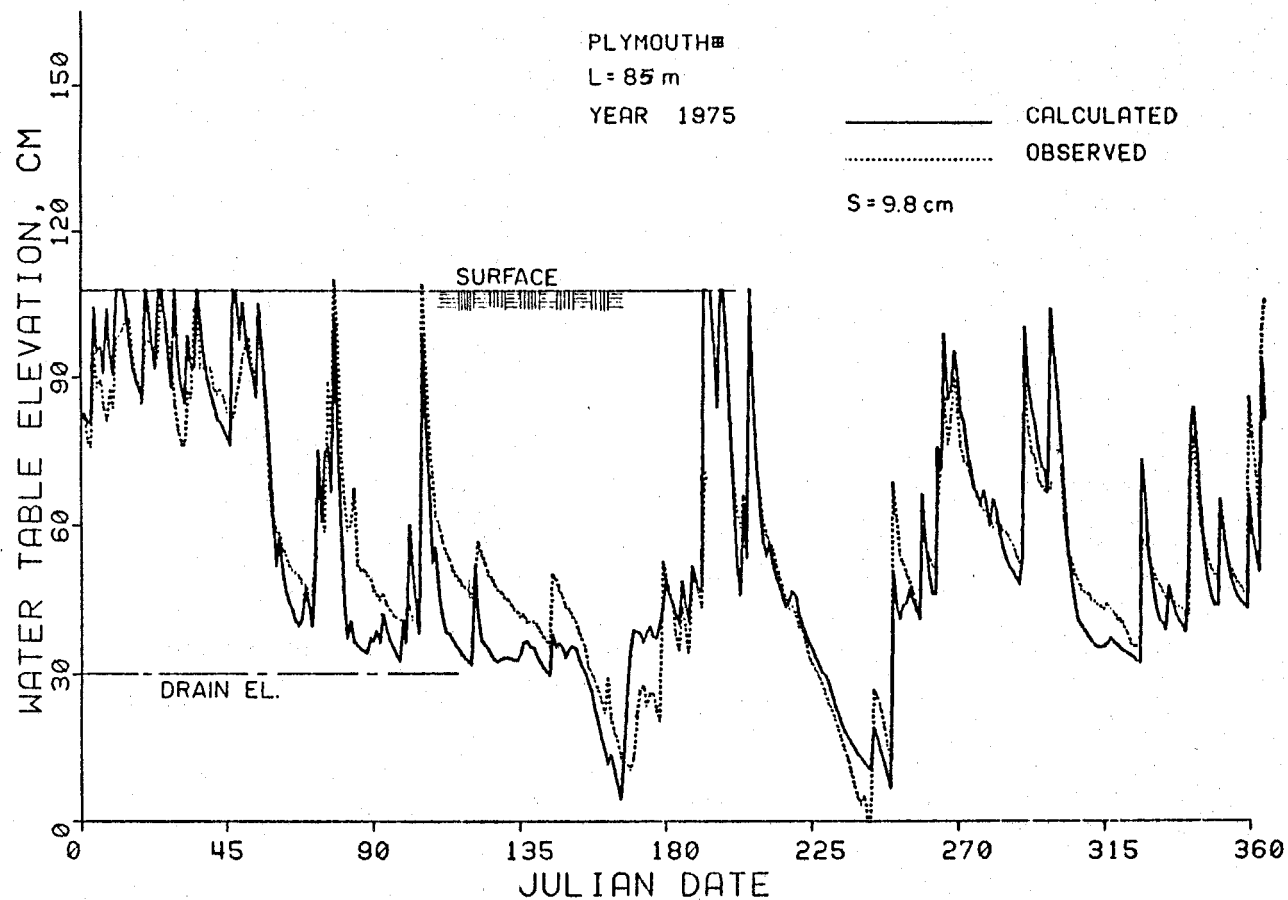
Figure 27. Observed and predicted water table elevations midway between drains spaced 85 m apart on the Plymouth site during 1974.
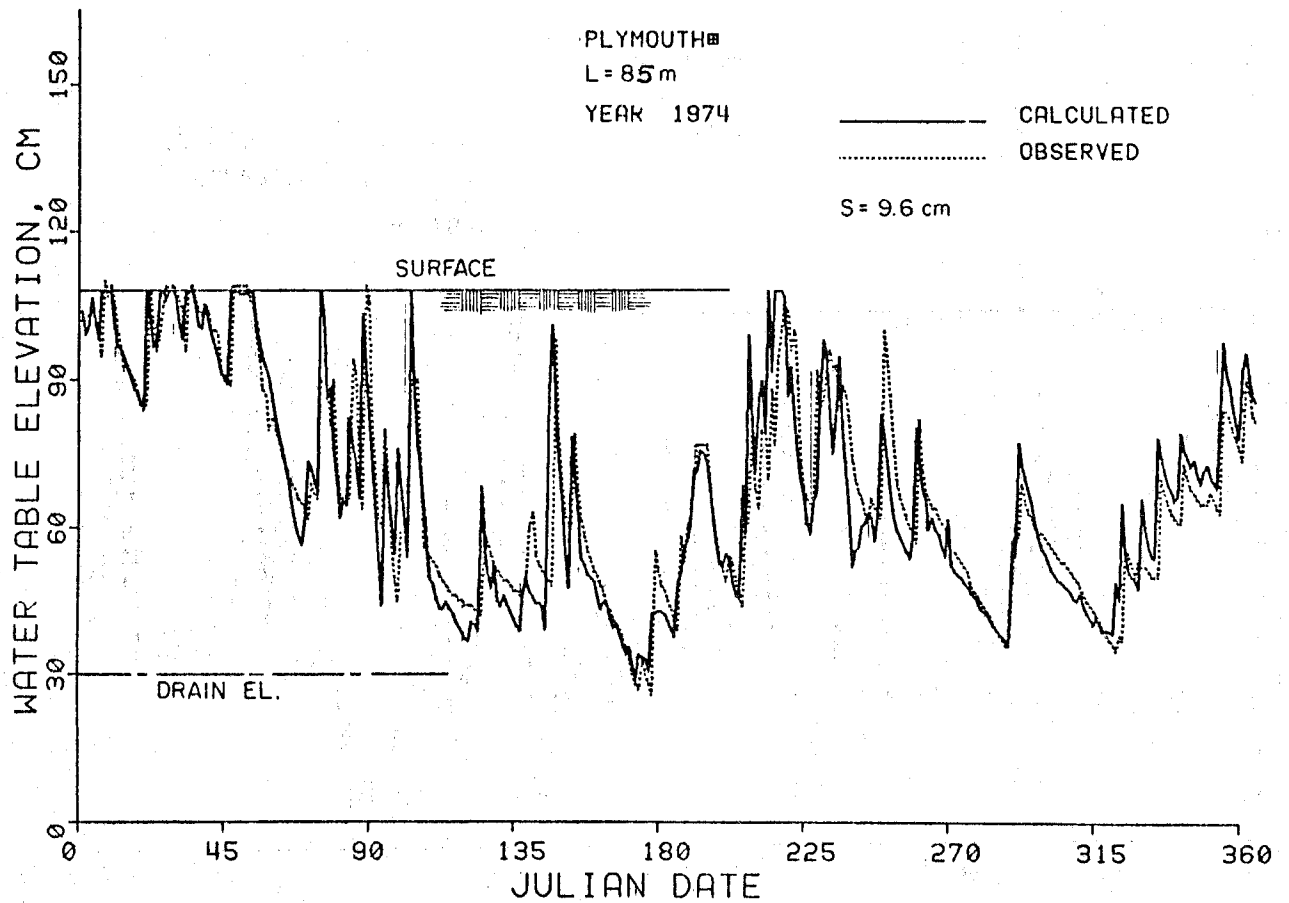
Figure 28. Observed and predicted water table elevations midway between drains space 85 m apart on the Plymouth site during 1975.
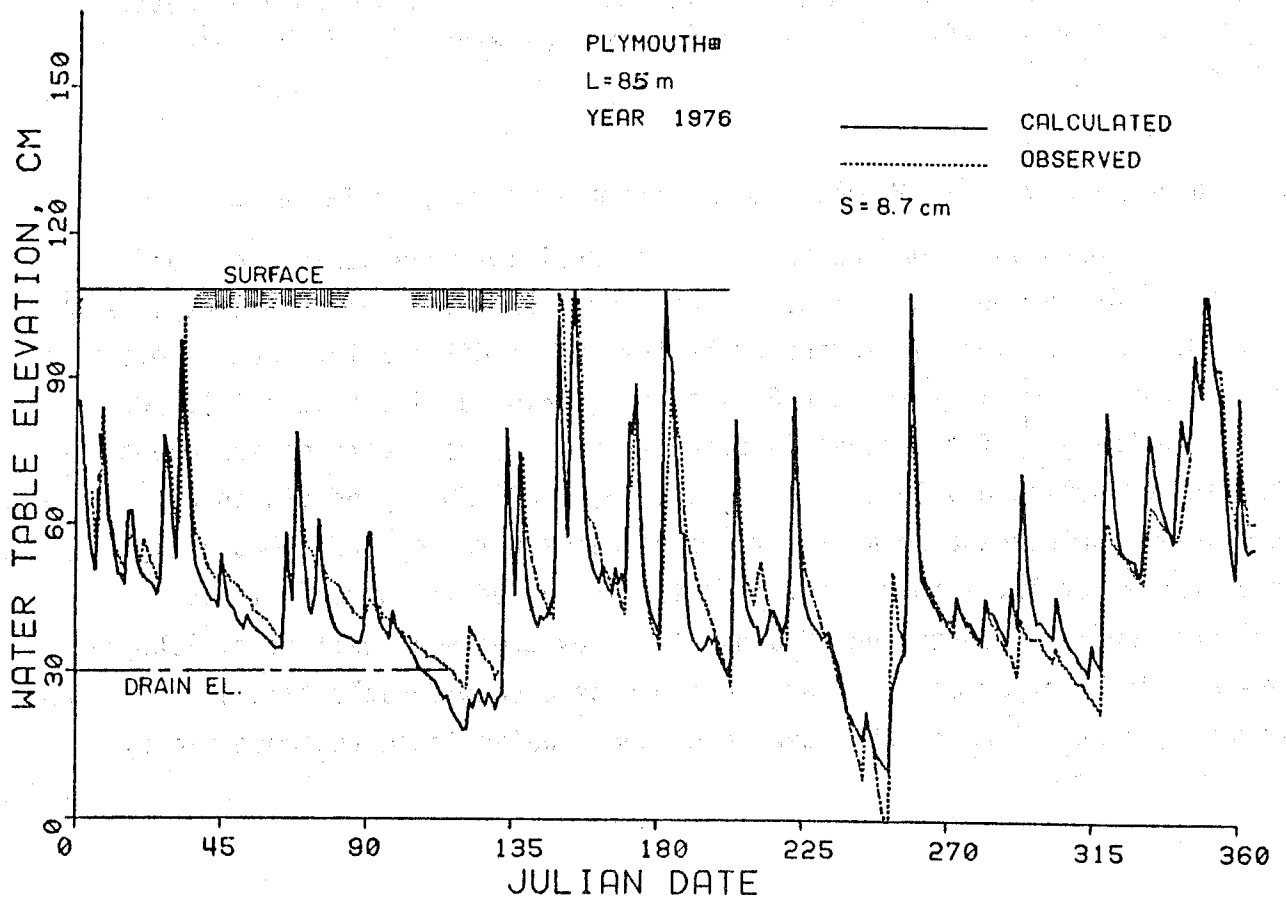
Figure 29. Observed and predicted water table elevations midway between drains space 85 m apart on the Plymouth site during 1976.
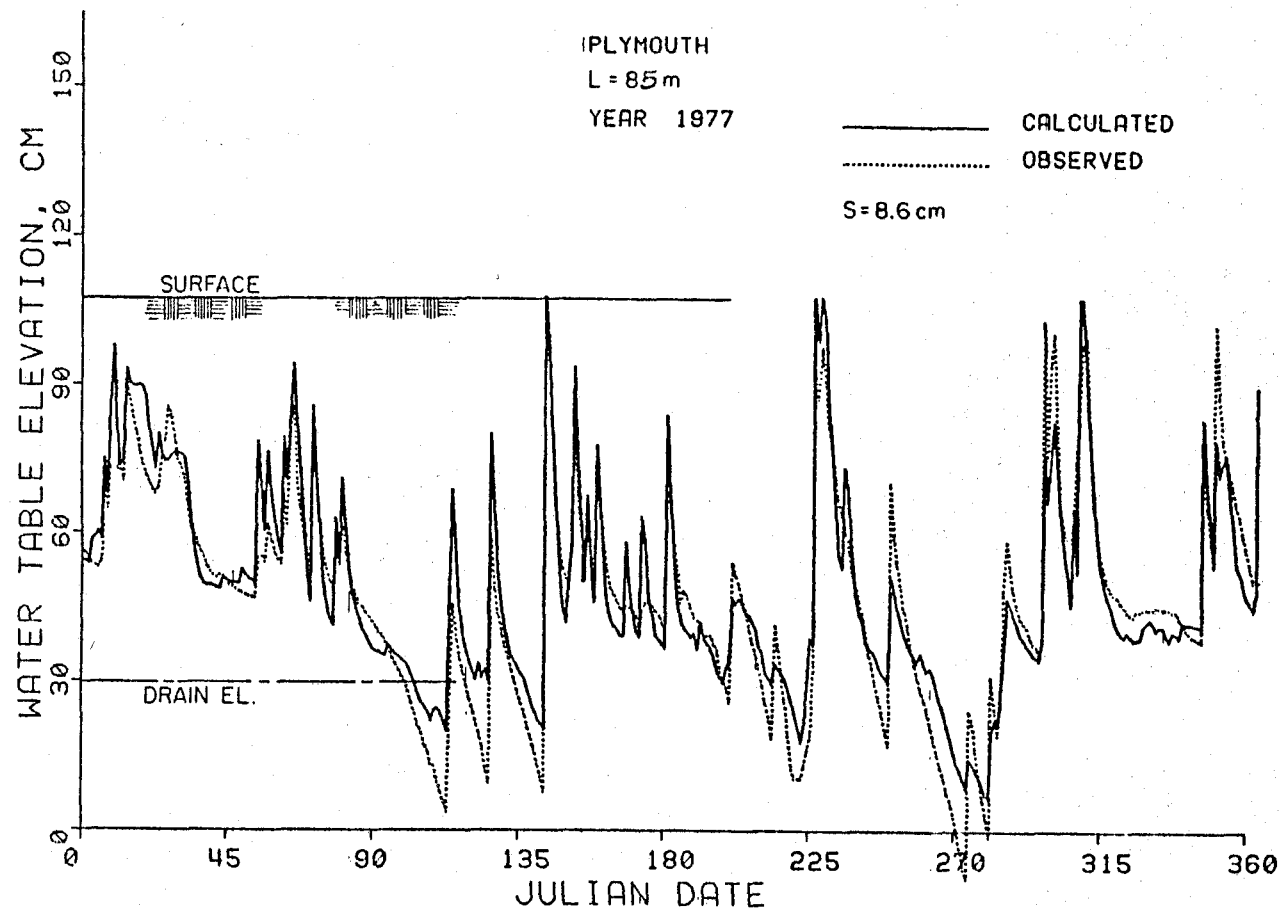
Figure 30. Observed and predicted water table elevations midway between drains spaced 85 m apart on the Plymouth site during 1977.

ponding values from the Plymouth and Laurinburg tests, in Table 15.

The Aurora system was operated in the drainage mode during most of the five year period. Subirrigation was used for relatively short periods in 1973, 1974 and 1975 as indicated by the outlet ditch water level elevations included in plots for the 30 m spacing (Figures 41 through 45). One of the weaknesses of the model is demonstrated by the subirrigation event starting on Julian day 150, 1975 (Figure 43). DRAINMOD predicts an upward water table response at the midpoint between the drains immediately after the water level in the outlet ditch is raised. However, it has been previously demonstrated (Skaggs, 1973) by theory as well as by laboratory and field experiments, that there may be a considerable time lag between a rise in the ditch water level and a water table response midway
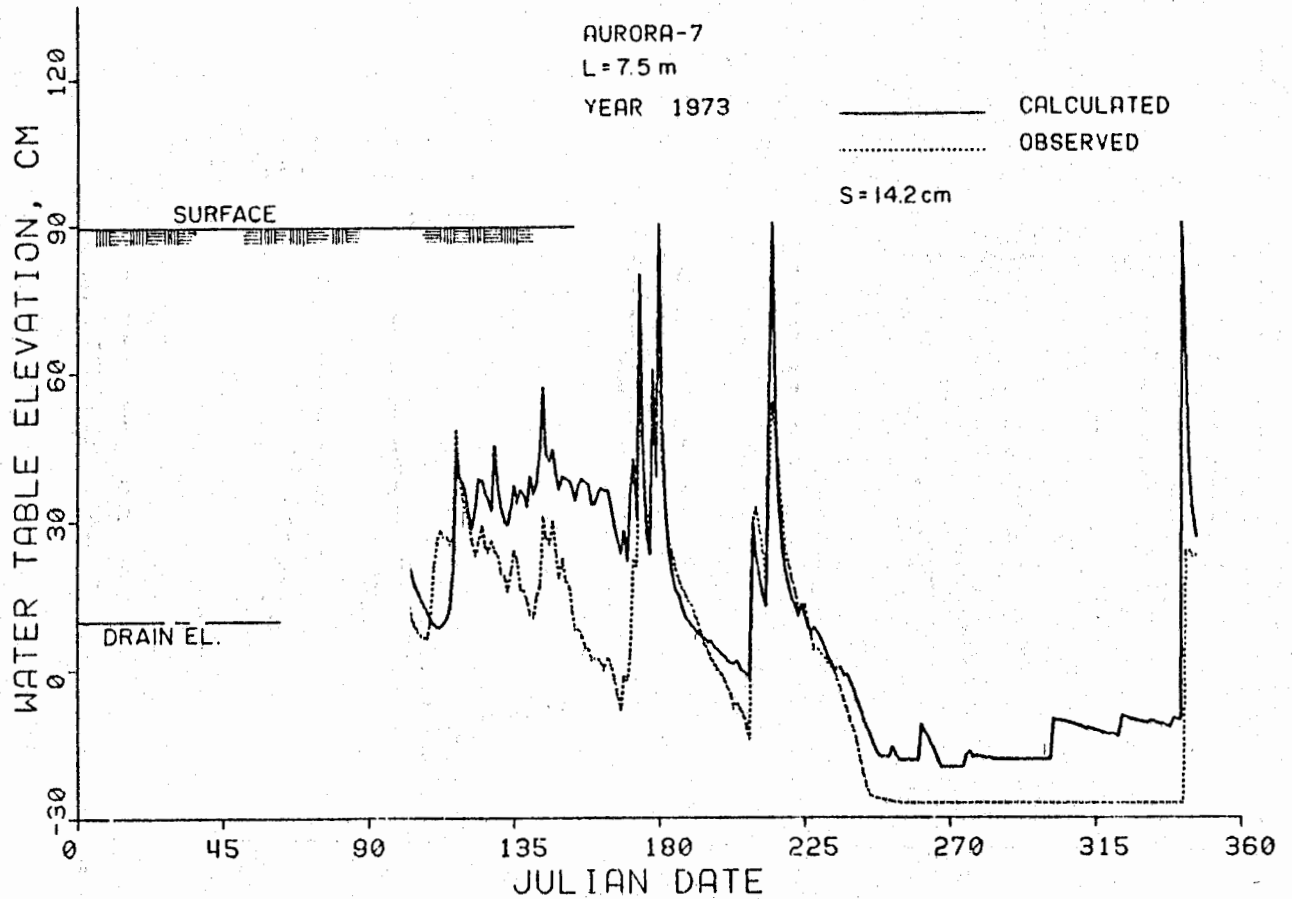
Figure 31. Observed and predicted water table elevations midway between drains spaced 7.5 m apart on the Aurora site during 1973.
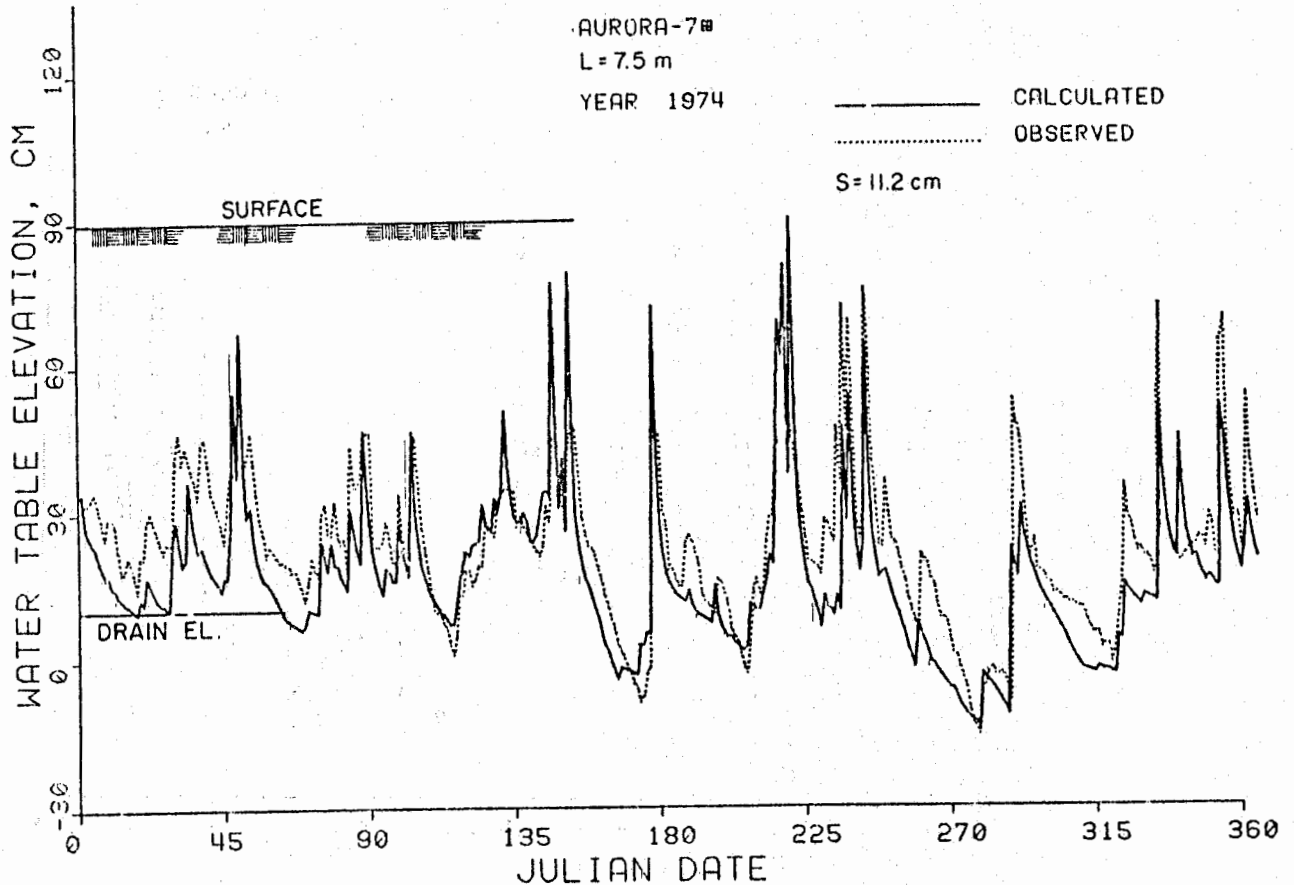
Figure 32. Observed and predicted water table elevations midway between drains spaced 7.5 m apart on the Aurora site during 1974.
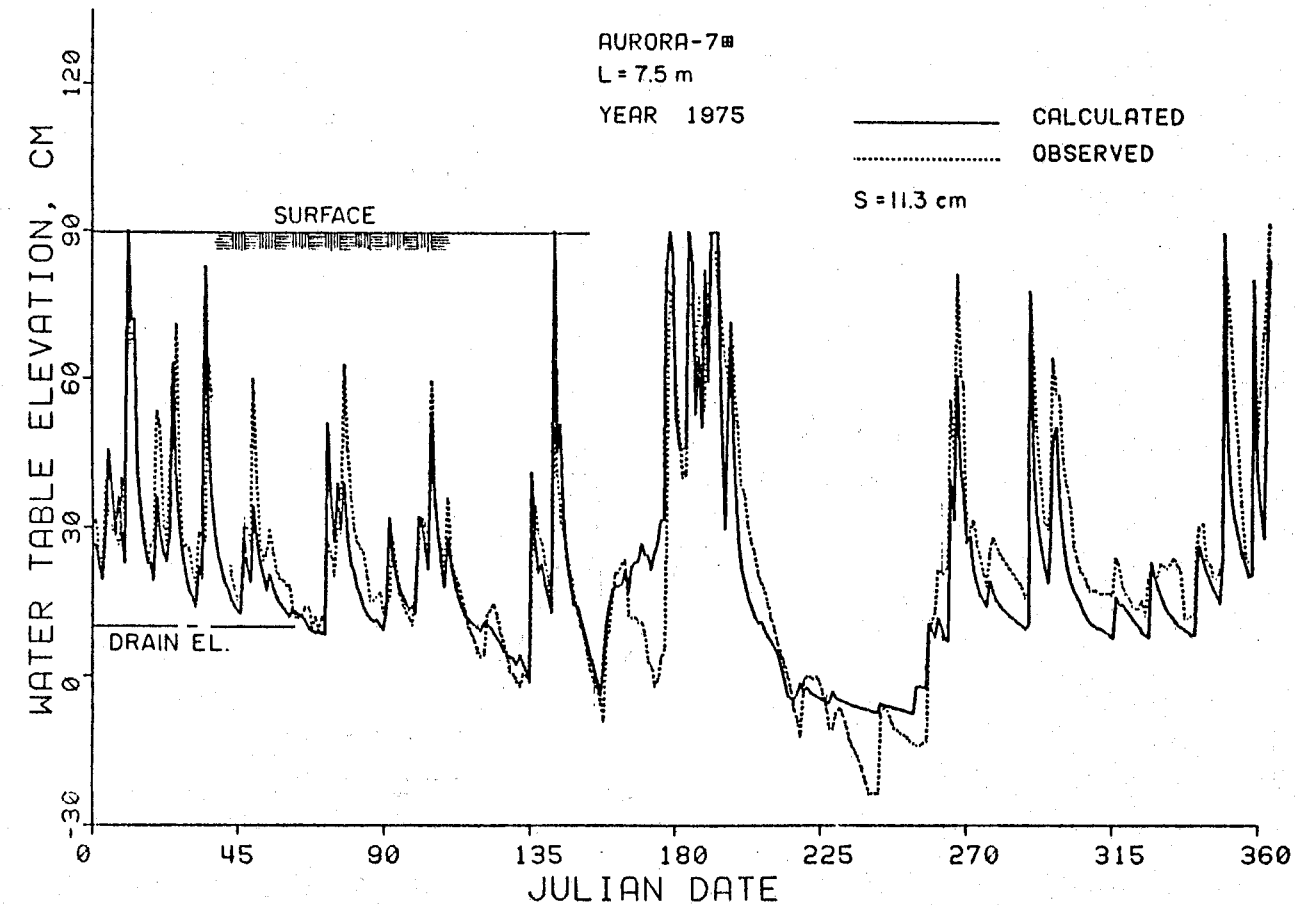
Figure 33. Observed and predicted water table elevations midway between drains
spaced 7.5 m apart on the Aurora site during 1975.
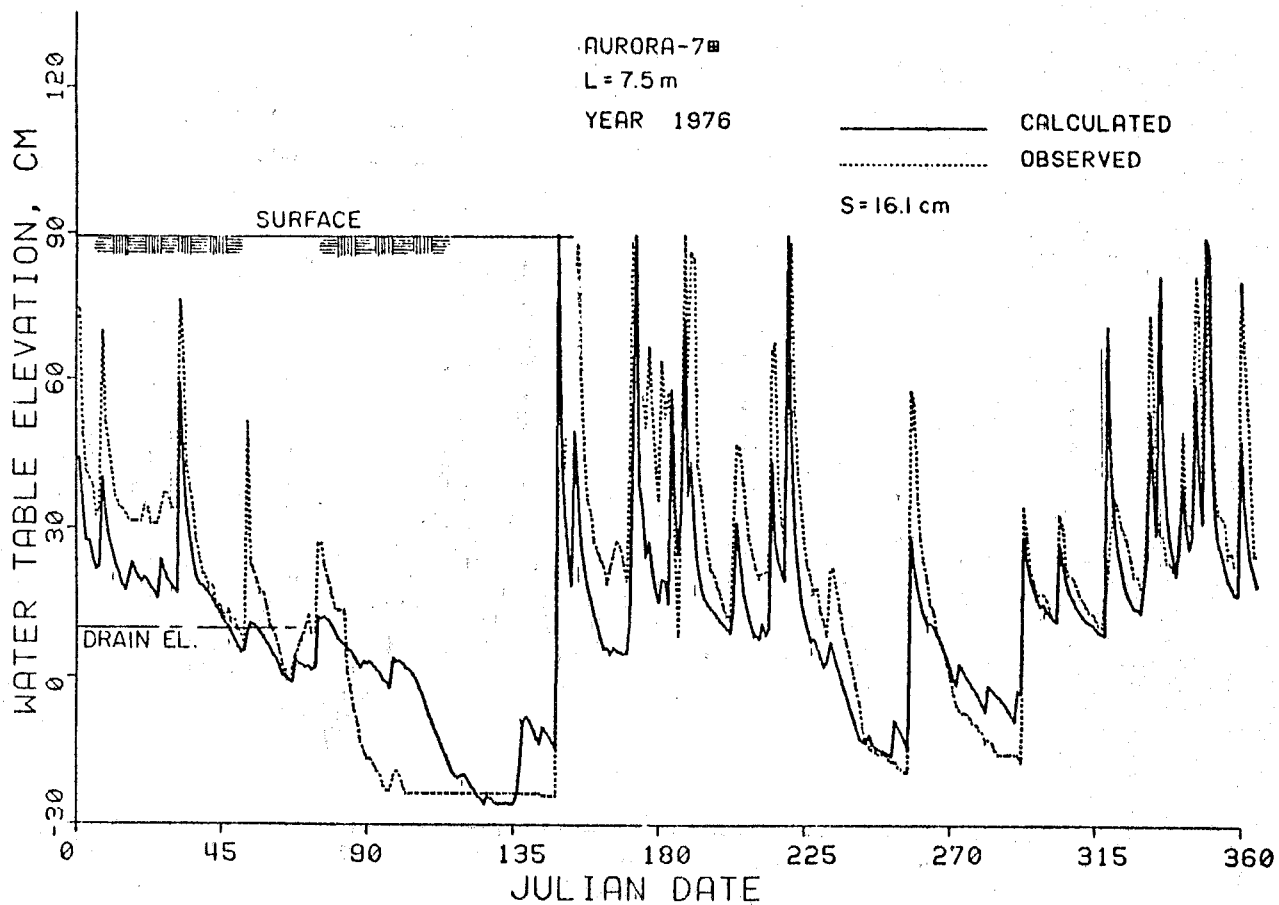
Figure 34. Observed and predicted water table elevations midway between drains
spaced 7.5 m apart on the Aurora site during 1976.
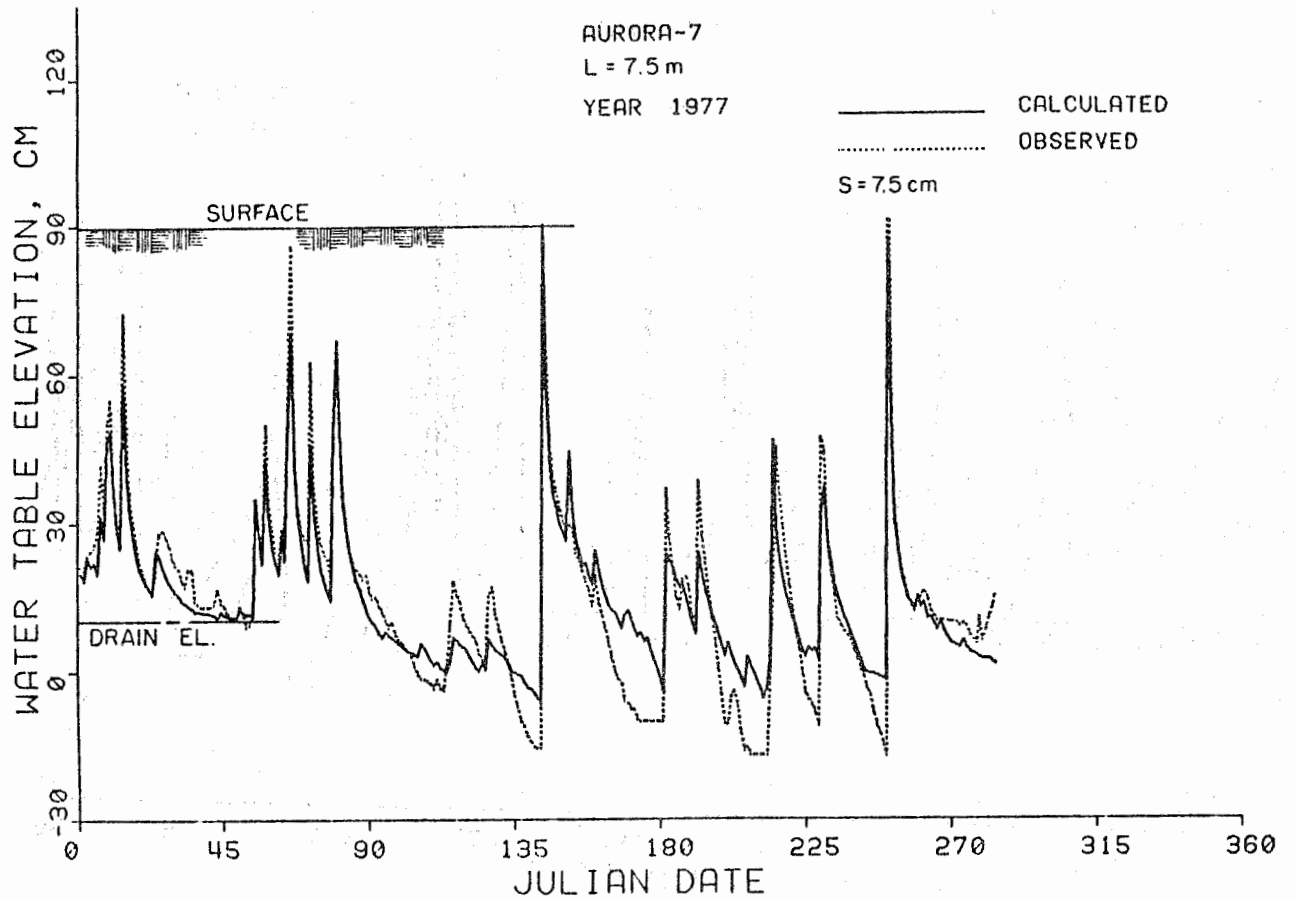
Figure 35. Observed and predicted water table elevations midway between drains spaced 7.5 m apart on the Aurora site during 1977.
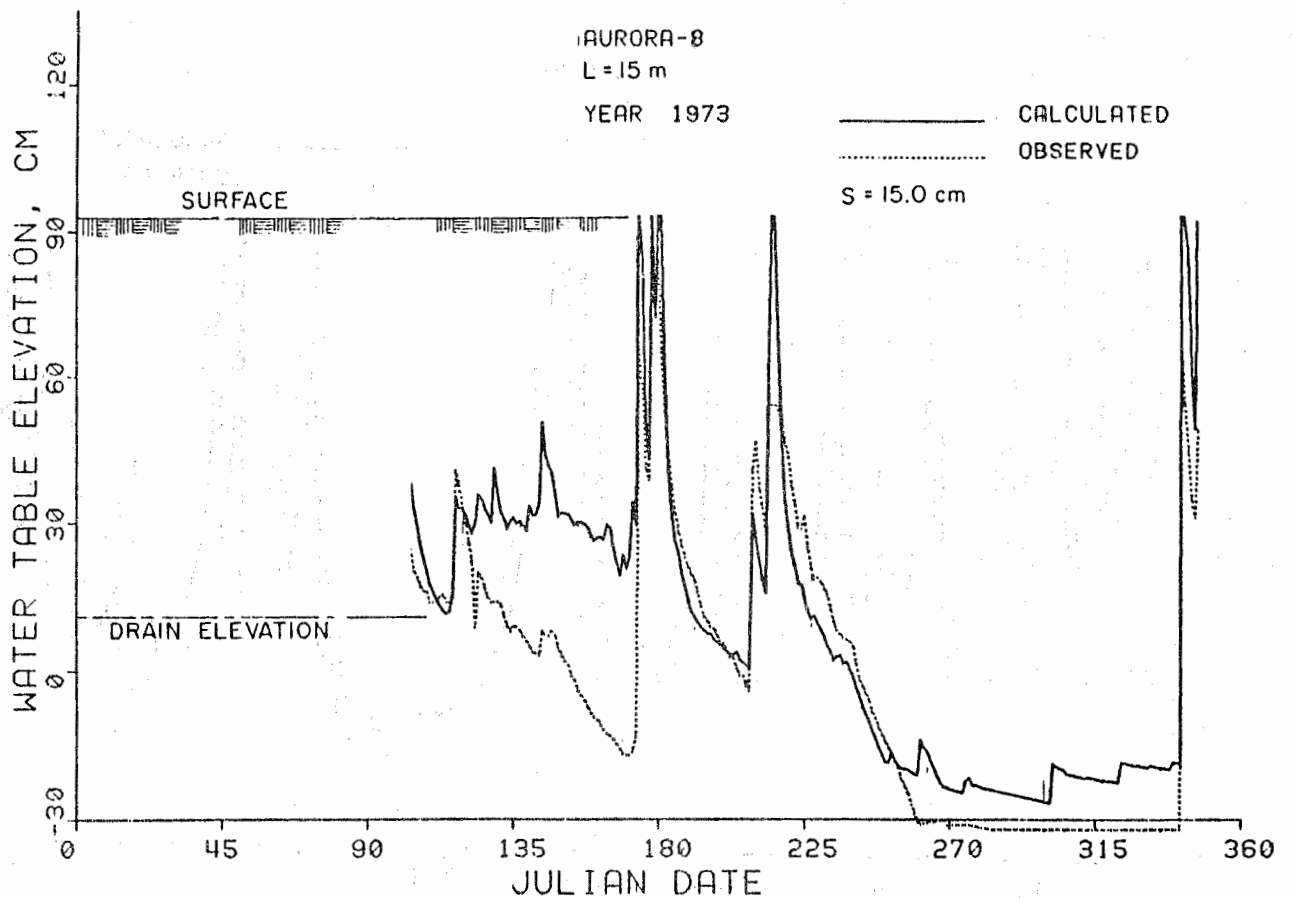
Figure 36. Observed and predicted water table elevations midway between drains spaced 15 m apart on the Aurora site during 1973.
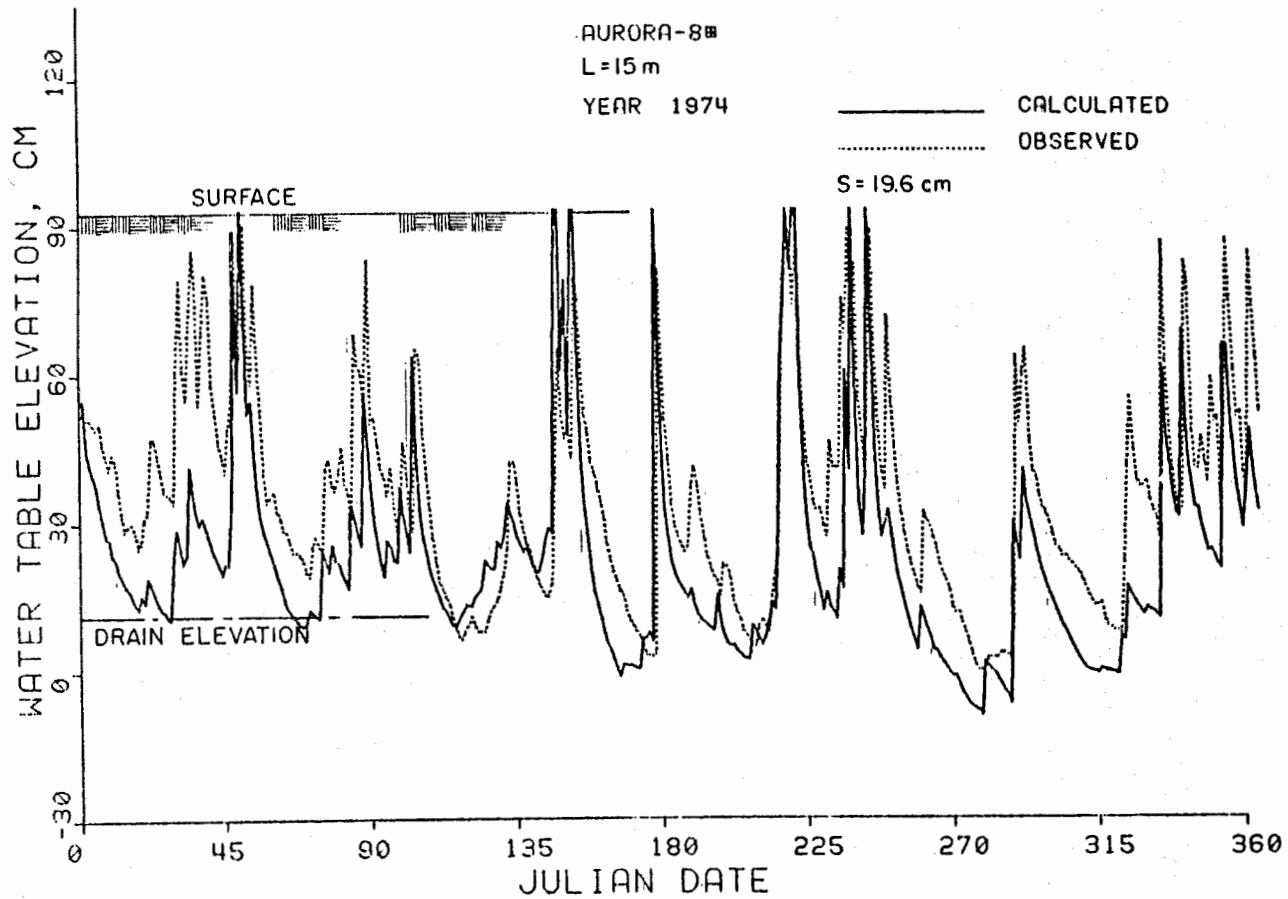
Figure 37. Observed and predicted water table elevations midway between drains spaced 15 m apart on the Aurora site during 1974.
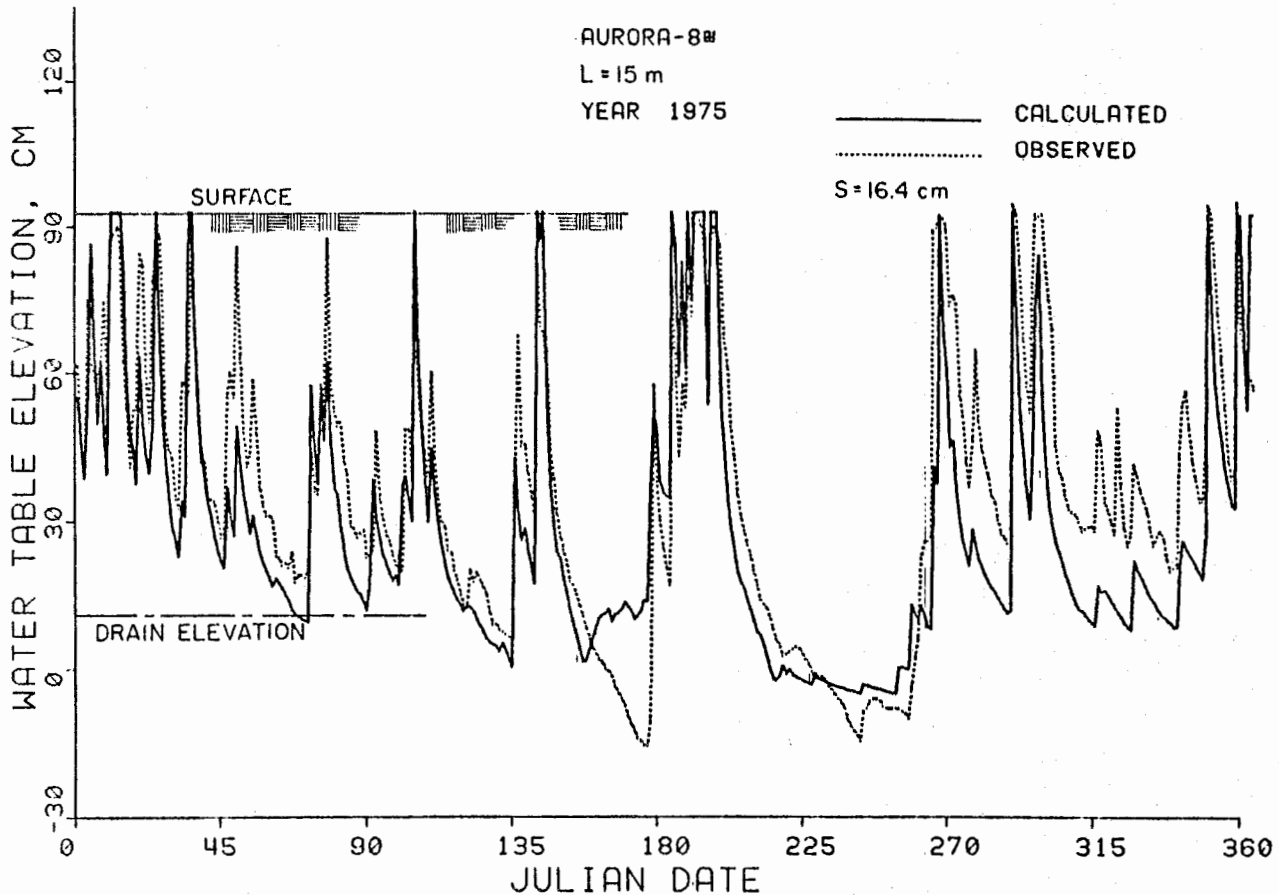
Figure 38. Observed and predicted water table elevations midway between drains spaced 15 m apart on the Aurora site during 1975.

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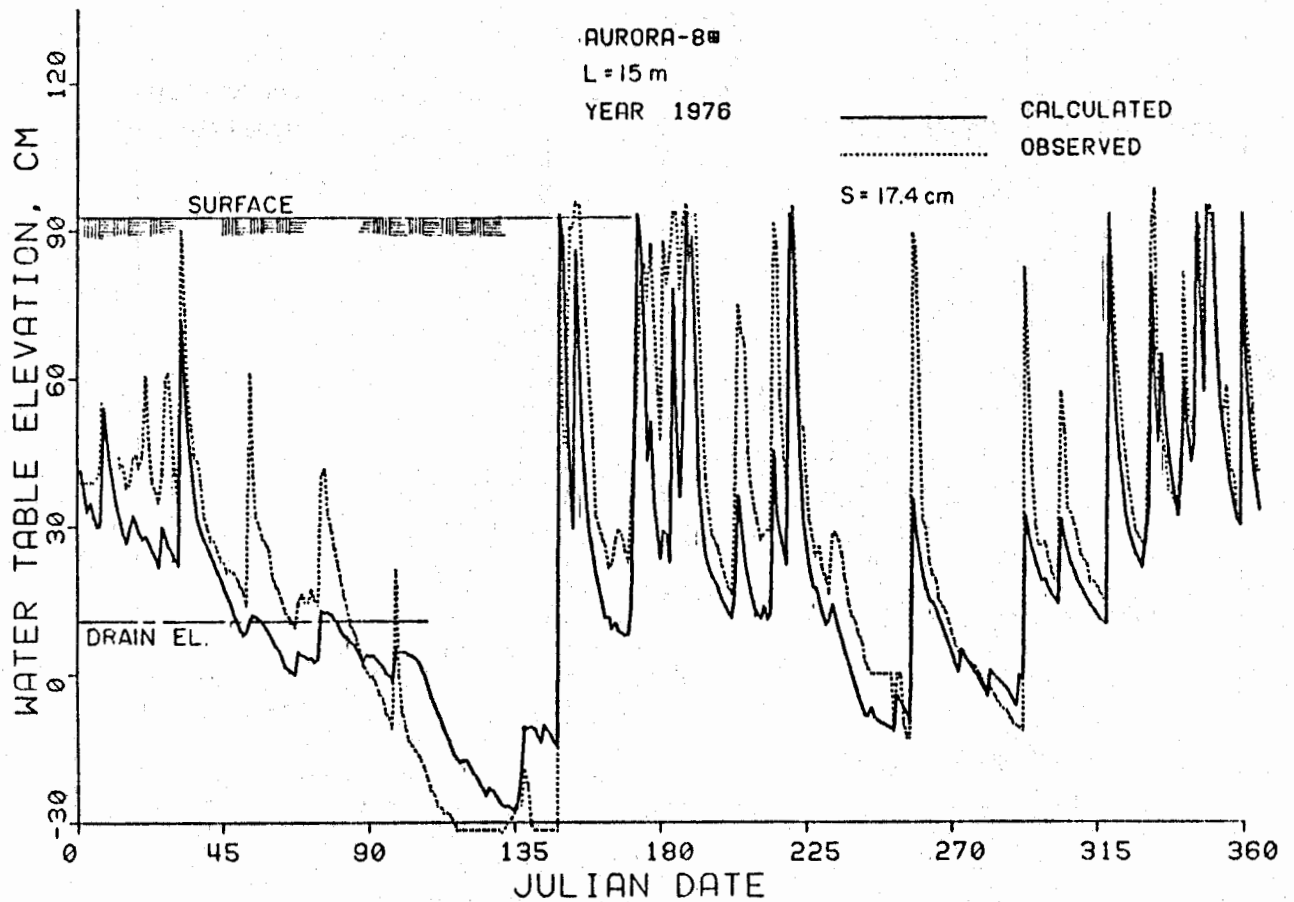
Figure 39. Observed and predicted water table elevations midway between drains spaced 15 m apart on the Aurora site during 1976.
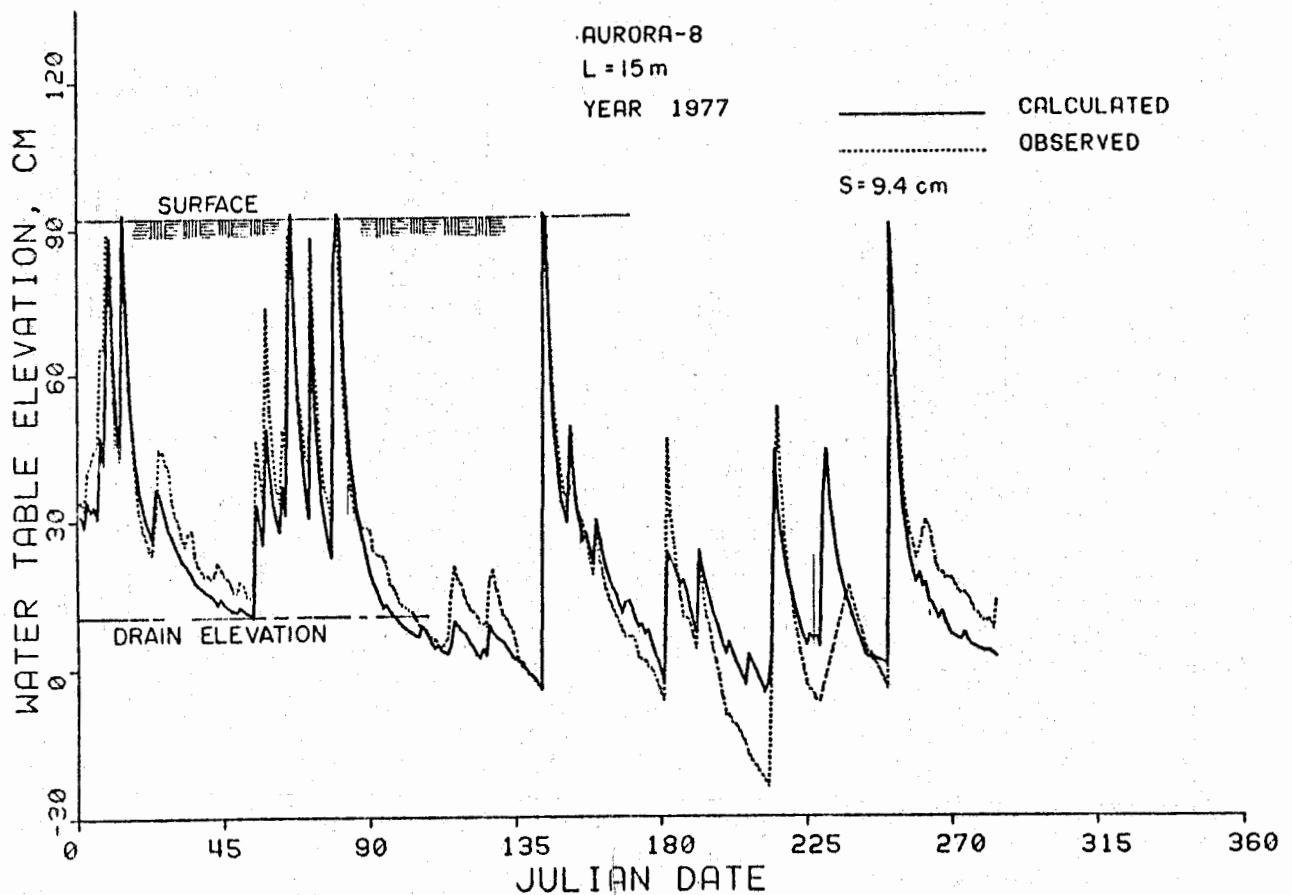
Figure 40. Observed and predicted water table elevations midway between drains spaced 15 m apart on the Aurora site during 1977.
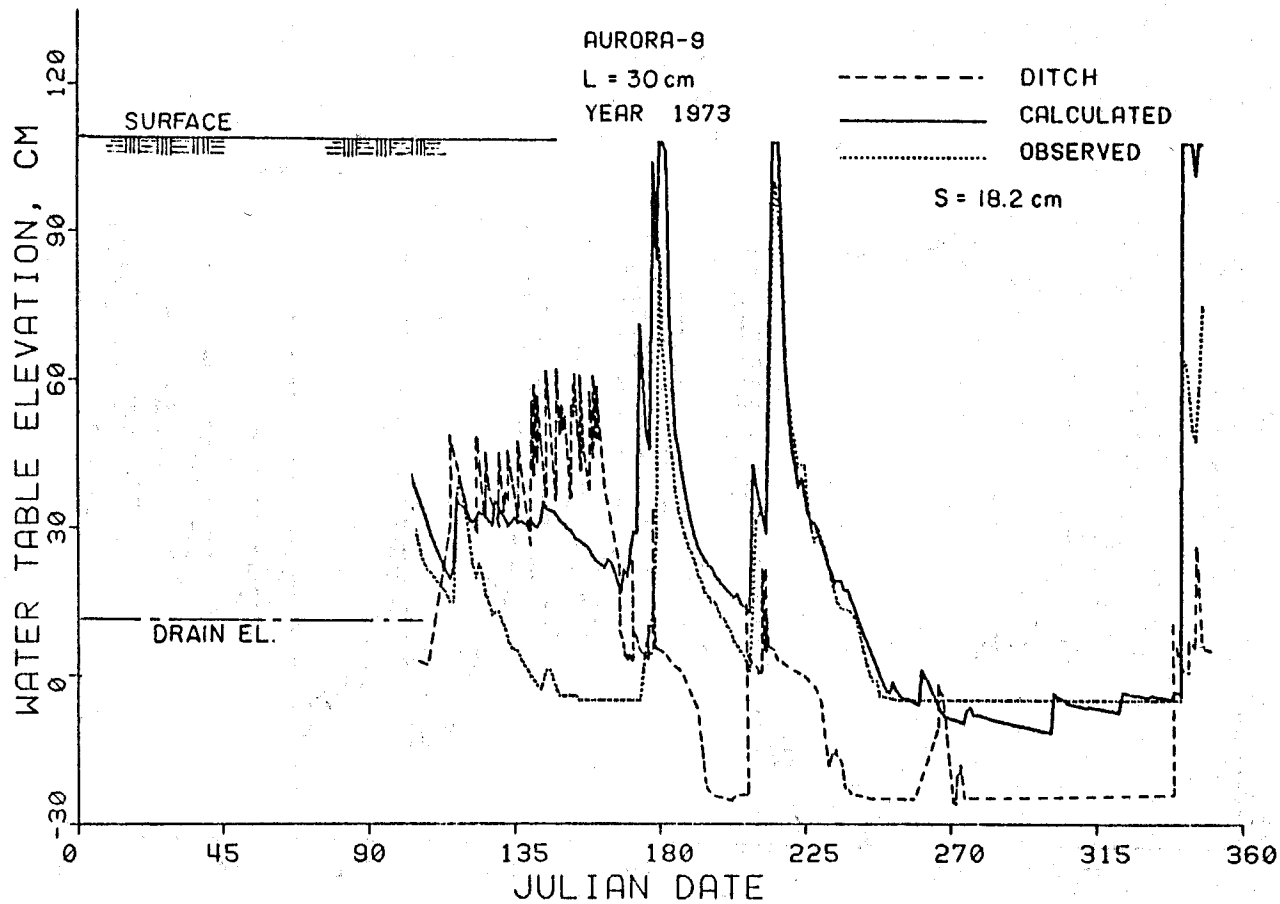
Figure 41. Observed and predicted water table elevations midway between drains spaced 30 m apart on the Aurora site, 1973.
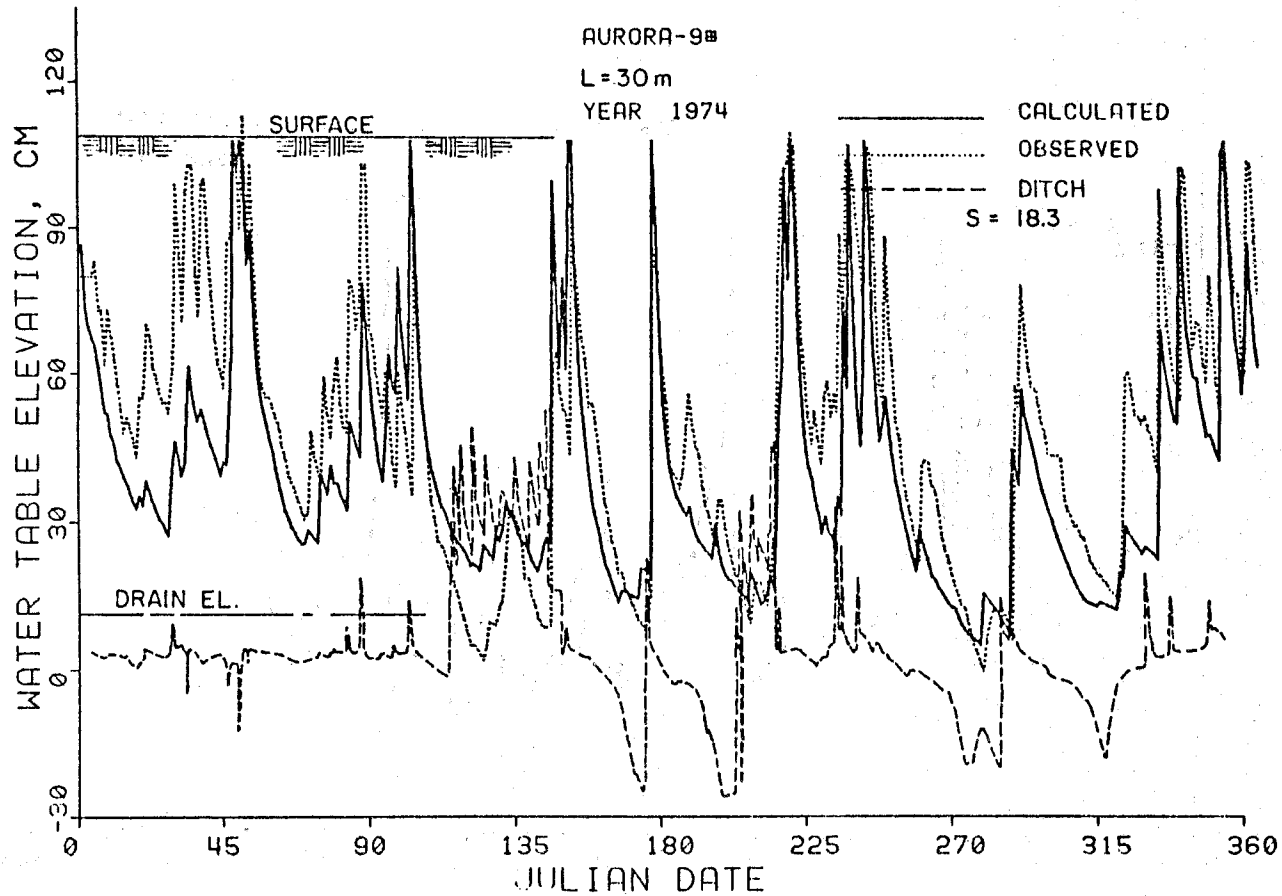
Figure 42. Observed and predicted water table elevations midway between drains spaced 30 m apart on the Aurora site, 1974.
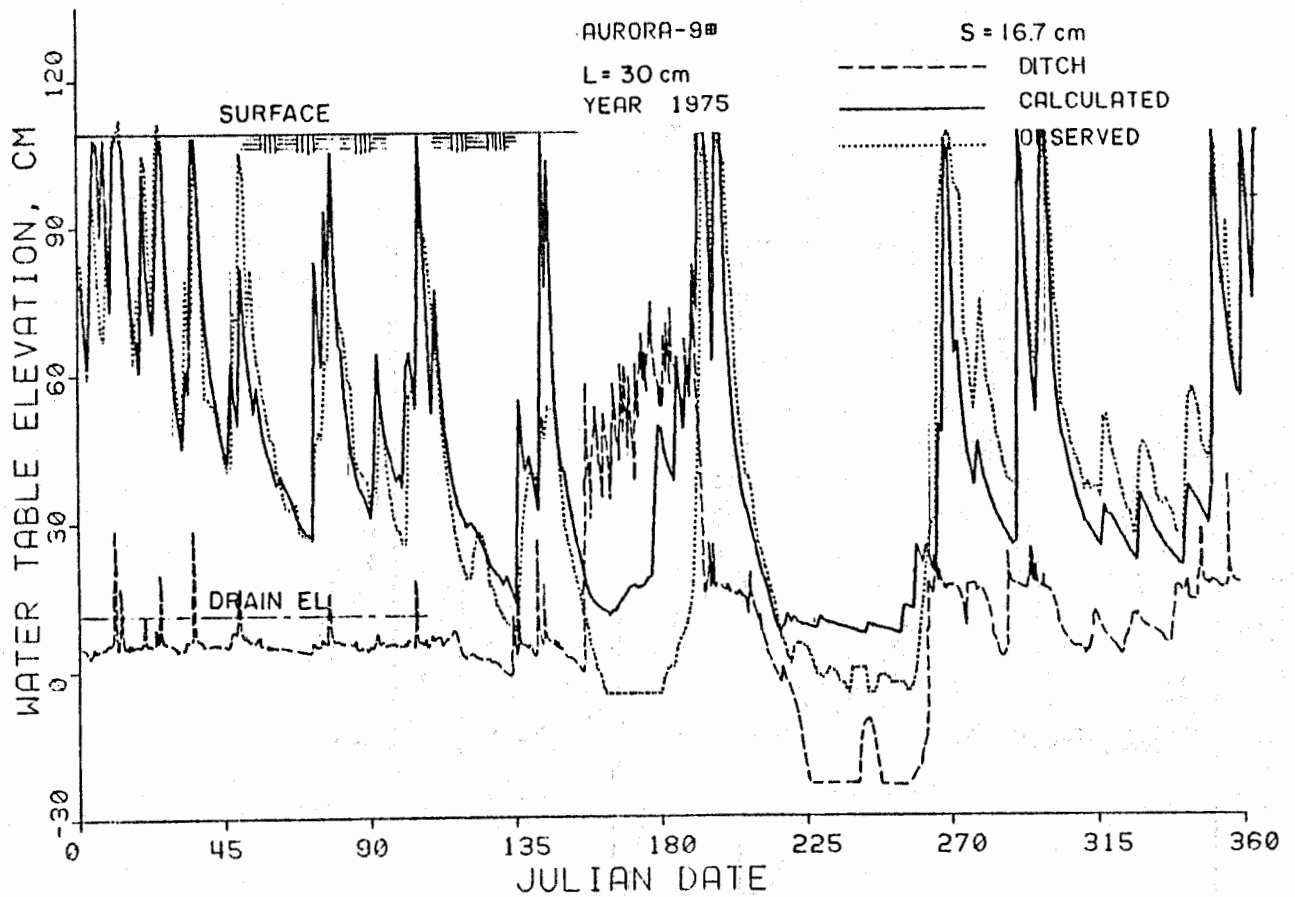
Figure 43. Observed and predicted water table elevations midway between drains spaced 30 m apart on the Aurora site, 1975.
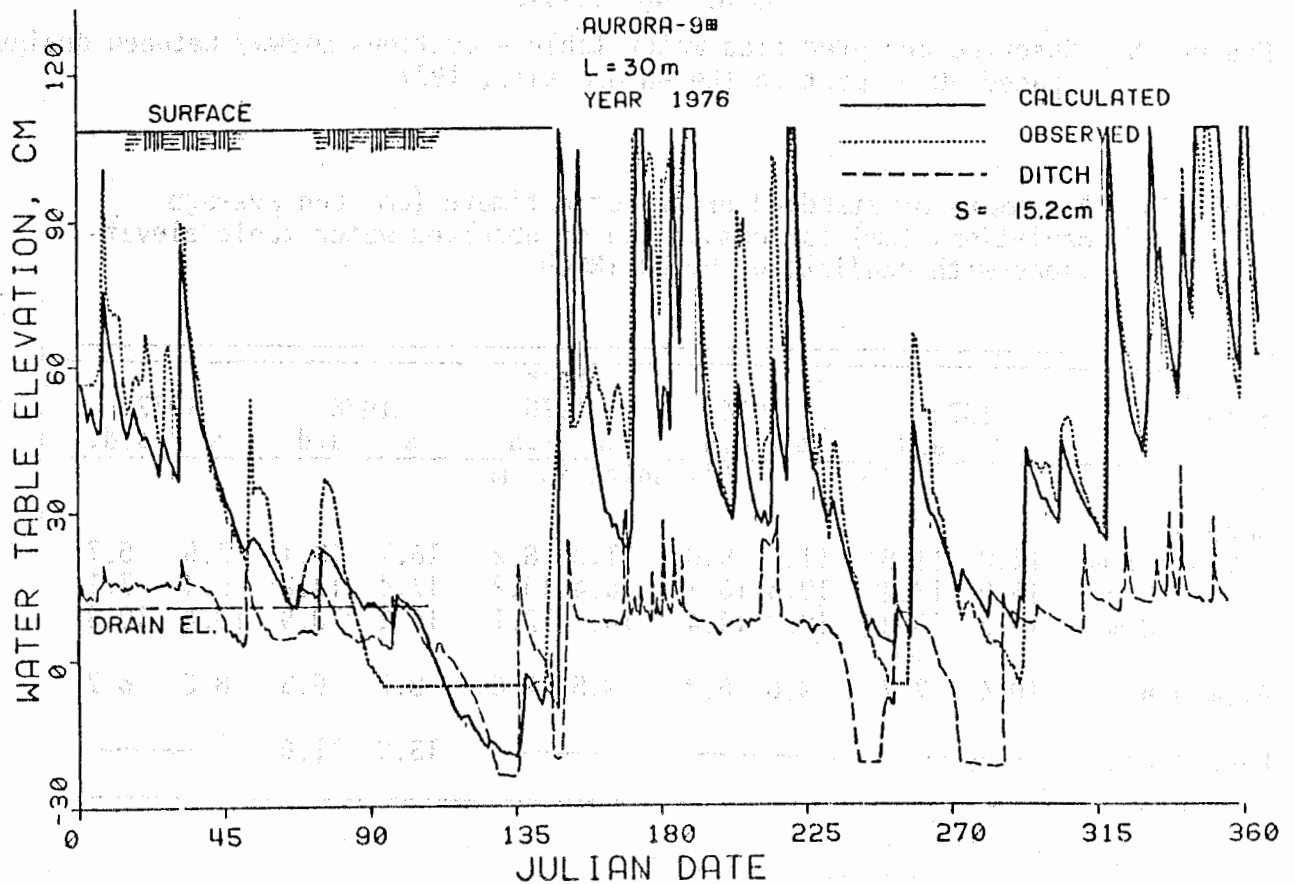
Figure 44. Observed and predicted water table elevations midway between drains spaced 30 m apart on the Aurora site, 1976.
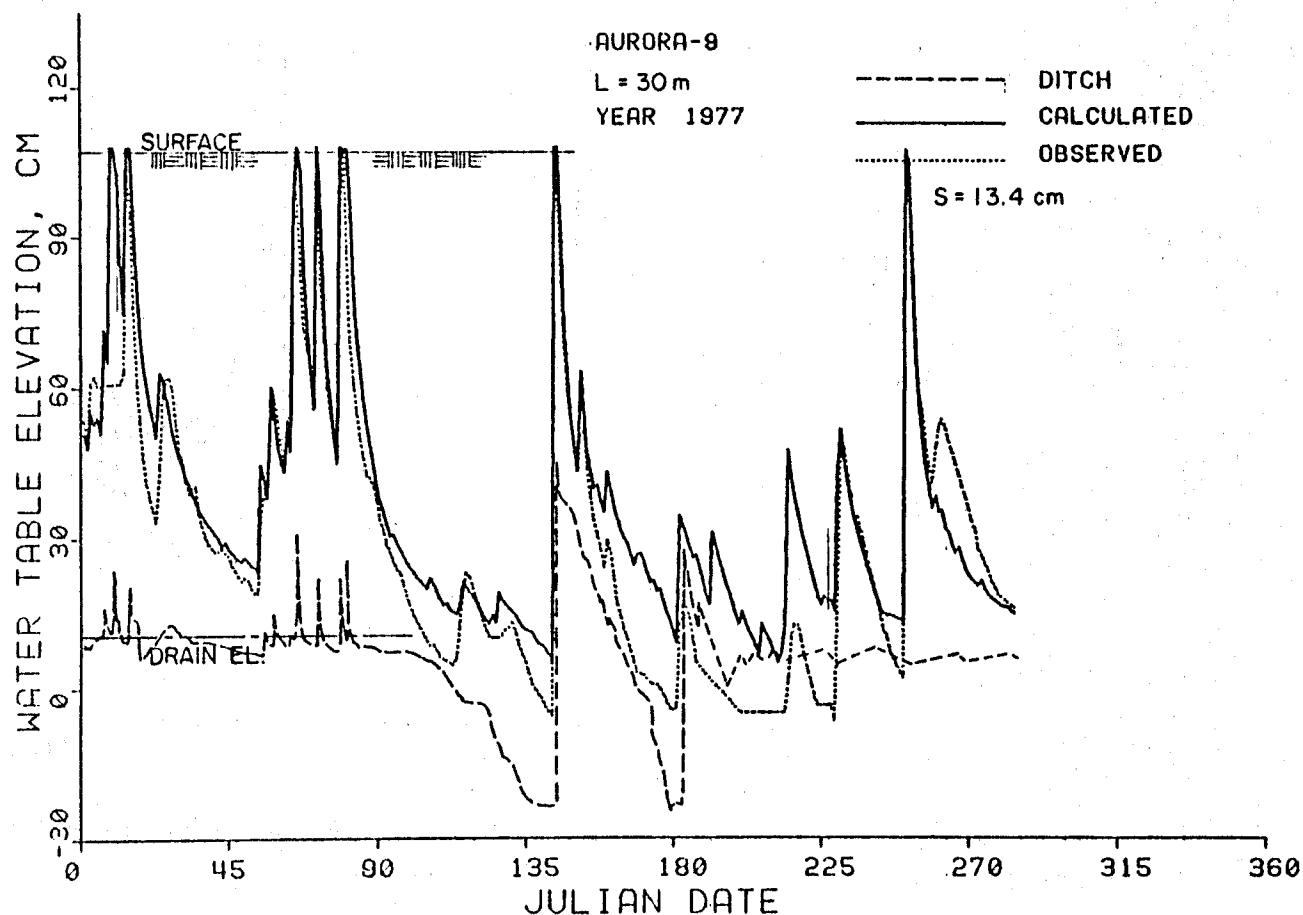
Figure 45. Observed and predicted water table elevations midway between drains spaced 30 m apart on the Aurora site, 1977.

Table 15. A summary of standard errors of estimate (cm) and average deviations (cm) for comparison of observed water table elevations with predictions by DRAINMOD.

Site	Year									
	1973		1974		1975		1976		1977	
	s	a.d.	s	a.d.	s	a.d.	s	a.d.	s	a.d.
	All units in cm									
Aurora										
L = 7.5 m	14.2	11.8	11.2	9.0	11.3	8.2	16.1	12.1	7.5	5.7
L = 15 m	15.0	13.4	19.6	16.1	16.4	13.2	17.4	13.2	9.4	7.1
L = 30 m	18.2	13.3	18.3	14.4	16.7	12.1	15.2	10.9	13.4	10.3
Plymouth	10.4	7.7	9.6	6.3	9.8	7.6	8.7	6.3	8.6	6.7
Laurinburg	—		—		—		13.9	11.6	—	

between drains. This is particularly true when subirrigation is initiated during dry soil conditions. This is consistant with the results given in Figures 43 for the 30 m spacing and Figure 38 for the 15 m spacing. In both cases the observed midpoint water table continued to recede, mostly due to ET, after the ditch water level was raised and did not reverse its downward trend until nearly 30 days later when rainfall occurred. This was not the case for the 7.5 m spacing which responded quickly to the raised water table as predicted by the model (Figure 33).

The model predicts an immediate response to subirrigation because flux is calculated with the Hooghoudt equation in terms of the water table elevation at the midpoint and the water level in the drain. No allowance is made for the time lag required to change from a drainage profile to a subirrigation profile which may be several days for large drain spacings. Everything else being equal, the time lag is proportional to the square of the drain spacing. It should be emphasized that the problem with the model in this respect occurs during the transition period from drainage to subirrigation or vice versa. Once the subirrigation profile is established, DRAINMOD will do a good job in characterizing the water table response (see for example the results for Plymouth, 1974 - Figure 27). Errors during the transition periods may also be negligible if the drain spacing is small or if hydraulic conductivity is high.

Predicted and observed results are in good agreement for all three spacings on the Aurora site with a maximum s value of 19.6 cm for the 15 m spacing during 1974 and a minimum s value of 9.4 cm for the 15 m spacing in 1977. The predicted water table drawdown rate was usually higher than the observed and the predicted water table elevations tended to be somewhat lower than measured for both the 7.5 and 15 m spacings (Figures 31 through 40). This could have been caused by a K value which was too high or an erroneous relationship for the drainage volume versus water table depth. However the values selected were based on actual hydraulic conductivity measurements and the same K values were used for the 30 m spacing which had about the same predicted drawdown rate as measured. Results of hydraulic conductivity tests indicated that the effective K of the

profile should be smaller for the 7.5 and 15 m spacings than for the 30 m spacing (Table 10). These differences were thought to be due to a thicker sandy layer for the 30 m profile. The results given in Figures 31 through 45 indicate that the conductivity of the individual layers for the 7.5 and 15 m spacings may be smaller than that for the 30 m spacing. If fact, trial runs showed that agreement between predicted and observed results can be improved considerably by using a lower K value for the 7.5 and 15 m spacings. However such values were not obtained from hydraulic conductivity measurements so their use would not provide a fair test of the validity of the model as discussed earlier in this section. In any event, the agreement between observed and predicted results for all spacings (Figures 31-46) is considered excellent for field conditions.

Laurinburg

Observed and predicted water table elevations are plotted in Figure 46 for the Laurinburg site during 1976. This was a very dry year at Laurinburg and the water table did not reach the surface at any time during the year. The total recorded rainfall on the experimental site was only 780 mm versus a normal annual rainfall of about 1200 mm for this area. The agreement between observed and predicted water table depths was good with a standard error of estimate of 13.9 cm for the year. Although subirrigation was possible on the site, it was not used during 1976. The drain depth was 1.07 m so the water table was actually below the drain for a large part of the year. Cotton, which has a rela- tively deep root system, was grown on the site and the water table was frequently lowered below the drain elevation by ET. The rate that the water table was drawn down by ET was more rapid than observed for the early part of the year, Julian days 45 to 100, but was in good agreement with observations during the peak and latter part of the season, days 180 to 300. Trials with a range of values of hydraulic conductivity showed that, as was the case with the Aurora data, agreement could be improved by reducing K. However the results given in Figure 46, which were obtained with independently measured K values, are considered

excellent for field conditions.
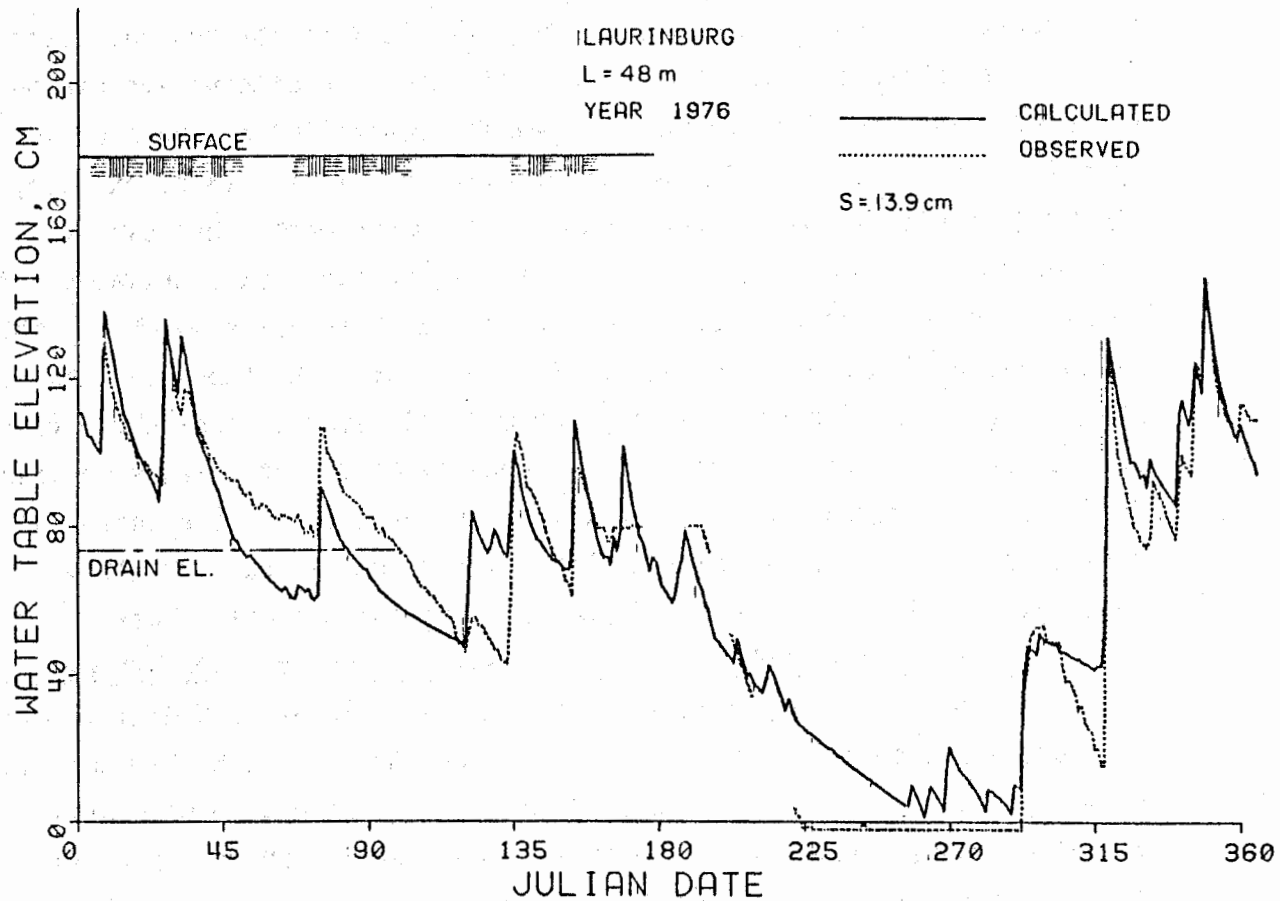
Figure 46.   Observed and predicted water table elevations midway between drains spaced 48 m apart on the Laurinburg site during 1976.

CHAPTER 6
APPLICATION OF DRAINMOD - EXAMPLES

The purpose of this chapter is to present examples of the use of DRAINMOD for designing and evaluating water management systems. Four examples will be considered. First, alternative designs of a combination surface-subsurface drainage system are analyzed for two soils and the results presented such that the least expensive alternative can be selected. The use of a drainage system for controlled drainage or sub-irrigation is considered in the second example. In the third example, DRAINMOD is used to determine the amount of waste water that can be applied to a disposal site that has surface and subsurface drainage and to determine the storage required to hold the waste water which can not be applied during the wet season of the year until the summer months when it can be irrigated. Finally the model is used to show the effects of root depth on the occurrence and frequency of drought stress on crops in N. C. The purpose of this example is to demonstrate the potential effects of removing physical and chemical barriers to root growth on water availability to plants and the frequency of drought stress.

Example 1 - Combination surface-subsurface drainage systems

The soils chosen for analysis in this example are a Wagram loamy sand and a Bladen clay loam. As noted in Chapter 4, the Wagram soil is normally well drained in its natural state and does not require artificial drainage. However the loamy sand considered here has a nearly level surface and is underlain at a depth of 1.8 m by a heavy subsoil that may be assumed impermeable so artificial drainage is needed. The Bladen soil has a profile depth of 2.0 m. It is a much tighter soil which is more difficult to drain and manage.

The soils are located near Greenville, N.C. Corn is to be grown on a continuous basis. The seedbed is prepared after about March 15 and corn planted by April 15. Both soils require drainage to provide trafficable conditions in the spring and to insure adequate conditions for crop growth.

Drainage System Design

Simulations were conducted for 20 years of climatological record (1952-1971) for alternative combinations of surface and subsurface drainage. The subsurface drainage system consisted of parallel 10.2 cm (4 inch) drain tubes buried at a 1.0 m depth and spaced a distance, L, apart. Drain spacings ranged from 7.5 m to 90 m. Surface drainage was quantified by the average depth of depression storage. Field studies on several eastern N.C. soils (Gayle and Skaggs, 1977) have shown that depressional storage varies from approximately 1.5 mm for fields that have been land formed and are on grade to more than 30 mm for fields with numerous potholes or which do not have adequate surface outlets. Three levels of surface drainage with depression storages of 2.5, 12.5, and 25 mm were used in the simulations conducted.

Drains were assumed to be 102 mm (4.0 in.) diameter corrugated plastic tubing. Envelopes are not generally used in humid regions and were not considered here. Convergence near the drains is accounted for by defining an equivalent depth from the drain to the impermeable layer as discussed in Chapter 2. The equivalent depth depends on the drain spacing; the values calculated for the cases considered in this example are given in Table 16.

Soil Properties, Crop and Other Input Data

The relationship between drainage volume and water table depth for the Wagram soil is given in Figure 23. The relationship given in Figure 23 for Portsmouth sandy loam was used for the Bladen soil. Relationships for the ratio of upward water movement versus water table depth are given in Figure 25 for both soils. The growing season for corn is approximately 120 days to about August 15. The 60 percent curve given in Figure 17 was used for the time distribution of effective rooting depth in all simulations. A summary of the input data used in the simulations for the Bladen and Wagram soils is given in Table 16.

Table 16. Summary of input data for the Bladen and Wagram soils.

	Bladen	Wagram
Depth to restricting layer	200 cm	180 cm
Depth of surface storage	0.25, 1.25, 2.50 cm	0.25, 1.25, 2.50 cm
Drain spacing	7.5 - 90 m	15 - 90 m
Drain depth	100 cm	100 cm
Drain diameter (corrugated plastic tubing)	11.2 cm	11.2 cm
Hydraulic conductivity (saturated)	1.0 cm/hr	6.0 cm/hr
Saturated water content (volumetric)	0.41	0.30
Wilting point (volumetric)	0.15	0.05
Surface irrigation	none	none
Minimum soil air volume required for tillage operations (AMIN1)	3.0	3.7
Minimum daily rain to stop field operations (ROUTA1)	0.75 cm	1.2 cm
Minimum time after rain before can till (ROUTT1)	2 days	1 day
Equivalent depths (d_e) for drain spacings of:		
7.5 m	45 cm	42 cm
15	62	55
30	77	65
60	87	72
90	91	75

Results - Alternative Drainage System Designs

Working days during the one-month period prior to planting,
March 15 - April 15, are plotted versus drain spacing in Figure 47 for
both soils. The number of working days required for seedbed preparation
and planting would depend on size of the farming operation, amount of
equipment and labor available, and efficiency of the tillage operations.
We will assume that 10 days are required for the cases considered here.
For the Wagram loamy sand, a drain spacing of 43 m will provide at least
10 days suitable for tillage and planting operations on a 5 year recur-
rence interval (5 YRI) basis. That is, this drain spacing will, on the
average, provide at least 10 working days in 4 out of 5 years. Surface
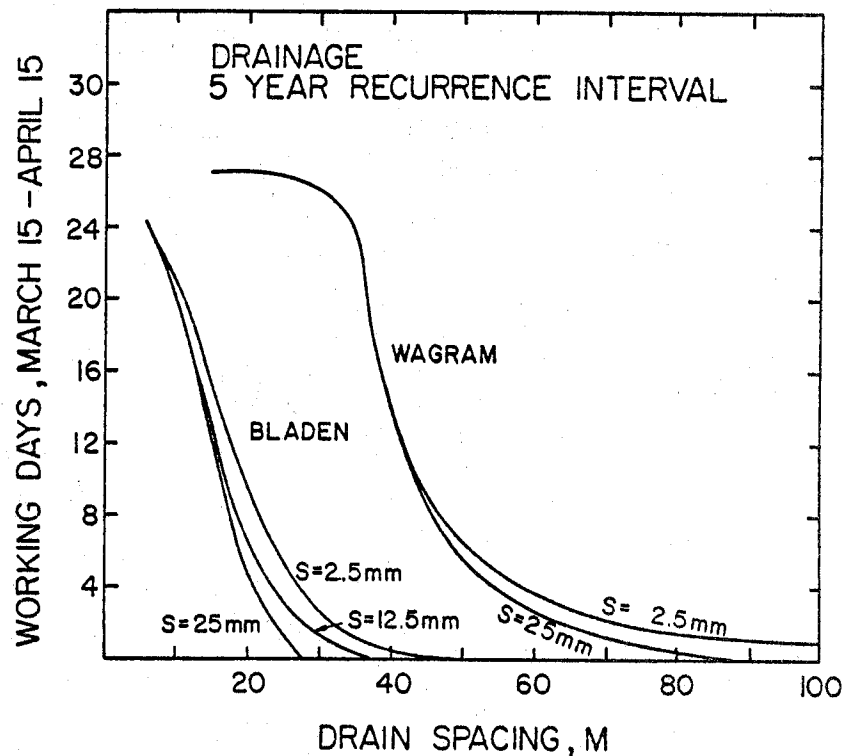
Figure 47. Working days during the period March 15 - April 15 as a function of drain spacing for the Bladen and Wagram soils.

drainage has little effect on trafficability during March and April for this soil. Improving the surface drainage from a depression storage of s = 25 mm to s = 2.5 mm only allows an increase of the drain spacing to 44 m for the same number of working days.

For the Bladen soil, 10 working days can be obtained by either using a drain spacing of 20 m with good surface drainage (s = 2.5 mm) or by a drain spacing of 16 m with poor surface drainage (s = 25 mm).

SEW_{30} values are plotted versus drain spacing for three levels of surface drainage in Figure 48. Surface drainage has a much greater effect on SEW_{30} than on the number of working days. For example the Wagram soil with poor surface drainage (s = 25 mm) would require a drain spacing of 50 m to insure an SEW_{30} value of 100 cm-days (5 YRI basis).
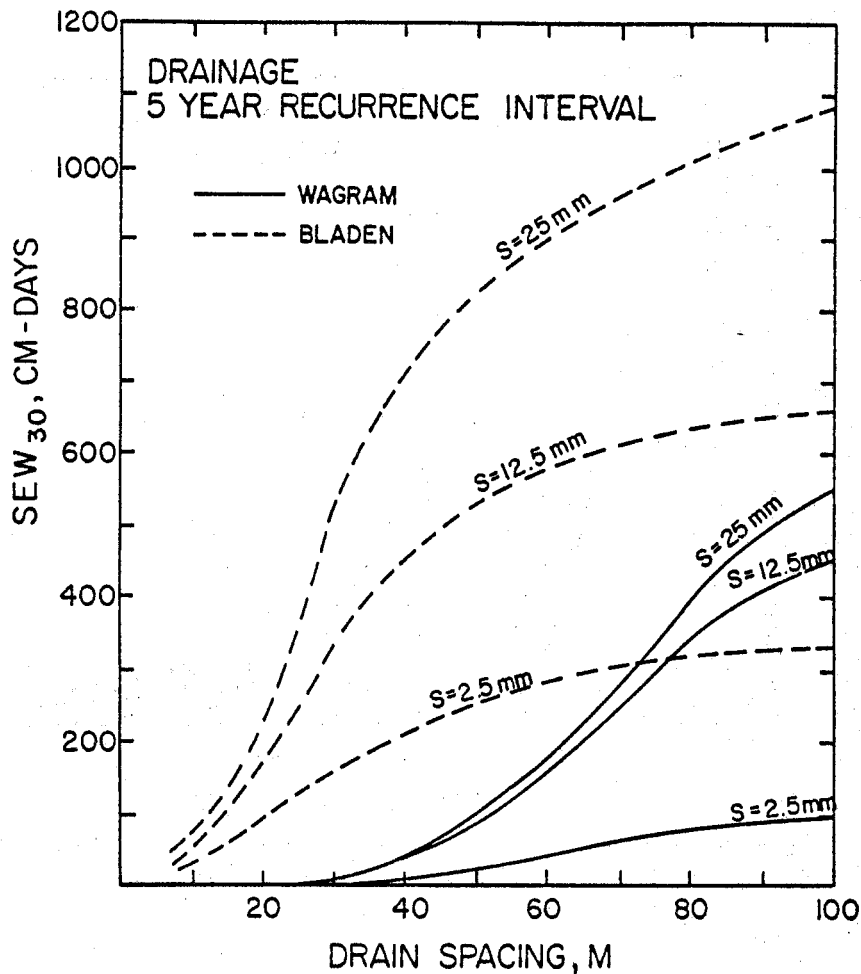
Figure 48.   SEW$_{30}$ as a function of drain spacing for three surface drainage treatments on Bladen and Wagram soils.

However, the same SEW$_{30}$ value could be obtained with a spacing greater than 100 m if surface drainage is good (s = 2.5 mm). In either case, the 43 m drain spacing needed to provide trafficable conditions in the spring (Figure 47) would also provide adequate drainage for crop growth with 5 YRI   SEW$_{30}$ values less than 50 even if surface drainage is poor. An alternative that should be considered for this soil is to use a later planting date thereby increasing the length of time for seedbed preparation and decreasing the drainage requirement for trafficability. Results of the simulations show that, because of higher evaporation and less rainfall, there are considerably more working days in April than in March. Thus by planting and harvesting at a later date, a wider

drain spacing could be used to satisfy the trafficability requirement. Adequate drainage for crop growth could be insured by providing good surface drainage. Consideration of this alternative departs somewhat from our original objective of evaluating the design of a water management system based on a fixed set of requirements - given planting date, required number of working days, etc. - and it is not treated further here. However, one of the advantages of using the water management model is that such alternatives can be easily evaluated.

For the Bladen clay loam an SEW_{30} value of 100 cm-days can be obtained with drainage spacings of 21, 15, and 12 m for surface depression storages of 2.5, 12.5, and 25 mm, respectively. Thus, for poor surface drainage (s = 12.5 and s = 25 mm), spacings required to insure adequate drainage during the growing season are smaller than those necessary to provide trafficable conditions for seedbed preparation.

The results for the Bladen soil demonstrate the utility of using DRAINMOD to evaluate alternative designs of combination surface-subsurface drainage systems. The required number of working days and drainage protection for plant growth as indicated by SEW_{30} values can be provided with a drain spacing of 12 m and poor surface drainage (s = 25 mm) or with a spacing of 20 m and good surface drainage (s = 2.5 mm). Both systems will do the required job so the farmer can choose the alternative that requires the least investment, although other factors such as maintenance costs and compatability with the farming operation must also be considered.

Example 2 - Subirrigation and Controlled Drainage

Both soils considered in Example 1 are relatively flat so water table control via subirrigation or controlled drainage should be considered. When subirrigation is used, a weir is placed in the drainage outlet and water is pumped into the outlet as required to maintain a constant water level. For controlled drainage a weir is also placed in the drainage outlet but no water is pumped in. This reduces the drainage rate and allows plant use of some runoff and drainage water that would be lost from the system under conventional drainage practices.

However controlled drainage is not expected to provide assistance
during dry years when drainage water is not available for use by such
conservation measures.

Simulations were conducted for subirrigation and controlled
drainage using the same period of record as discussed above for drain-
age systems.

Results - Subirrigation and Controlled Drainage

The effect of drainage, controlled drainage and subirrigation
on the number of dry days during the growing season is shown in Figure
49 for the loamy sand soil. The relationship plotted for drainage
shows clearly that drainage systems should not be over designed. For
example, a drain spacing of 43 m would give, on the average, 34 or more
dry days in one year out of five. Closer spacings, which are not re-
quired for trafficability (Figure 47) nor for crop production (Figure
48) would increase the number of dry days and have detrimental effects
on crop growth. Recall that a dry day does not mean that there is no
water available to growing plants but that ET is limited by soil water
conditions. The relationships plotted in Figure 49 are for good surface
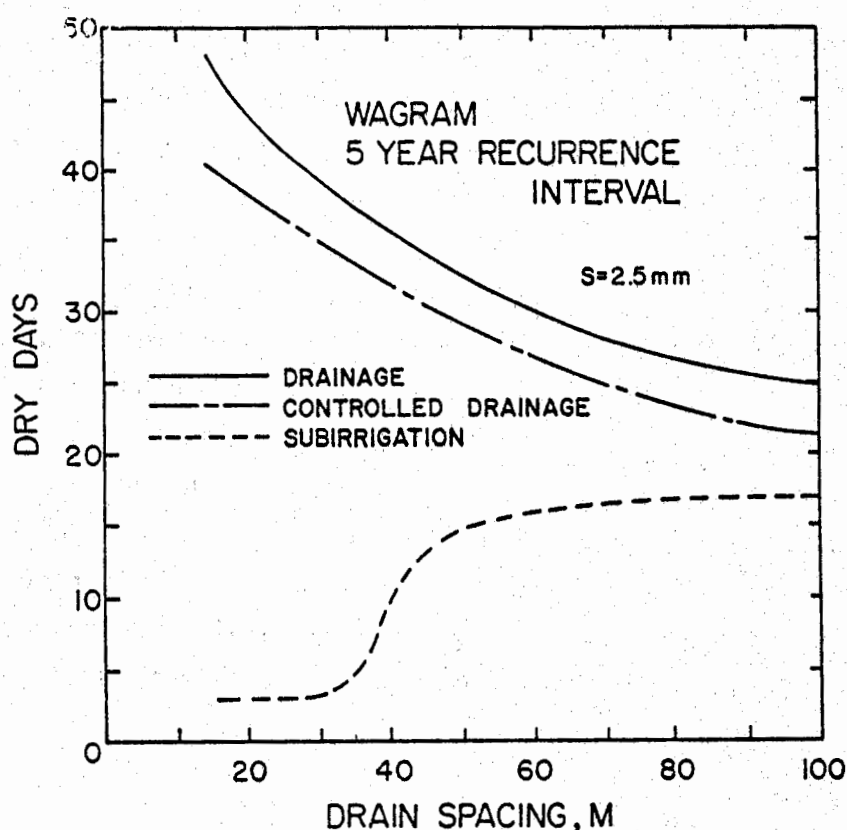
Figure 49. Dry days during the growing season as a function
of drain spacing for three water management
methods on Wagram soil.

drainage (s = 0.25 cm). Surface drainage had little effect on the number of dry days and similar relationships were obtained for the other surface drainage treatments.

When subirrigation is used, water is pumped into the drainage outlet such that the water level is held constant at a depth of 60 cm below the soil surface during the growing season. The water table depth directly over the drain tubes during subirrigation will be approximately equal to that in the drainage outlet but will increase with distance away from the drain during dry periods because of ET (Fox, et al., 1956). The 60 cm depth was chosen so that the water table would not be too close to the surface directly over the drain tubes. Williamson and Kriz (1970) reported that a 60 cm steady water table depth caused a 15 percent reduction in yield from the optimum depth of 76 cm for a loam soil. Yield reduction for the area directly over the drains is expected to be less for the lighter Wagram loamy sand. Results plotted in Figure 49 for subirrigation show that a drain spacing of 30 m or less will provide sufficient water table control to allow only 3 dry days on a 5 YRI basis. For spacings between 30 and 60 m the number of dry days increases to 16. Further examination of the results of simulations show that the three dry days occurred immediately after planting when rooting depths were negligible and subirrigation had just been initiated. Under these conditions three dry days appeared to be acceptable and a drain spacing of 30 m sufficient for subirrigation on the loamy sand.

One of the major concerns in using subirrigation in humid regions is that a high water table reduces storage available for infiltrating rainfall and may result in frequent conditions of excessive soil water. The effect of subirrigation on SEW_{30} values is shown in Figure 50. These results show the importance of good surface drainage if subirrigation is to be used. A 30 m drain spacing gives an SEW_{30} value of 210 cm-days for poor surface drainage (s = 25 mm). Additional simulations showed that an SEW_{30} value of less than 100 cm-days can be obtained with only moderate surface drainage (s = 7.5 mm). When a 30 m spacing is
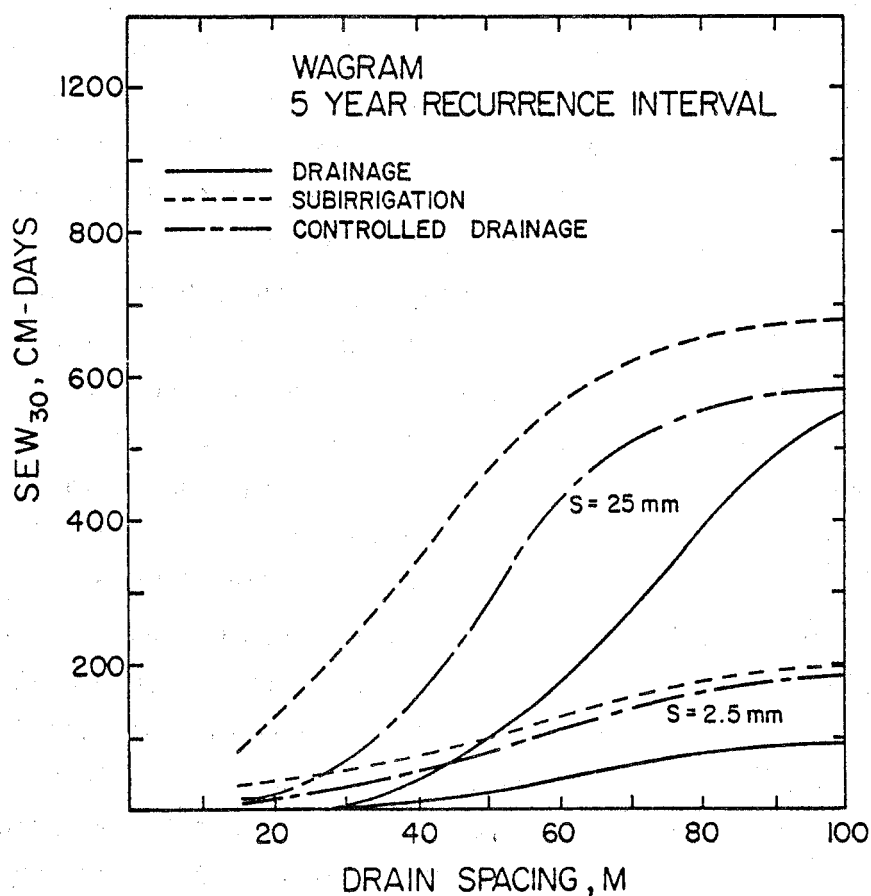
Figure 50. SEW$_{30}$ as a function of drain spacing for conventional drainage, subirrigation and controlled drainage on Wagram soil. Results are plotted for two levels of surface drainage.

used with good surface drainage (s = 2.5 mm) the 5 YRI SEW$_{30}$ value exceeded 100 cm-days only once in 20 years and that value was only 114 cm-days.

The results presented for Wagram loamy sand indicate that, if subirrigation is used, a drain spacing of 30 m with good surface drainage will satisfy both drainage and irrigation requirements. If subirrigation is not used a drain spacing of 43 m will satisfy drainage requirements for both trafficability and plant growth, regardless of surface drainage. However, unless irrigation water is applied through other means, we can expect at least 34 dry days during the growing season on

an average frequency of once every five years. The number of dry days can be reduced somewhat by using controlled drainage. Simulations were conducted for controlled drainage by assuming a wier is placed in the drainage outlet at a depth of 60 cm below the soil surface. From Figure 49 we see that this practice reduced the number of dry days on a 5 YRI basis by only 4, from 34 to 30. Obviously, this provides very little assistance for dry years and cannot replace an irrigation system. However for wetter years controlled drainage did provide some assistance. For example, a 43 m drain spacing gave fewer than 10 dry days in a growing season in 12 of 20 years of simulation when controlled drainage was used versus only 6 of the 20 years when it was not used. When good surface drainage is provided, controlled drainage will not cause a problem with inadequate drainage during wet years as shown in Figure 50.

The effect of the various water management alternatives on the number of dry days is plotted in Figure 51 for the Bladen soil. The relationships given in Figure 51 were obtained for good surface drainage, s = 2.5 mm, but the quality of surface drainage had little effect on the number of dry days. Subsurface drainage had only a small effect on number of dry days as shown by the fact that the number of dry days decreased from 50 to only 40 when the drain spacing is increased from 7.5 to 60 m. The number of dry days during the growing season for drainage seems high, even on the basis of a 5 YRI. This may be due to assuming a root zone depth which is too shallow. Spot checks using a 75 rather than 60 percent curve in Figure 17 for the root zone depth showed a reduction in number of dry days for a 30 m spacing to about 30.

The relatively high number of dry days is consistent with the reputation that Bladen soils have for being droughty. This is caused by the low hydraulic conductivity which decreases rapidly with water content for unsaturated conditions so that the rate of upward water movement from wetter regions is slow (Figure 25). Thus plants must obtain their water from a relatively shallow zone which extends only a small distance below the root zone. These soils have severe water shortages during dry years as indicated by Figure 51 and it is not uncommon to experience large reductions in yield every three or four years if

irrigation is not used.
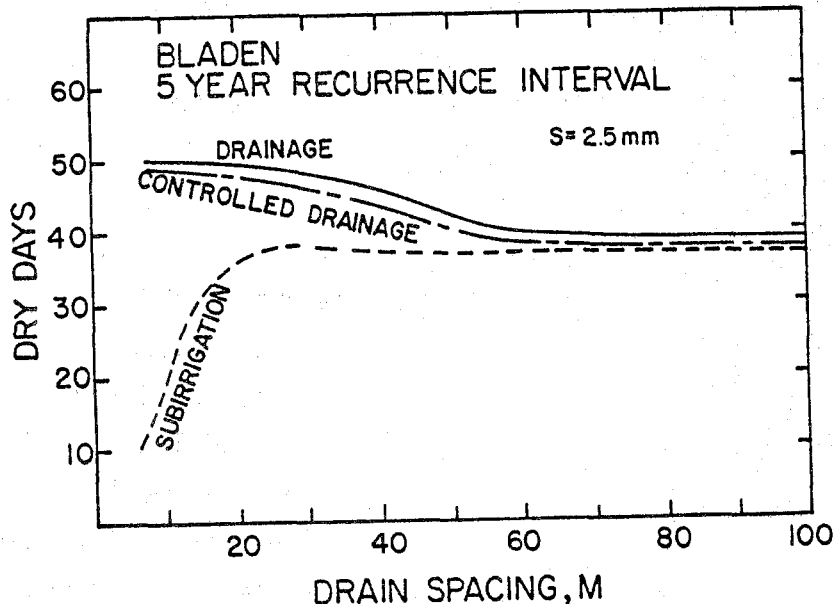
Figure 51. Dry days during the growing season for three
water management methods on Bladen soil.

The relationship given for subirrigation in Figure 51 was obtained
for a water level in the drainage outlet of 60 cm below the surface. In
order to use subirrigation on this soil, the drains would have to be
spaced about 5 m apart to provide (on a 5 YRI basis) less than 10 dry
days during the growing season. Furthermore, it would be necessary to
have good surface drainage in order to insure that the soil is adequately
drained during wet periods (Figure 52). Such close drain spacings are
not economically feasible and other methods of applying irrigation water
should be used on this soil. For example a drain spacing of 5 m rather
than the 20 m necessary to meet trafficability and crop requirements for
conventional drainage (Figures 47 and 48) would require 2000 m/ha of
tubing as compared to 500 m/ha for conventional drainage. At an assumed
cost of $2.00/m (installed), the tubing cost alone would be $4000/ha

BLADEN , 5 YEAR RECURRENCE INTERVAL
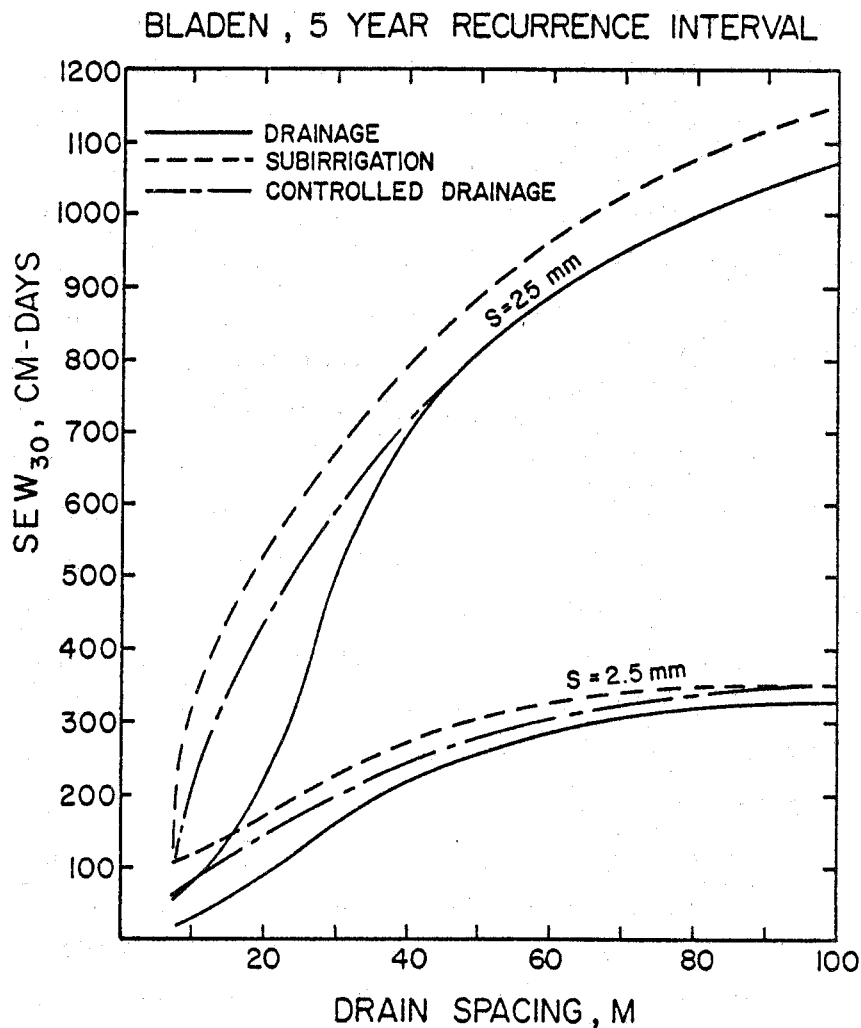
Figure 52. SEW_{30} as a function of drain spacing for conven-
tional drainage, subirrigation and controlled
drainage on Bladen soil. Results are plotted for
two levels of surface drainage.

($1620/ac) for subirrigation versus $1000/ha ($400/ac) for conventional
drainage. One possibility of increasing the drain spacing for subirri-
gation is to hold the water level in the drainage outlet closer to the
surface. A water table depth at the drain of 40 rather than 60 cm was
tried but could not be used because of high SEW_{30} values that occurred
during wet years. In order to meet both subirrigation and drainage
requirements it was still necessary to have drain spacings of about 5-7
m.

Controlled drainage is not attractive for this soil either. Use of controlled drainage reduced the number of dry days by only 2 on a 5 YRI basis (Figure 51). For a 20 m drain spacing, controlled drainage decreased the average number of dry days over the 20 year simulation period by only 2. Thus neither subirrigation nor controlled drainage appear feasible for the Bladen soil.

Example 3 - Irrigation of Wastewater on Drained Lands

Land application of agricultural, municipal, processing or industrial wastewater, with appropriate pretreatment, is an economically and technically feasible alternative to conventional waste disposal methods for many situations. A major step in designing a land application system is determining the permissible loading rate for a given site. In some cases the loading rate is limited by the pollutants in the waste water. In others the application rate is limited hydraulically by drainage conditions of the site. In the latter cases it may be feasible to provide subsurface drainage to increase the amount of wastewater that can be applied to a given site and reduce the land area required. Since the costs of land and irrigation systems to apply wastewater are relatively high, increasing the application rate by the use of artificial drainage could significantly lower the cost of a land disposal system.

In this example we consider wastewater application to the Wagram loamy sand discussed in examples 1 and 2 above. The site is located near Greenville, N.C. Fescue is grown year around and wastewater from a processing plant pretreatment lagoon is to be irrigated (sprinkler) onto the surface. Consideration of the nutrient levels in the water limit the application rate to 25 mm/week. The water may be applied at any irrigation frequency but the average must not exceed 25 mm/week. As discussed in example 1, the soil surface is flat and a restrictive layer exists at a depth of 1.8 m so that drainage under natural conditions is slow. Outlet conditions limit the depth of the drain tube to 1.25 m which is considered deep enough to prevent short-circuiting of the irrigated wastewater directly into the drain.

The objective in this example is to determine the effect of sur-
face and subsurface drainage on the amount of water that can be irriga-
ted without causing surface runoff. The effect of irrigation frequency
(e.g. one irrigation per week of 25 mm versus one irrigation of 50 mm
every 2 weeks), on the total permissible irrigation will also be con-
sidered. Simulations were conducted for good surface drainage, s = 2.5
mm, poor surface drainage, s = 25 mm, and very poor surface drainage,
s = 150 mm. The very poor surface drainage was considered because it
may be desirable in some cases to construct dikes or otherwise artifi-
cially form the surface to prevent runoff during high rainfall intensi-
ties. This would prevent pollutants deposited on the surface, grass
cover, etc., from washing off the site with runoff water. Simulations
were conducted for five drain spacings and for 3 irrigation strategies
as follows: (1) 10.5 mm every 3 days; (2) 25 mm every 7 days; (3) 50
mm every 14 days. All 3 strategies would give an average application
rate of 25 mm/week. As discussed in Chapter 3, wastewater application
is simulated by DRAINMOD on the irrigation interval, INTDAY, if the
drained volume (air volume) in the profile is greater than a given
amount, REQDAR, and if rainfall occurring on the scheduled day is less
than AMTRN. Parameter values used to determine whether an irrigation
event will be skipped or postponed are listed in Table 17 for the cases
considered in this example. In all cases the required drained volume,
REQDAR, was 10 mm greater than the amount of water to be irrigated.

Table 17. Irrigation parameter values used in Example 3.

Irrigation interval, INTDAY	3 days	7 days	14 days
Irrigation amount	10.5 mm	25 mm	50 mm
Time irrigation starts	1000	1000	1000
Time irrigation ends	1200	1200	1200
Drained (air) volume required in the profile, REQDAR	20.5 mm	35 mm	60 mm
Amount of rain to postpone irrigation, AMTRN	10 mm	10 mm	10 mm

Results - Irrigation of Wastewater

All simulations were conducted for a 25 year period and the re-
sults analyzed to determine the total annual irrigation on a 5 year re-
currence interval basis. The results are plotted in Figure 53 for the
7 day irrigation frequency and all three surface drainage treatments.
The results show that, for drain spacings of 25 m or less, water could
be applied at every scheduled irrigation for a total of 1300 mm (52
weeks x 25 mm/week) on a 5 YRI basis. In some weeks irrigation may
have to be postponed to the next day due to rainfall but the scheduled
amount could be applied in all cases. For larger drain spacings many
of the scheduled irrigations could not be applied because there was
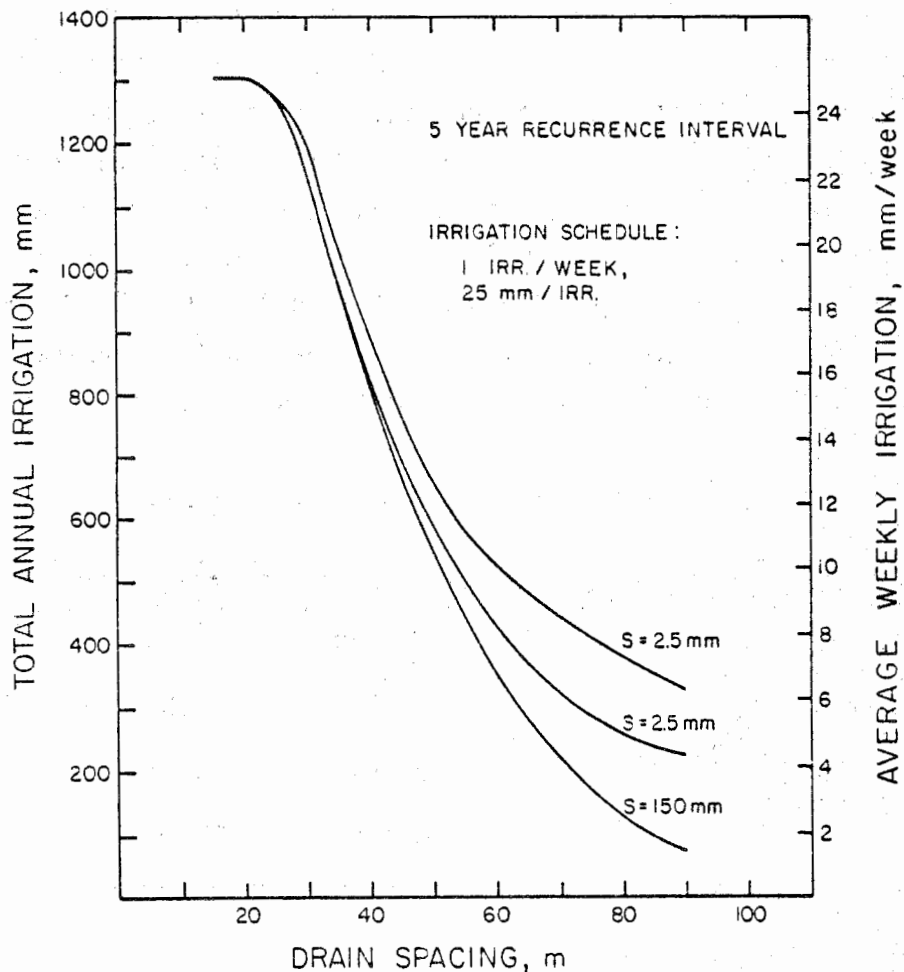
Figure 53. Effects of drain spacing and surface storage
on annual irrigation for irrigation scheculed
once per week, 25 mm per irrigation.

insufficient water-free (drained) volume in the profile. When this
happened irrigation was canceled for that period and conditions were
checked on the next scheduled irrigation day. For example, only 770 mm
could be irrigated (5 YRI basis) for a drain spacing of 45 m and good
surface drainage. Closer inspection of the simulation results showed
that most of the irrigation cancellation due to wet conditions occurred
in the winter and early spring when ET is low. The results plotted in
Figure 53 show that the amount of water that can be irrigated is more
dependent on subsurface drainage, as indicated by the drain spacing, than
on surface drainage. However, when subsurface drainage is poor (large
drain spacings) the amount of wastewater that can be irrigated is heavily
dependent on surface drainage. When surface drainage is poor, water may
be stored on the surface after periods of high rainfall and can be removed
only by evaporation or subsurface drainage. Time required for removal of
this surface water may cause the next scheduled irrigation event to be
canceled due to wet soil conditions.

The effect of the irrigation interval on annual irrigation is
shown in Figure 54. Recall that the intervals and amounts to be irrigat-
ed were selected so that the average application rate was 25 mm/week for
all three combinations simulated. This is obvious for good subsurface
drainage where 1300 cm could be irrigated for all three irrigation fre-
quencies. For slower subsurface drainage (i.e. drain spacings greater
than 25 m) the results in Figure 54 indicate that more water can be
irrigated by applying smaller amounts on a more frequent basis. For ex-
ample, if drains are spaced 45 m apart, 950 mm of water could be applied
(on a 5 YRI basis) by irrigating 10.6 mm every 3 days, while only 650 mm
could be applied by scheduling 50 mm every 14 days. The reason for the
difference is that, due to random occurrence of rainfall, it is more
difficult to get the required water free (drained) volume for larger,
less frequent irrigations. For the 14 day irrigation interval, a water-
free pore volume of 60 mm was required in order to apply irrigation at
the scheduled time. This volume may be available on the 12th day but
rainfall on the 13th day could cause conditions to be too wet for irri-
gation at the scheduled time on day 14. For the 3 day interval, on the
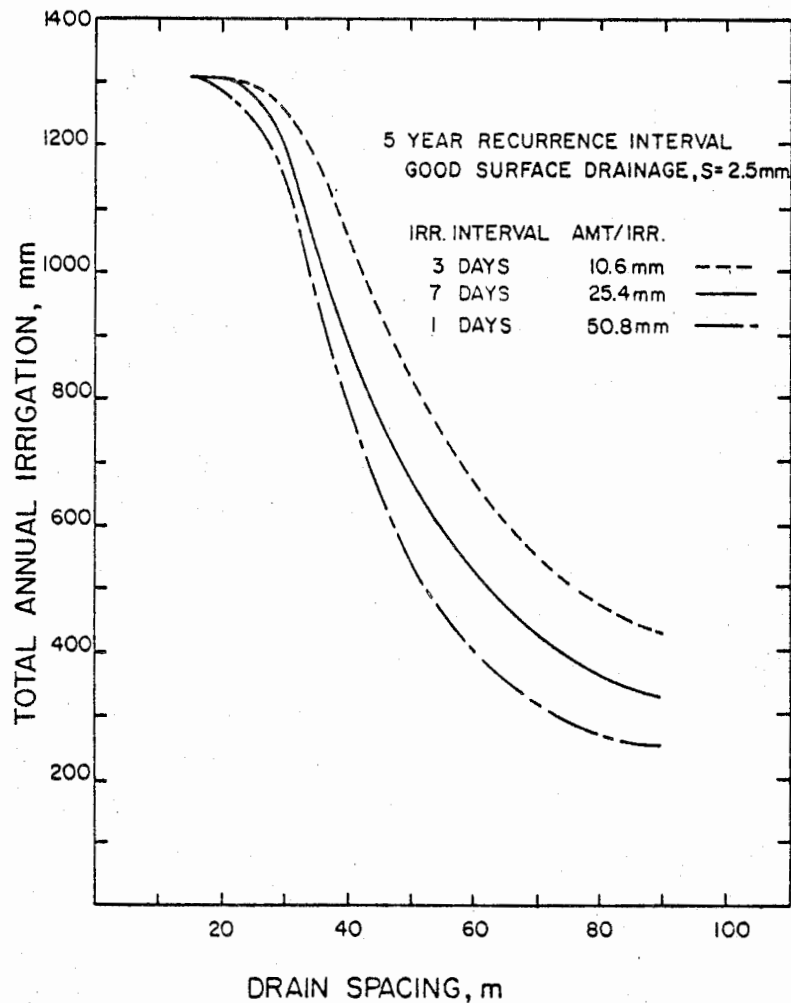
Figure 54. Effect of drain spacing and irrigation frequency on total annual irrigation for a Wagram loamy sand.

other hand, the same rainfall conditions would cause cancellation of only one or perhaps none of the 4 scheduled smaller wastewater applications during the same period.

The results discussed above assumed that a given amount of waste water is applied at a scheduled time providing that soil water and rainfall conditions are not limiting. For a given drainage system, soil water conditions are more likely to be limiting in the winter and early spring because of lower ET rates as mentioned above. However, it may also be possible to increase the amount irrigated during the late spring

and summer months because of the relatively high ET rates during this season. Thus, it would be possible to increase the annual irrigation over that shown in Figures 53 and 54 by storing the water in a reservoir during periods when irrigation is not possible and increasing the irrigation rate during the summer. In this case it is important to determine the amount of storage that would be required for a given drainage system and irrigation strategy as the storage reservoir would be a component of the total system design. The storage required for the alternative systems considered here is shown in Figure 55 for drain spacings up to 45 m. The values given represent the storage required (5 YRI basis) to permit irrigation of an average of 25 mm per week for 52 weeks per year. For example, a drain spacing of 45 m with good surface drainage would require storage capacity for 350 mm of irrigation water. This amounts to 13 weeks of irrigation at 25 mm per week.

The results of this example show that DRAINMOD can be used to determine the amount of wastewater that can be applied to drained soils. The storage volume required because irrigation is not possible during wet periods can also be accessed. Since simulations are made with actual weather data, designs can be made on a probability basis. By considering alternative systems, DRAINMOD can be used to select the most economical system that will meet the design requirements for a given situation.

Example 4 - Effect of Root Depth on the Number and Frequency of Dry Days

Root depths are limited in many N.C. soils due to physical barriers caused by hard pans or layering and by chemical barriers such as a low Ph below a given depth. In other cases root depths are limited by high water table conditions which frequently prune back deeper roots. Some varieties of a given crop have more shallow rooting depths than others. Thus, increasing the rooting depth for a given crop may be a matter of variety selection, providing good drainage, or removing physical and chemical barriers to root growth. Because increasing the rooting depth directly increases the water available for plant use, there has been much interest in removing barriers to root growth and in developing plant varieties with deeper rooting systems. The purpose of this example
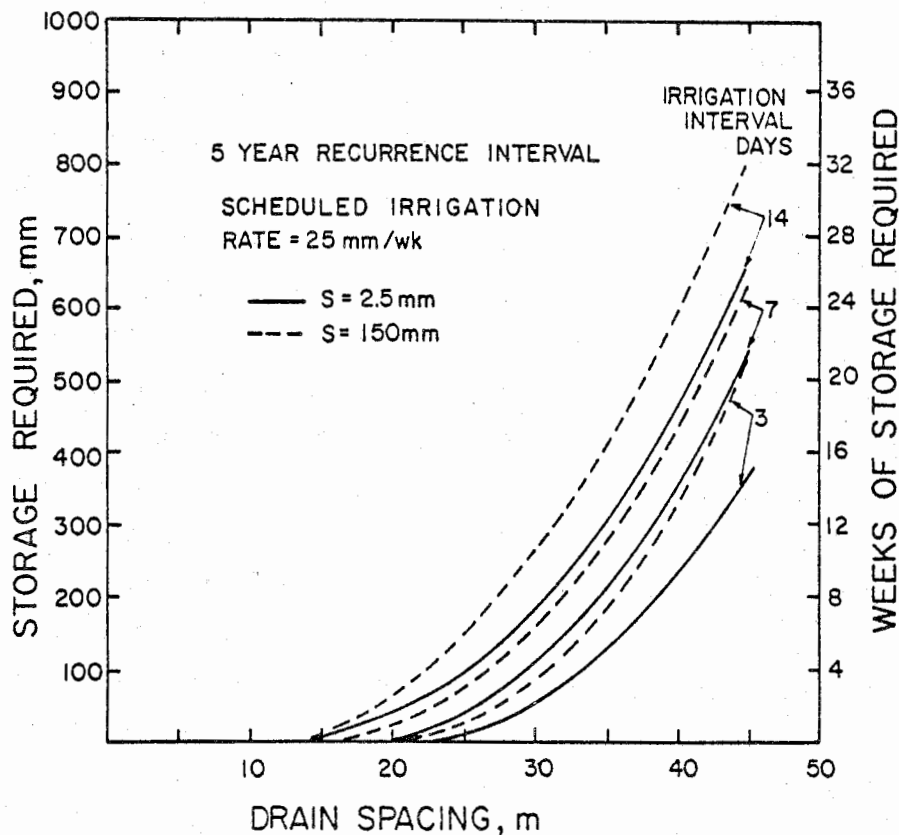
Figure 55. Effect of drain spacing, surface drainage
and irrigation frequency on storage volume
required for application of an average of
25 mm/week on a Wagram loamy sand.

is to examine the effect of root depth on the number of days that the
plant is under stress due to dry conditions. A day when plants are
under stress due to dry conditions is assumed here to be a dry day
and is defined in Chapter 3 as a day in which ET is limited by soil
water conditions.

The soils and drainage systems considered here are those discus-
sed in example 1, Bladen loam and Wagram loamy sand. The drainage system
for the Bladen soil is composed of parallel drains buried 1 m deep and
placed 20 m apart with good surface drainage (s = 2.5 mm). For the
Wagram soil the drain spacing, as suggested by results in example 1 is
43 m with poor surface drainage (s = 25 mm). Conventional drainage is

assumed without controlled drainage or subirrigation. Simulations were conducted for 20 years of climatological data for Greenville, N.C. It was assumed that corn was to be grown on a continuous basis and the maximum effective rooting depth was varied from 0.1 m to 0.6 m to determine the effects on number of dry days. The basic relationship for rooting depth versus time was the same as used in the previous examples and is given by the 60% curve in Figure 16 which has a maximum depth of 0.3 m. When the value given in Figure 16 was greater than the maximum rooting depth chosen, the rooting depth was set equal to the maximum. For maximum rooting depths greater than 0.3 m the values given by the CO% curve in Figure 16 were increased by the ratio M/.30 where M is the maximum depth.

The results of the simulations are plotted in Figure 56 for 5 year and 2 year recurrence intervals for both Bladen and Wagram soils. An example interpretation of these results yields the following for a Wagram soil with a limiting root depth of 0.15 m. On a 5 YRI basis we should expect to have 38 or more dry days during the growing season in one year out of 5 when the root depth is limited to 0.15 m. However if the barrier to root growth is removed and the maximum effective depth reaches 0.3 m the expected dry days (once in 5 years) would be 23. From another point of view, we can say that 23 or fewer dry days would be expected in 4 years out of 5 when the maximum effective root depth is 0.3 m. If the effective maximum root depth could be further increased to 60 cm the expected number of dry days in 4 years out of 5 would be 7 or fewer.

Use of the model as in this example allows an evaluation of the potential benefit of operations to increase rooting depths such as chisel plowing to break hardpans or deep incorporation of lime to raise subsoil pH. Potential benefits of research to develop varieties with deeper rooting systems could also be evaluated.
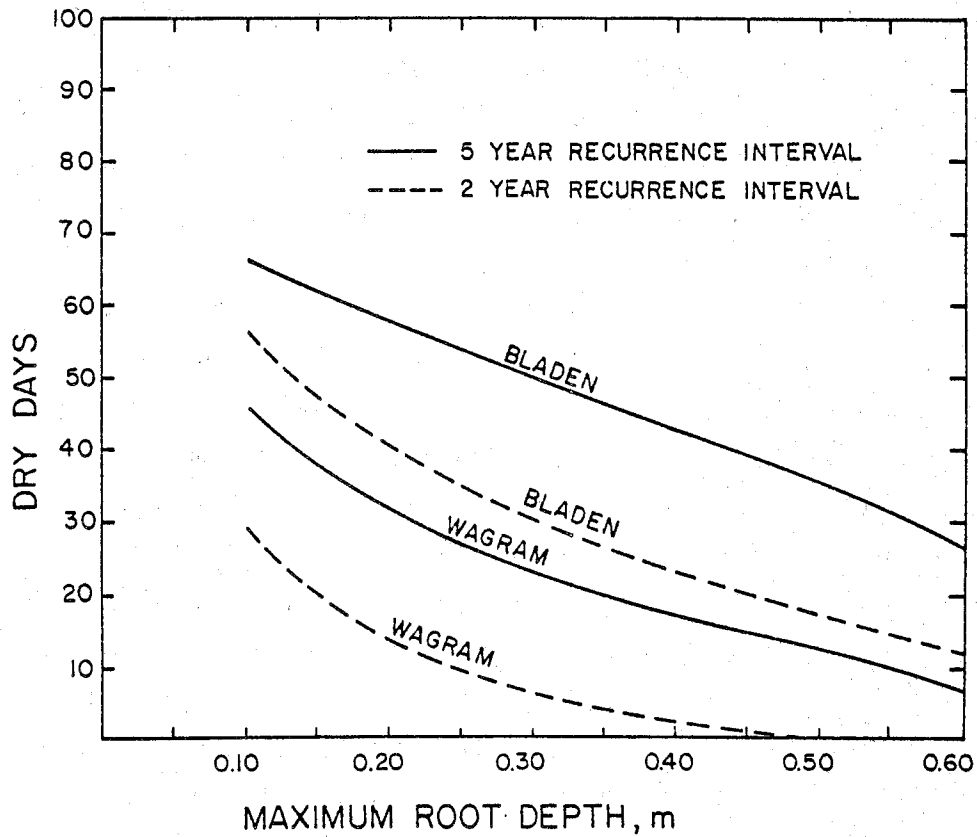
Figure 56. Effect of maximum root depth on number of dry
days, 2 and 5 year recurrence intervals.

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APPENDIXES

APPENDIX   A

DRAINMOD - COMPUTER PROGRAM DOCUMENTATION

The program documentation consists of five parts as follows:

1. A brief description of each segment of the program and a
   discussion of its function.
2. A program listing complete with definitions of all variable
   names.
3. An example set of input data.
4. An example of the program output - results of the simu-
   lation.

Program Segments and Their Functions

A. Main Program

The main program is written in PL1. It reads year, month, and
hourly rainfall for each hour of the month from HISARS files. It also
reads the maximum and minimum daily temperatures and calculates PET
using the Thornthwaite method. Inputs to main through the EXECUTE
JCL card are the station ID for the hourly rainfall file and the
station ID and latitude for the temperature file. These are usually
the same station but can be different so that PET can be estimated
from temperature records at a nearby station when necessary. Other
inputs are the beginning and ending years of simulation and the heat
index for the PET calculation.

The main program transfers the hourly rainfall and daily ET value
for the entire month to subroutine FORSUB. The simulation is made in
FORSUB for the month; control is returned to the MAIN program; another
month's data is read from the file and the process is repeated until
the simulation has been conducted for the desired period.

A FORTRAN version of MAIN was also developed to read hourly rain-
fall and daily PET directly from cards. This program was used to test
the validity of DRAINMOD by reading in measured hourly rainfall and out-
let water level elevations. Observed water table elevations were also
read in and deviations between predicted and observed were computed.
The predicted and observed water table depths were also plotted by
the computer for visual comparison.

B. <u>Subroutine FORSUB</u>

FORSUB accepts hourly rainfall and daily PET values for a one month period from the main program. At the beginning of simulation it reads soil properties, crop parameters and water management system parameters and initializes variables. The basic water management simulation is carried out in this subroutine. It determines if rainfall occurs on a given day, calculates infiltration, surface runoff, drainage or subirrigation, water table depth, depth of the dry zone, etc. These values may be printed out on a daily or monthly basis at the option of the user. It also calculates, stores and prints out water management system objective functions - those functions which the water management system is designed to provide at some minimal level. Objective functions or parameters are: working days during a given period, SEW - 30, dry days during the growing season, or the amount of wastewater irrigation. The operations of this subroutine depend on other subroutines which are called to read certain input data, to perform detailed calculations such as determining drainage flux, and to store and rank objective function values.

This subroutine can be divided into the following sections:

1. Obtain hourly rainfall and daily ET values from main program. Change values from inches to cm.

2. Read input parameters on the first time through the simulation. Most are read in directly; others are read in by calling subroutines PROP and ROOT.

3. Initilization of variables prior to beginning of simulation.

4. Determine hourly rainfall, PET and initialize other variables for a new day.

5. Determine infiltration and conduct water balance on an hourly basis if rain or irrigation occurs that day or if water was stored on the surface at the beginning of the day.

6. Conducts water balance calculations on a two-hour interval or one-day interval, depending on drainage flux, when no rain or surface irrigation.

7. Re-evaluates the water balance for the day, determines water table depth, dry zone depth etc, for the end of the day, and updates some variables to be used the next day.

8. Determines objective parameters such as SEW-30 and working days, accumulates and stores these values and prints out daily values for all water management components if the user calls for daily output.

9. Computes yearly summaries and prints out monthly and yearly summaries. Calls subroutine ORDER to store and rank yearly summaries.

C. Subroutine PROP

This routine reads in the soil water characteristic (h vs. θ) as a table of values. It interpolates between the values of water contents, θ, at 1 cm increments of pressure head from 0 to -500 cm of water. The relationship between air volume in the profile and water table depth is determined from the soil water characteristic by assuming a drained to equilibrium profile. Air volumes are calculated for incremental water table depths from 0 to 500 cm. As an alternative the relationship between water table depth, air volume (or drainage volume) and steady state upward flux can be read in and interpolated for intermediate values at the user's option. In either case the water table depth-air volume relationship is stored in arrays such that the air volume can be easily determined for a given water table or wet zone depth and the water table or wet zone depth can be immediately determined for a given air volume. For example, the value stored as VOL(1) would be the air volume for a water table depth of 0.0 cm, VOL(6) the volume for a 5 cm water table depth, etc. Conversely the value stored as WTD(6) would be the water table depth corresponding to an air volume of 0.5 cm, WTD(51) corresponds to a volume of 5 cm and so on.

PROP also reads in a tabular relationship between water table depth and the Green-Ampt infiltration constants, A and B. These values are read in and interpolated for unit water table depth increments from 0 to 500 cm and stored in arrays for easy retrieval.

D. Subroutine ROOT

This subroutine reads in tabular values of effective root depth versus Julian date and interpolates between the values so that the root depth for any day can be called directly.

E. Subroutine SURIRR

This subroutine determines if surface irrigation for waste water disposal is scheduled and if conditions are suitable for irrigation. The amount of surface irrigation is considered as additional rain. If the air volume in the soil is less than the required air volume for surface irrigation, REQDAR, the irrigation day is skipped and no surface irrigation is done until the next preplanned day. If rainfall in excess of AMTRN occurs on the first scheduled hour of surface irrigation, the operation for that day is postponed and surface irrigation is tried again the next day. The program also counts the number of skips, number of postponements, and the number of irrigation days.

F. Subroutine WET

Determines the pressure head and water content distribution in the wet zone by assuming a hydrostatic condition above the water table.

G. Subroutine EVAP

The daily PET is distributed over the daylight hours of approximately 6:00 AM to 6:00 PM in this subroutine. PET for any hour, between these times, HPET, is calculated by dividing the daily PET by 12, assumed number of daylight hours. Then HPET for any hour in which rainfall occurs is set equal to zero. When the critical depth concept is used for determining the limit of upward water movement, HPET is also set equal to zero for any hour that the depth of dry zone exceeds the root depth. Finally the daily PET, adjusted for hours when rainfall occurs is obtained by summing the hourly values. The hourly and daily PET values so determined are taken as the actual ET values in FORSUB when the critical depth concept is used. Otherwise the PET values are used in subroutine ETFLUX to determine actual ET values.

H. Subroutine SOAK

This subroutine finds the infiltration constants A and B for the Green-Ampt infiltration equation, $f = (A/F) + B$, where f is infiltra-

tion rate and F, cumulative infiltration. Infiltration constants vary from soil to soil and with initial water content or depth of water table. In this subroutine, the values of A and B are chosen from a stored array using the water table depth at the beginning of the infiltration event as the index. When a dry zone exists, an effective water table depth which would correspond to the total air volume in the profile is defined and used as the index for obtaining A and B. Once the values of A and B are chosen, they are not changed until the infil- tration event ends. The only exception is when the water table rises to the surface; then A is set to A = 0 and B is set equal to the sum of the drainage and ET fluxes.

I. Subroutine DRAINS

This subroutine determines the effective lateral hydraulic conduc- tivity based on the conductivities of the profile layers from the input data and on the position of the water table. Then the drainage (or sub- irrigation) flux is determined using the Hooghoudt equation as discussed in the text of the report. Convergence near the drain has already been accounted for by adjusting the depth from the drain to the impermeable layer in the input parameters.

J. Subroutine ETFLUX

This subroutine uses the adjusted PET values, either hourly or daily, obtained from subroutine EVAP to determine actual ET which may be limited by soil water conditions. The water table depth, rooting depth, depth of the dry zone and upward flux from the water table are used as inputs to determine the actual ET. If upward flux is insuffi- cient to meet the ET demand, water is removed from the root zone to make up the difference. If root zone water is not available, ET is limited to the amount that will be transferred by upward flux.

K. Subroutine YDITCH

The purpose of this subroutine is to determine the water level in the drain at all times during the simulation. For a conventional drainage system this water level would probably be constant; i.e. the outlet would be designed to have sufficient capacity to hold the water level at a constant elevation. For subirrigation the water in the

drainage outlet or drainage ditches would also probably be held at the elevation of the weir by pumping. However in controlled drainage situations the weir would be set at a given elevation and the ditch water level may be at or below that elevation depending on drainage and runoff. YDITCH was written to compute the water level in parallel ditch drains which are trapezoidal in cross-sections (Figure A.1).

If YD is the water level in the ditch, then the total volume of water would be

$$CV = \frac{B + (2\ YD)\ S}{2} \cdot YD \qquad\qquad (A.1)$$

where S is the slope of the ditch bank, B is the bottom width and CV is the total volume of water stored in the ditch in cm^3 per cm of ditch length. Hence if CV is known, then YD could be found easily:

$$YD = \frac{1}{2}\ (\frac{B}{S})2 + \frac{4\ CV}{S}^{\ \frac{1}{2}} - \frac{1}{2}\frac{B}{S} \text{ in cm} \qquad\qquad (A.2)$$
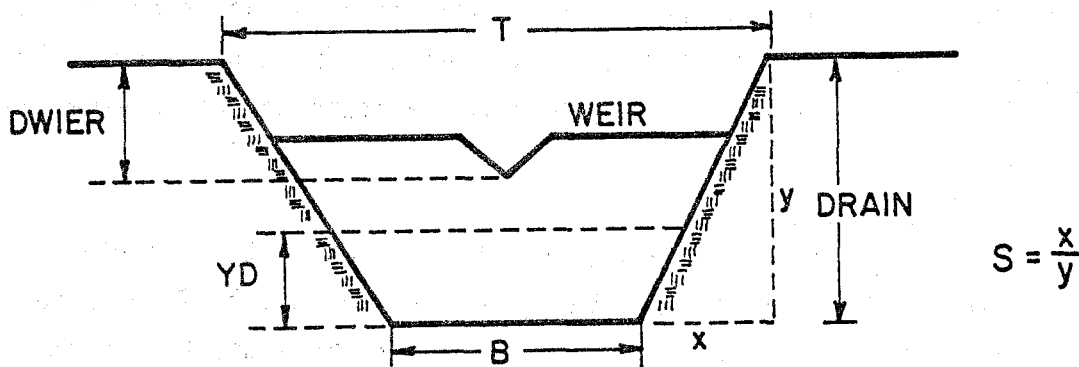
Figure A.1. Schematic of drainage ditch with water table control weir.

The change in CV during a given time increment can be found as

$$\Delta\ CV = (RO + DVOL) \cdot SDRAIN \qquad\qquad (A.3)$$

where SDRAIN is the drain spacing, RO is the runoff in cm (cm^3 per unit area) and DVOL is the drainage volume in cm. Thus after a time increment Δt the water available for ditch storage is

$$CV|_{t + \Delta t} = CV|_{t} + \Delta CV \qquad\qquad (A.4)$$

and the new YD can be obtained by substituting this value for CV in equation A.2. However the maximum value of YD is DDRAIN - DWEIR and this corresponds to a maximum value CV_{max} which may be obtained from equation A.1. Therefore, when the new value of YD is greater than

YD_{max}, the water lost from the system, WLOSS, may be determined as

$$SLOSS = (CV|_{t + \Delta t} - CV_{max})/SDRAIN \qquad (A.5)$$

in cm (or cm^3/cm^2).

When the ditch water level is higher than the water table in the field, subirrigation will occur and DVOL will be negative. Then the ditch water level will decrease with time.

When drain tubes rather than parallel ditches empty into an outlet ditch or canal, the storage available in the outlet may be partitioned to the parallel drains by computing effective ditch dimensions. For example, consider a system of parallel drain tubes 500 m long spaced 50 m apart emptying into a rectangular canal 5 m wide. If the drain depth is 1 m, the storage volume available per tube above the drain depth would be 1 m x 5 m x 50 m = 250 m^3. Since each tube is 500 m long, the storage per unit length is 250 m^3/500 m = 0.5 m^3/m. So an effective ditch dimension for this case would be a rectangular ditch 0.5 m wide and 1 m deep. This assumes that drains enter the main ditch from only one side.

When drain tubes are used for both mains and laterals, storage would usually be negligible and small values of B and S would be used in the program. Internal division by S prohibits the use of S=0 although B=0 is allowed.

Note again that this subroutine is important when the program is used in the controlled drainage mode. When conventional drainage or sub-irrigation are used the water level is normally assumed to be constant. A possible exception would be some schemes of subirrigation which would raise the water level in the field on a periodic basis then allow it to decline.

L. Subroutine WORK

The purpose of this subroutine is to determine if conditions are suitable for field work on a given day. Three criteria are used to determine if the day is a working day. First there must be a minimum air volume (or drained volume), AMIN. If the air volume is less than AMIN it is not a working day. Second, if the rainfall exceeds a given

amount, field operations are stopped on that day. Third, field operations cannot resume until a given amount of time has passed since rainfall caused them to be terminated.

Two working periods may be considered, usually spring seedbed preparation and fall harvest, with separate working day criteria and with specified maximum day lengths for each period. Partial working days may result when rainfall interrupts field operations; this possibility is also considered in the program.

M. Subroutine ORDER

This subroutine stores yearly totals for the objective functions (SEW-30, working days, etc.) determines the average values over the simulation period and prints out the yearly values along with their rank after the simulation is completed. At the end of the simulation, ORDER calls subroutine RANK for each objective function and it ranks the values from smallest to largest.

N. Subroutine RANK

The yearly values of the objective functions are ranked from smallest to largest by this subroutine.

```
        SUBROUTINE FORSUB( IR,MO,ET,HOURLY,LOOP,  IEDYR)                      1A
C ***************************************************************************   2A
C * THIS SUBROUTINE IS THE MAIN BODY OF THE MODEL, DRAINMOD.             *   3A
C * IT CONDUCTS THE BASIC WATER BALANCE CALCULATIONS ON INTERVALS OF 1   *   4A
C * HR., 2HR., OR 1DAY.                                                  *   5A
C * INFILTRATION, SURFACE STORAGE, AND WATER MANAGEMENT PARAMETERS SUCH  *   6A
C * AS SEW-30 ARE CALCULATED WITHIN THIS SUBROUTINE.                     *   7A
C * OTHER COMPONENTS SUCH AS DRAINAGE FLUX AND ET ARE CALLED FROM ADD-   *   8A
C * ITIONAL SUBROUTINES.                                                 *   9A
C ***************************************************************************  10A
C                                                                            11A
C ***************************************************************************  12A
C *                          SECTION 1                                   *  13A
C * THIS SECTION RECEIVES DAILY PET AND HOURLY RAINFALL VALUES FOR ONE   *  14A
C * MONTH FROM THE MAIN PROGRAM AND CHANGES THE VALUE FROM INCHES TO CM. *  15A
C ***************************************************************************  16A
        DIMENSION ET(31),HOURLY(744),DAYM(12)                               17A
        DIMENSION PROOT(370)                                                18A
        INTEGER DAYM,DAY                                                    19A
        DATA DAYM/31,28,31,30,31,30,31,31,30,31,30,31/                      20A
C                                                                            21A
        IF(MO.NE.2) GO TO 5                                                 22A
        IR1=IR/4                                                            23A
        IR2=IR1*4                                                           24A
        IF(IR1.EQ.IR2)DAYM(2)=29                                            25A
    5   DO 10 I=1,744                                                       26A
        HOURLY(I)=HOURLY(I)*2.54                                            27A
   10   CONTINUE                                                            28A
        DO 15 I=1,31                                                        29A
        ET(I)=ET(I)*2.54                                                    30A
   15   CONTINUE                                                            31A
        DAY=0                                                               32A
        IF(LOOP.GT.1)GO TO 30                                              33A
        IRFST=IR                                                            34A
C                                                                            35A
C |-------------------------------------------------------------------|  36A
C |                      END OF SECTION 1                              |  37A
C | IF LOOP=0, I.E. FIRST TIME THROUGH THIS SECTION, GO TO SECTION 2 TO|  38A
C | READ INITIAL DATA;  OTHERWISE GO TO SECTION 4.                     |  39A
C |-------------------------------------------------------------------|  40A
C                                                                            41A
C ***************************************************************************  42A
C *                          SECTION 2                                   *  43A
C * STORAGE BLOCKS ARE ALLOCATED AND ARRAYS ARE DIMENSIONED.  SOILS,     *  44A
C * SYSTEM PARAMETER AND PLANT ROOT DATA ARE READ IN AND LISTED ON THE   *  45A
C * OUTPUT IN THIS SECTION.                                              *  46A
C ***************************************************************************  47A
C                                                                            48A
        INTEGER BWKDY1,BWKDY2,SWKHR1,SWKHR2,EWKHR1,EWKHR2,EWKDY1,EWKDY2     49A
        INTEGER FDAYSI,HOUR                                                 50A
        COMMON /IWK/SWKHR1,EWKHR1,SWKHR2,EWKHR2                             51A
        COMMON /WRK/AMIN1,ROUTA1,ROUTT1,AMIN2,ROUTA2,ROUTT2                 52A
        COMMON/ICNT/ISICNT,ISKIP,IPOST,IK                                  53A
        COMMON/JCNT/JSICNM,JSKIPM,JPOSTM                                   54A
        COMMON/IDAY/FDAYSI,NDAYSI,INTDAY,NOIRR1,NOIRR2,NOIRR3,NOIRR4        55A
        COMMON/IHR/IHRSTA,IHREND                                           56A
        COMMON/PAR/AVOL,REQDAR,AMTRN,AMTSI,DAMTSI                          57A
        COMMON/WHX/WATER(500),W(101),H(101),X(101),NN                      58A
        COMMON/ABDT/EDTWT,AA(500),BB(500),A,B                              59A
        COMMON/EVAPO/PET,DDZ,ROOTD                                         60A
        COMMON/DRABLK/HDRAIN,DEPTH,CONK(5),DZ(5)                           61A
        COMMON/DLK/SDRAIN,DDRAIN                                           62A
        COMMON/DBLK/DRNSTO                                                 63A
        COMMON/PLT/YODTWT(31),YCDTWT(31),XDATE(31)                         64A
        COMMON/RAIN/R(24)                                                  65A
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```
      COMMON/ORDR/TOSIRR(50),TOTDD(50),TOTWD(50),SEW(50),IRY(50)          66A
C                                                                          67A
      DIMENSION RVOLM(12),FVOLM(12),ROM(12),DVOLM(12),PUMPVM(12)          68A
      DIMENSION DWIER(12),DACHNG(12),TWLOSS(12)                           69A
      DIMENSION DRYDAY(12),WETDAY(12),WRKDAY(12),WATDAY(12)               70A
      DIMENSION ISICNM(12),ISKIPM(12),IPOSTM(12),SIRRMO(12)               71A
      DIMENSION F(24),FRATE(24),HET(24),ACCR(24)                          72A
      DIMENSION WTD(1000),VOL(501)                                        73A
      DIMENSION SWIER(12)                                                 74A
      DIMENSION WATERL(31)                                                75A
      DIMENSION SEWM(12)                                                  76A
      DIMENSION UPFLUX(500),HPET1(24)                                     77A
      DIMENSION SUMAET(12)                                                78A
C                                                                          79A
C READ INPUT                                                              80A
      READ(1,600)FDAYSI,INTDAY,IHRSTA,IHREND,NOIRR1,NOIRR2,              81A
     $NOIRR3,NOIRR4                                                      82A
      READ(1,610)REQDAR,AMTRN,AMTSI                                       83A
      READ(1,620)DDRAIN,HDRAIN,SDRAIN,          STMAX,DEPTH,XNI          84A
      READ(1,625)(DZ(I),CONK(I),I=1,5)                                   85A
      READ (1,630)AMINC,NOPORT,NMONTH                                    86A
      READ(1,640)(DACHNG(I),DWIER(I),I=1,12)                             87A
      READ(1,645) BWKDY1,EWKDY1,SWKHR1,EWKHR1,AMIN1,ROUTA1,ROUTT1        88A
      READ(1,645) BWKDY2,EWKDY2,SWKHR2,EWKHR2,AMIN2,ROUTA2,ROUTT2        89A
      READ(1,650)DITCHB,DITCHS,ROOTD,CRITD,WP,DTWT                       90A
      READ(1,670)ISEWMS,ISEWDS,ISEWME,ISEWDE,SEWX                        91A
      READ(1,670)IDRYMS,IDRYDS,IDRYME,IDRYDE                             A91A
      READ(1,670)INDET,INWIER                                            92A
C         IF INDET .GT.0 USE VALUES READ  IN SUB PROP TO CALCULATE ET AS  93A
C         LIMITED BY SOIL CONDITIONS.  IF INDET .GT.0 USE LIMITING DEPTH  94A
C         CONCEPT.                                                        95A
C      START SEW CALCULATION ON ISEWDS IN MO. ISEWMW.                     96A
C         END IT ON DAY ISEWDE IN MO. ISEWME.                            97A
C         SEW CALCULATES DAYS W.T. IS ABOVE SEWX CM.                     98A
C                                                                          99A
C PRINT INPUT                                                             100A
      WRITE(3,790)                                                       101A
      WRITE(3,800)DDRAIN,HDRAIN,SDRAIN,STMAX,DEPTH,XNI                   102A
      WRITE(3,810)AMIN,AMINC,ROUTA,ROUTT                                 103A
      WRITE(3,820)ROOTD,CRITD,WP,DTWT,DITCHB,DITCHS                      104A
      WRITE(3,850)FDAYSI,INTDAY,IHRSTA,IHREND,NOIRR1,NOIRR2,            105A
     $NOIRR3,NOIRR4                                                      106A
      WRITE(3,860)REQDAR,AMTRN,AMTSI                                     107A
      WRITE(3,822)                                                       108A
      CST1=0.0                                                           109A
      DO 824 I=1,5                                                       110A
      CST2=DZ(I)                                                         111A
      IF(CONK(I).GT..1E-5) WRITE(3,823)CST1,CST2,CONK(I)                112A
  824 CST1=CST2                                                          113A
      WRITE(3,830)(DACHNG(I),I=1,12)                                     114A
      WRITE(3,840)(DWIER(I),I=1,12)                                      115A
      WRITE(3,835)NOPORT                                                 116A
C                                                                          117A
C SOIL PROPERTIES                                                         118A
      WRITE(3,870) INDET                                                 119A
      CALL PROP(WTD,VOL,WATER,AA,BB,UPFLUX)                              120A
C                                                                          121A
C   SOME SOIL  PROPERTIES ARE READ IN AND INITIALIZED IN SUBROUTINE PROP 122A
C                                                                          123A
      CALL ROOT(DROOT)                                                   124A
      JDAY=0                                                             125A
C                                                                          126A
C |-------------------------------------------------------------------| 127A
C |                    END OF SECTION 2                               | 128A
C |-------------------------------------------------------------------| 129A
```

```
127

C                                                                          130A
C ****************************************************************************  131A
C *                          SECTION 3                                     *  132A
C * INITIALIZATION OF VARIABLES PRIOR TO BEGINNING OF SIMULATION          *  133A
C ****************************************************************************  134A
C                                                                          135A
      EDTWT=DTWT                                                           136A
      LRAIN = 0                                                            137A
      DDAY=0.                                                              138A
      ISKIP=0                                                              139A
      IPOST=0                                                              140A
      IK=0                                                                 141A
      ISICNT=0                                                             142A
      IRRDAY=0                                                             143A
      DEBT=0.0                                                             144A
      DDZ=0.0                                                              145A
      DRNSTO=0.0                                                           146A
      STOR=0.0                                                             147A
      TOTR=0.                                                              148A
      TOTF=0.                                                              149A
      TOTD=0.                                                              150A
      TOTRO=0.                                                             151A
      TOTNT=0.                                                             152A
      TOTFD=0.                                                             153A
      TOTWF=0.                                                             154A
      TPUMPV=0.0                                                           155A
      YTAV=0.0                                                             156A
      YSUMET=0.0                                                           157A
      WETZ=DTWT                                                            158A
      ID=DTWT+1.0                                                          159A
      YDEBT=0.0                                                            160A
      CRITD1=CRITD+1.                                                      161A
      ICRIT=CRITD1                                                         162A
      CRITAV=VOL(ICRIT)                                                    163A
      AVOL=VOL(ID)                                                         164A
      UPQ=UPFLUX(ID)                                                       165A
      UPVOL=UPQ*1.                                                         166A
      DELX=DEPTH/XNI                                                       167A
      NI=XNI                                                               168A
      NN=NI+1                                                              169A
      NR1=NOIRR1                                                           170A
      NR2=NOIRR2                                                           171A
      NDAYSI=FDAYSI                                                        172A
      DO 20 I=1,12                                                         173A
      ISICNM(I)=0                                                          174A
      ISKIPM(I)=0                                                          175A
      IPOSTM(I)=0                                                          176A
      SIRRMO(I)=0.                                                         177A
      TWLOSS(I)=0.0                                                        178A
      SUMAET(I)=0.0                                                        179A
      RVOLM(I)=0.0                                                         180A
      ROM(I)=0.0                                                           181A
      FVOLM(I)=0.0                                                         182A
      DVOLM(I)=0.0                                                         183A
      PUMPVM(I)=0.0                                                        184A
      WRKDAY(I)=0.0                                                        185A
      WETDAY(I)=0.0                                                        186A
      WATDAY(I)=0.0                                                        187A
      DRYDAY(I)=0.                                                         188A
      SWIER(I)=DWIER(I)                                                    189A
      SEWM(I)=0.0                                                          190A
   20 CONTINUE                                                             191A
      DO 23 I=1,50                                                         192A
      IRY(I)=0                                                             193A
      SEW(I)=0.0                                                           194A
```

```
         TOTDD( I) =0.0                                                   195A
         TOTWD( I) =0.0                                                   196A
      23 TOSIRR( I) =0.0                                                  197A
C                                                                        198A
         X( 1) =0.0                                                       199A
         DO 25  I=2,NN                                                    200A
         X( I) =X( I-1) +DELX                                             201A
      25 CONTINUE                                                         202A
C                                                                        203A
C  |------------------------------------------------------------------|  204A
C  |                      END OF SECTION 3                           |  205A
C  |------------------------------------------------------------------|  206A
C                                                                        207A
C  ****************************************************************       208A
C  *                        SECTION 4                          *        209A
C  * INCREMENT DAY, DETERMINE HOURLY RAINFALL, WEIR DEPTH, AND ROOT DEPTH * 210A
C  * FOR NEW DAY.  INITIALIZE VARIABLES FOR A NEW DAY.          *        211A
C  ****************************************************************       212A
C                                                                        213A
      30 DAY=DAY+1                                                        214A
         IRRDAY= IRRDAY+1                                                 215A
         JDAY=JDAY+1                                                      216A
         ROOTD=DROOT( JDAY)                                              217A
C                                                                        218A
         DWIER( MO) =SWIER( MO)                                          219A
         PDEBT=ROOTD*( WATER( 1) -WP)                                    220A
         IF( DAY.LT. DACHNG( MO) .AND.MO.EQ. 1) GO  TO  31               221A
         IF  ( DAY.LT. DACHNG( MO) ) DWIER( MO) =DWIER( MO-1)            222A
         GO  TO  32                                                      223A
      31 DWIER( MO) =DWIER( 12)                                          224A
C                                                                        225A
      32 DAMTSI=0.0                                                      226A
         DEEPET=DEPTH-DDZ                                                227A
         JPOSTM=0                                                        228A
         JSKIPM=0                                                        229A
         JSICNM=0                                                        230A
         WLOSS=0.0                                                       231A
         RO=0.0                                                          232A
         RVOL=0.0                                                        233A
         DVOL=0.0                                                        234A
         PUMPV=0.0                                                       235A
         DELTWK=0.0                                                      236A
         AMRAIN=0.0                                                      237A
         STOR1=STOR                                                      238A
         STOR2=STOR                                                      239A
         AVOL1=AVOL                                                      240A
         HSEW=0.0                                                        241A
C                                                                        242A
C     FIND HOURLY RAINFALL VALUES FOR NEW DAY                           243A
C                                                                        244A
         L=( DAY-1) *24                                                  245A
         DO 35  I=1,24                                                   246A
         K=L+I                                                           247A
         R( I) =HOURLY( K)                                               248A
         AMRAIN=AMRAIN+R( I)                                             249A
         ACCR( I) =AMRAIN                                                250A
      35 CONTINUE                                                        251A
C                                                                        252A
C  CHECK IF SURFACE IRRIGATION IS PREPLANNED ON THAT DAY               253A
         IF( IRRDAY.EQ. FDAYSI.OR. IRRDAY.EQ. NDAYSI) CALL SURIRR        254A
C                                                                        255A
C  FIND WATER CONTENT AND HEAD DISTRIBUTION                            256A
         CALL WET( WETZ)                                                 257A
C                                                                        258A
         PET=ET( DAY)                                                    259A
```

```
C   GET POTENTIAL DAILY EVAPOTRANSPIRATION FOR NEW DAY - DISTRIBUTES PET TO   260A
C   HOURLY VALUES                                                              261A
C                                                                             262A
      CALL EVAP(AET,HET,HPET1,TPET)                                           263A
C                                                                             264A
      DO 40 I=1,24                                                            265A
      IF(R(I).GT.0.0)GO TO 45                                                 266A
   40 CONTINUE                                                                267A
      IRAIN=24                                                                268A
      IF(STOR.GT.0.001)GO TO 50                                              269A
      GO TO 130                                                               270A
C                                                                             271A
C IF IT RAINS OR IF PREVIOUS SURFACE STORAGE, FIND HOURLY INFILTRATION       272A
C BY USING THREE MINUTE TIME INCREMENT                                        273A
C                                                                             274A
C !-----------------------------------------------------------------------!  275A
C !                   END OF SECTION 4                                     !  276A
C !-----------------------------------------------------------------------   277A
C                                                                             278A
C ****************************************************************************  279A
C *                        SECTION 5                                       *  280A
C * DETERMINES INFILTRATION AND CONDUCTS WATER BALANCE CALCULATIONS ON AN  *  281A
C * HOURLY BASIS.   ACCUMULATE TOTALS SO AT END OF SECTION 5 HAVE ESTIMATED* 282A
C * ALL PARAMETERS FOR THE DAY.                                            *  283A
C ****************************************************************************  284A
C *          SECTION 5A - INFILTRATION CALCULATION                         *  285A
C ****************************************************************************  286A
C                                                                             287A
   45 IRAIN=I                                                                 288A
   50 DT=1.0                                                                  289A
      DDT=0.05                                                                290A
      DTTDT=DT-0.01*DDT                                                       291A
C                                                                             292A
      RDT=23-LRAIN+IRAIN                                                      293A
      F(1)=0.001                                                             294A
      IF(RDT.LT.2.5)F(1)=F(LRAIN)                                            295A
      IF(STOR.GT.0.01)F(1)=F(24)                                            296A
      IF(DTWT.LT.0.001) F(1)=0.0                                             297A
      IF(F(1).LT.0.001)F(1)=0.001                                           298A
      YESF=F(1)                                                              299A
      LRAIN=1                                                                 300A
C                                                                             301A
      DO 55 I=1,24                                                            302A
      RVOL=RVOL+R(I)                                                         303A
      IF(R(I).GT.0.0001)LRAIN=I                                             304A
   55 CONTINUE                                                               305A
C                                                                             306A
      J=1                                                                    307A
      IF(F(J).LT.0.01)CALL SOAK                                             308A
      IF((DAYSTR.GE.2).AND.(DTWT.GT.0.0)) CALL SOAK                         309A
C DETERMINES INFILTRATION CONSTANTS FOR SMALL INITIAL INFILTRATION          310A
C                                                                             311A
   60 CALL DRAINS(DTWT,DFLUX)                                               312A
      IF(AVOL1.LE.0.01)A=0.0                                                313A
      IF((A.LT.0.00001).AND.(DTWT.GT.0.10)) CALL SOAK                      314A
      IF(A.EQ.0.0)B=HET(J)+DFLUX                                           315A
      IF((A.LE.0.000001).AND.(B.LT.0.0))B=0.0                              316A
      FRATE(J)=A/F(J)+B                                                     317A
      IF(STOR.GT.0.0)GO TO 65                                              318A
      IF(FRATE(J).GT.R(J))GO TO 90                                         319A
C                                                                             320A
   65 RAT1=FRATE(J)                                                         321A
   70 SUM=0.0                                                               322A
      F1=F(J)                                                               323A
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```
C                                                                        324A
   75 DF=RAT1*DDT                                                        325A
      F2=F1+DF                                                           326A
      RAT2=A/F2+B                                                        327A
      IF(STOR.GT.0.0)GO TO 80                                            328A
      IF(RAT2.GT.R(J))RAT2=R(J)                                          329A
   80 DF=0.5*(RAT1+RAT2)*DDT                                             330A
      SPR=STOR+R(J)*DDT                                                  331A
      IF(DF.GT.SPR)DF=SPR                                                332A
      F1=F1+DF                                                           333A
      SUM=SUM+DDT                                                        334A
      RAT1=A/F1+B                                                        335A
      IF(STOR.GT.0.0)GO TO 85                                            336A
      IF(RAT1.GT.R(J))RAT1=R(J)                                          337A
   85 STOR=STOR+R(J)*DDT-DF                                              338A
      IF(STOR.GT.STMAX)STOR=STMAX                                        339A
      IF(SUM.GE.DTMDT)GO TO 100                                          340A
      GO TO 75                                                           341A
C                                                                        342A
   90 F1=F(J)+R(J)*DT                                                    343A
      RAT1=A/F1+B                                                        344A
      IF(RAT1.GT.R(J))GO TO 95                                           345A
      RAT1=R(J)                                                          346A
      GO TO 70                                                           347A
C                                                                        348A
   95 RAT1=R(J)                                                          349A
  100 F(J)=F1                                                            350A
      DVOL1=DFLUX*DT                                                     351A
      DVOL=DVOL+DVOL1                                                    352A
      IF(DVOL1.LT.0.0)PUMPV=PUMPV+DVOL1                                  353A
      IF(J.EQ.1)GO TO 105                                                354A
      FVOL=F(J)-F(J-1)                                                   355A
      GO TO 110                                                          356A
C                                                                        357A
C ***************************************************************** 358A
C * SECTION 5B - WATER BALANCE CALCULATION FOR ONE HOUR INTERVAL  * 359A
C ***************************************************************** 360A
C                                                                        361A
C REEVALUATION OF WETZ,DDZ ETC                                           362A
  105 FVOL=F(1)-YESF                                                     363A
  110 WETZ=DTWT-DDZ                                                      364A
      IF(INDET.GT.0) GO TO 117                                           365A
      IF(WETZ.GT.CRITD)GO TO 115                                         366A
      IF(DEBT.GT.0.01)GO TO 115                                          367A
      TVOL=FVOL-HET(J)-DVOL1                                             368A
      AVOL1=AVOL1-TVOL                                                   369A
      GO TO 120                                                          370A
  115 AVOL1=AVOL1+DVOL1                                                  371A
      DEBT=DEBT+HET(J)-FVOL                                              372A
      IF(DEBT.GT.0.0)GO TO 120                                           373A
      AVOL1=AVOL1+DEBT                                                   374A
      DEBT=0.0                                                           375A
      GO TO 120                                                          376A
  117 CONTINUE                                                           377A
      CALL ETFLUX(AVOL1,DEBT,FVOL,DVOL1,UPVOL,HPET1(J),HET(J),PDEBT)     378A
  120 DDZ=DEBT/(WATER(1)-WP)                                             379A
      IF(AVOL1.GT.0.001)GO TO 125                                        380A
      STOR=STOR-AVOL1                                                    381A
      IF(STOR.GT.STMAX)STOR=STMAX                                        382A
      F(J)=F(J)+AVOL1                                                    383A
      FVOL=FVOL+AVOL1                                                    384A
      AVOL1=0.0                                                          385A
  125 IAVOL=10.*AVOL1+1.0                                                386A
      AV=10.*AVOL1+1.0                                                   387A
      XV=IAVOL                                                           388A
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      WETZ=WTD(IAVOL)+(AV-XV)*(WTD(IAVOL+1)-WTD(IAVOL))         389A
      IWET=WETZ+1.                                              390A
      UPQ=UPFLUX(IWET)                                          391A
      IF(WETZ.GT.DEEPET)UPQ=0.0                                 392A
      UPVOL=UPQ*DT                                              393A
      DTWT=WETZ+DDZ                                             394A
      TAV1=AVOL1+DEBT                                           395A
      DSTOR=STOR-STOR2                                          396A
      STOR2=STOR                                                397A
      RO=R(J)-FVOL-DSTOR                                        398A
      CALL YDITCH(DWIER(MO),DVOL1,YD,RO,WLO,DITCHB,DITCHS)      399A
      IF(INWIER.GT. 0.0)YD=DDRAIN-DWIER(MO)                     400A
      HDRAIN=DEPTH-DDRAIN+YD                                    401A
      WLOSS=WLOSS+WLO                                           402A
      IF(DTWT.LT.SEWX)HSEW=HSEW+SEWX-DTWT                       403A
C         THE FOLLOWING STATEMENTS DETERMINE IF THIS HOUR IS COUNTED    404A
C         AS AN HOUR IN WHICH FIELD WORK CAN BE DONE            405A
      DWRKDY=0.0                                                406A
      IF((JDAY .GE. BWKDY1) .AND. (JDAY .LE. EWKDY1))           407A
     *  CALL WORK(1,J,TAV1,DWRKDY,ACCR(J),DDAY,YTAV)            408A
      IF((JDAY .GE. BWKDY2) .AND. (JDAY .LE. EWKDY2))           409A
     *  CALL WORK(2,J,TAV1,DWRKDY,ACCR(J),DDAY,YTAV)            410A
      IF(R(J) .LT. 0.01) DDAY=DDAY+1./24.                       411A
      DELTWK=DELTWK+DWRKDY                                      412A
      J=J+1                                                     413A
      IF(J.GT.24)GO TO 155                                      414A
      F(J)=F(J-1)                                               415A
      IF(F(J).LT.0.001)F(J)=0.001                               416A
      GO TO 60                                                  417A
C                                                               418A
C     WHEN CALCULATIONS HAVE BEEN MADE FOR HOUR, J=24, GO TO SECTION 7    419A
C |----------------------------------------------------------------|   420A
C |                  END OF SECTION 5                          |   421A
C |----------------------------------------------------------------|   422A
C                                                               423A
C ***********************************************************************   424A
C *                          SECTION 6                        *   425A
C * WATER BALANCE CALCULATION WHEN HAVE NO RAIN OR SURFACE IRRIGATION  *   426A
C * DURING THE DAY OR SURFACE STORAGE AT THE BEGINING OF THE DAY.  *   427A
C * THE WATER BALANCE CALCULATION IS BASED ON A 1 DAY TIME INTERVAL IF  *   428A
C * DRAINAGE FLUX AT BEGINING OF DAY IS LESS THAN .02 CM./DAY AND ON A  *   429A
C * 2 HR.  INTERVAL IF DFLUX IS GREATER THAN THAT VALUE.      *   430A
C ***********************************************************************   431A
  130 HOUR=0                                                    432A
      YESF=0.0                                                  433A
      FVOL=0.0                                                  434A
      DO 135 I=1,24                                             435A
      F(I)=0.0                                                  436A
      FRATE(I)=0.0                                              437A
  135 CONTINUE                                                  438A
C                                                               439A
      CALL DRAINS(DTWT,DFLUX)                                   440A
      DVOL1=24.*DFLUX                                           441A
C       IF INDET>0 USE SUBROUTINE ETFLUX TO ESTIMATE AET        442A
C       THEN CAN GET GOOD ESTIMATE OF DVOL                      443A
      UPVOL=UPQ*24.0                                            444A
      IF(INDET.LE.0) GO TO 137                                  445A
      CALL ETFLUX (AVOL1,DEBT,FVOL,DVOL1,UPVOL,TPET,AET,PDEBT)   446A
      AVOL1=AVOL                                                447A
      DDZ=DEBT*ROOTD/PDEBT                                      448A
  137 CONTINUE                                                  449A
C CHECK FOR DRAINAGE VOLUME. FOR SMALL VOLUME, TAKE 24 HOUR INCREMENT   450A
C AND FOR LARGE VOLUME TAKE 2 HOURLY INCREMENT                  451A
      IF(ABS(DVOL1).LE.0.02)GO TO 145                           452A
      AVOL1=AVOL                                                453A
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      AET=AET/12.                                                      454A
      H2PET=TPET/12.                                                   455A
C                                                                      456A
  140 HOUR=HOUR+2                                                      457A
      UPVOL1=UPQ*2.0                                                   458A
      DVOL1=2.0*DFLUX                                                  459A
  145 CONTINUE                                                         460A
      IF(INDET.LE.0) GO TO 147                                         461A
      IF(HOUR.EQ.0) GO TO 147                                          462A
      CALL ETFLUX(AVOL1,DEBT,FVOL,DVOL1,UPVOL1,H2PET,AET,PDEBT)        463A
      IF(AVOL1.LT.0.0) AVOL1=0.0                                       464A
      GO TO 148                                                        465A
  147 TVOL=FVOL-AET-DVOL1                                              466A
      AVOL1=AVOL1-TVOL                                                 467A
      IF(AVOL1.LT.0.0)AVOL1=0.0                                        468A
      IF(WETZ.GT.CRITD)AVOL1=AVOL1+DVOL1                               469A
  148 IAVOL=10.*AVOL1+1.0                                              470A
      AV=10.*AVOL1+1.0                                                 471A
      XV=IAVOL                                                         472A
      WETZ=WTD(IAVOL)+(AV-XV)*(WTD(IAVOL+1)-WTD(IAVOL))                473A
      IWET=WETZ+1.                                                     474A
      UPQ=UPFLUX(IWET)                                                 475A
      DDZ=DEBT*ROOTD/PDEBT                                             476A
      DTWT=WETZ+DDZ                                                    477A
      IF(WETZ.GT.DEEPET)UPQ=0.0                                        478A
      CALL YDITCH(DWIER(MO),DVOL1,YD,RO,WLO,DITCHB,DITCHS)             479A
      IF(INWIER.GT.0.0)YD=DDRAIN-DWIER(MO)                            480A
      HDRAIN=DEPTH-DDRAIN+YD                                           481A
      WLOSS=WLOSS+WLO                                                  482A
      DVOL=DVOL+DVOL1                                                  483A
      CALL DRAINS(DTWT,DFLUX)                                          484A
      IF(DTWT.LT.SEWX)HSEW=HSEW+2.0*(SEWX-DTWT)                        485A
      IF(HOUR.GE.24)AET=AET*12.0                                       486A
      IF(HOUR.GE.24)GO TO 155                                          487A
      IF(HOUR.EQ.0)GO TO 150                                           488A
      GO TO 140                                                        489A
C                                                                      490A
  150 DVOL2=24.*DFLUX                                                  491A
      HSEW=12.0*HSEW                                                   492A
      DVOL=0.5*(DVOL1+DVOL2)                                           493A
      IF(DVOL.LT.0.0) PUMPV=DVOL                                       494A
      CALL YDITCH(DWIER(MO),DVOL,YD,RO,WLO,DITCHB,DITCHS)              495A
      IF(INWIER.GT.0.0)YD=DDRAIN-DWIER(MO)                            496A
      HDRAIN=DEPTH-DDRAIN+YD                                           497A
C                                                                      498A
C |-------------------------------------------------------------------| 499A
C |                  END OF SECTION 6                                  | 500A
C |-------------------------------------------------------------------| 501A
C                                                                      502A
C ********************************************************************* 503A
C *                        SECTION 7                                 * 504A
C * REEVALUATION OF WATER TABLE DEPTH, DRY ZONE DEPTH, WET ZONE DEPTH, AIR* 505A
C * VOLUMES, AND RUNOFF AT END OF DAY.  ALSO UPDATE SOME VARIABLES TO BE * 506A
C * USED DURING NEXT DAY SUCH AS UPQ.                                * 507A
C ********************************************************************* 508A
  155 FVOL=F(24)-YESF                                                  509A
      DEBT=YDEBT                                                       510A
      UPVOL=0.5*(24.0*UPQ+UPVOL)                                       511A
      IF(INDET.LE.0)GO TO 157                                          512A
      CALL ETFLUX(AVOL,DEBT,FVOL,DVOL,UPVOL,TPET ,AET,PDEBT)          513A
      GO TO 165                                                        514A
C                                                                      515A
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C ******************************************************************* 516A
C * THE FOLLOWING SECTION (TO STATEMENT NO.165) USES THE CRITICAL DEPTH * 517A
C * (CRITD) CONCEPT TO ESTIMATE WHEN UPWARD MOVEMENT OF WATER FROM WATER * 518A
C ******************************************************************* 519A
  157 CONTINUE                                                       520A
C * TABLE IS LIMITED.                                               * 521A
      WETZ=DTWT-DDZ                                                   522A
      IF(WETZ.GE.CRITD)GO TO 160                                     523A
      IF(DEBT.GT.0.01)GO TO 160                                      524A
      TVOL=FVOL-AET-DVOL                                             525A
      AVOL=AVOL-TVOL                                                 526A
      GO TO 165                                                      527A
C                                                                    528A
  160 AVOL=AVOL+DVOL                                                 529A
      DEBT=DEBT+AET-FVOL                                             530A
      IF(DEBT.GT.0.0)GO TO 161                                       531A
      AVOL=AVOL+DEBT                                                 532A
      DEBT=0.0                                                       533A
      GO TO 165                                                      534A
  161 TAV=AVOL+DEBT                                                  535A
      IF(WETZ.GT.CRITD1)GO TO 165                                    536A
      AVOL=CRITAV                                                    537A
      DEBT=TAV-AVOL                                                  538A
C THE NEXT ARE NEEDED WHEN HOURLY WETZ<CRITD BUT DEBT>0             539A
      IF(DEBT.GE.0.)GO TO 165                                        540A
      AVOL=AVOL+DEBT                                                 541A
      DEBT=0.                                                        542A
C                                                                    543A
  165 DDZ=DEBT/(WATER(1)-WP)                                         544A
  166 DSTOR=STOR-STOR1                                               545A
      RO=RVOL-DSTOR-FVOL                                             546A
      IF(AVOL.LT.0.0)AVOL=0.0                                        547A
      AV=10.*AVOL+1                                                  548A
      IAVOL=AV                                                       549A
      XV=IAVOL                                                       550A
      WETZ=WTD(IAVOL)+((AV-XV)*(WTD(IAVOL+1)-WTD(IAVOL)))           551A
      IWET=WETZ+1.                                                   552A
      UPQ=UPFLUX(IWET)                                               553A
      DTWT=WETZ+DDZ                                                  554A
      IF(WETZ.GT.DEEPET)UPQ=0.0                                      555A
      TAV=AVOL+DEBT                                                  556A
      TAV1=TAV                                                       557A
      TV=10*TAV+1                                                    558A
      ITAV=TV                                                        559A
      EDTWT=WTD(ITAV)                                                560A
      YDEBT=DEBT                                                     561A
      SEWD=0.0                                                       562A
C                                                                    563A
C |-------------------------------------------------------------| 564A
C |                    END OF SECTION 7                          | 565A
C |-------------------------------------------------------------| 566A
C                                                                    567A
C ******************************************************************* 568A
C *                      SECTION 8                                * 569A
C * DETERMINATION OF PLANT GROWTH AND TRAFFICABILITY PARAMETERS, OUTPUT * 570A
C * OF DAILY SUMMARIES IF DESIRED, AND MONTHLY SUMMARY CACULATIONS. * 571A
C ******************************************************************* 572A
      IF((MO.LT.ISEWMS).OR.(MO.GT.ISEWME))GO TO 169                 573A
      IF((MO.EQ.ISEWMS).AND.(DAY.LT.ISEWDS))GO TO 169               574A
      IF((MO.EQ.ISEWME).AND.(DAY.GT.ISEWDE))GO TO 169               575A
      IF(DTWT.GT.SEWX)GO TO 168                                     576A
      SEWD=SEWX-DTWT                                                 577A
  168 CONTINUE                                                       578A
      IF(HSEW.GT.0.01)SEWD=HSEW/24.0                                579A
  169 CONTINUE                                                       580A
```

```
C                                                                        581A
C                                                                        582A
C                                                                        583A
C                                                                        584A
      IF(NOPORT.EQ.0)GO TO 175                                           585A
C                                                                        586A
      IF(DAY.NE.1)GO TO 170                                              587A
C                                                                        588A
C DAILY SUMMERIES                                                        589A
      WRITE(3,900)                                                       590A
      WRITE(3,910)IR,MO                                                  591A
      WRITE(3,920)                                                       592A
  170 WRITE(3,930)DAY,RVOL,FVOL,AET,DVOL,AVOL,TAV,DDZ,WETZ,DTWT,         593A
     $STOR,RO,WLOSS,YD,DRNSTO,SEWD,DAMTSI                                594A
C                                                                        595A
C MONTHLY CALCULATIONS                                                   596A
  175 RVOLM(MO) = RVOLM(MO)+RVOL                                         597A
      FVOLM(MO) = FVOLM(MO)+FVOL                                         598A
      ROM(MO) = ROM(MO)+RO                                               599A
      DVOLM(MO) = DVOLM(MO)+DVOL                                         600A
      PUMPVM(MO) = PUMPVM(MO)+PUMPV                                      601A
      TWLOSS(MO) = TWLOSS(MO)+WLOSS                                      602A
      SUMAET(MO) = SUMAET(MO)+AET                                        603A
      SIRRMO(MO) = SIRRMO(MO)+DAMTSI                                     604A
      ISICNM(MO) = ISICNM(MO)+JSICNM                                     605A
      ISKIPM(MO) = ISKIPM(MO)+JSKIPM                                     606A
      IPOSTM(MO) = IPOSTM(MO)+JPOSTM                                     607A
      SEWM(MO) = SEWM(MO)+SEWD                                           608A
      IF(DDZ.GE.(ROOTD-1.0)) GO TO 172                                   609A
      IF(RVOL .GT. 0.005) GO TO 176                                      610A
      GO TO 173                                                          A610A
  172 IF((MO.LT.IDRYMS).OR.(MO.GT.IDRYME)) GO TO 173                     B610A
      IF((MO.EQ.IDRYMS).AND.(DAY.LT.IDRYDS)) GO TO 173                   C610A
      IF((MO.EQ.IDRYME).AND.(DAY.GT.IDRYDE)) GO TO 173                   D610A
      DRYDAY(MO)=DRYDAY(MO)+1.0                                          E610A
  173 CONTINUE                                                           F610A
      DELTWK=0.0                                                         611A
      IF((JDAY .GE. BWKDY1) .AND. (JDAY .LE. EWKDY1))                    612A
     *   CALL WORK(1.-1,TAV,DELTWK,0.0,DDAY,YTAV)                        613A
      IF((JDAY .GE. BWKDY2) .AND. (JDAY .LE. EWKDY2))                    614A
     *   CALL WORK(2.-1,TAV,DELTWK,0.0,DDAY,YTAV)                        615A
      DDAY=DDAY+1                                                        616A
  176 WRKDAY(MO)=WRKDAY(MO)+DELTWK                                       617A
      IF(TAV.LT.AMINC) WATDAY(MO)=WATDAY(MO)+1.                          618A
C                                                                        619A
      IF(DAY.GE.DAYM(MO))GO TO 180                                       620A
      YTAV=TAV                                                           621A
      GO TO 30                                                           622A
C                                                                        623A
C                                                                        624A
C  IF PREVIOUS DAY WAS LAST DAY OF MONTH GO TO SECTION 9;  OTHERWISE     625A
C  RETURN TO SECTION 4                                                   626A
C |-------------------------------------------------------------------|  627A
C |                    END OF SECTION 8                             |  628A
C |-------------------------------------------------------------------|  629A
C                                                                        630A
C **********************************************************************  631A
C *                          SECTION 9                               *  632A
C * IF MONTH JUST COMPLETED WAS LESS THAN 12, RETURNS TO MAIN PROGRAM FOR * 633A
C * NEW SET OF RAINFALL AND ET DATA.   IF MONTH=12, THIS SECTION PRINTS OUT* 634A
C * MONTHLY SUMMARIES, COMPUTES YEARLY SUMMARIES, PRINTS, AND DETERMINES * 635A
C * AVERAGES OVER PREVIOUS YEARS OF SIMULATION.                      *  636A
C **********************************************************************  637A
  180 DAYMT=DAYM(MO)                                                     638A
      WETDAY(MO)=DAYMT-WRKDAY(MO)                                        639A
      IF(MO.LT.12)RETURN
```

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      IF(NMONTH.NE.0) GO TO 181                                      A639A
C                                                                     640A
C MONTHLY SUMMARIES                                                   641A
      WRITE(3,940)IR                                                  642A
      WRITE(3,950)                                                    643A
      WRITE(3,960)(MO,RVOLM(MO),FVOLM(MO),ROM(MO),DVOLM(MO),SUMAET(MO),   644A
     2DRYDAY(MO),WRKDAY(MO),WATDAY(MO),TWLOSS(MO),SEWM(MO),SIRRMO(MO),    645A
     $ISICNM(MO),PUMPVM(MO),IPOSTM(MO),MO=1,12)                      646A
C                                                                     647A
  181 CONTINUE                                                        A647A
      YEARS=IR-IRFST+1                                                648A
      IYEAR=YEARS                                                     649A
      IRY(IYEAR)=IR                                                   650A
      TOSIRR(IYEAR)=AMTSI*ISICNT*(IHREND-IHRSTA)                      651A
C                                                                     652A
      DO 185 I=1,12                                                   653A
      TOTR=TOTR+RVOLM(I)                                              654A
      YSUMET=YSUMET+SUMAET(I)                                         655A
      TOTF=TOTF+FVOLM(I)                                              656A
      TOTRO=TOTRO+ROM(I)                                             657A
      TOTD=TOTD+DVOLM(I)                                              658A
      TPUMPV=TPUMPV+PUMPVM(I)                                         659A
      TOTDD(IYEAR)=TOTDD(IYEAR)+DRYDAY(I)                             660A
      TOTNT=TOTNT+WETDAY(I)                                           661A
      TOTWD(IYEAR)=TOTWD(IYEAR)+WRKDAY(I)                             662A
      TOTFD=TOTFD+WATDAY(I)                                           663A
      TOTWF=TOTWF+TWLOSS(I)                                           664A
      SEW(IYEAR)=SEW(IYEAR)+SEWM(I)                                   665A
      WETDAY(I)=0.0                                                   666A
      WRKDAY(I)=0.0                                                   667A
      DRYDAY(I )=0.0                                                  668A
      PUMPVM(I)=0.0                                                   669A
      RVOLM(I)=0.0                                                    670A
      FVOLM(I)=0.0                                                    671A
      ROM(I)=0.0                                                      672A
      WATDAY(I)=0.                                                    673A
      TWLOSS(I)=0.                                                    674A
      DVOLM(I)=0.0                                                    675A
      SIRRMO(I)=0.0                                                   676A
      SUMAET(I)=0.0                                                   677A
      ISICNM(I)=0                                                     678A
      ISKIPM(I)=0                                                     679A
      SEWM(I)=0.0                                                     680A
      IPOSTM(I)=0                                                     681A
  185 CONTINUE                                                        682A
C                                                                     683A
C YEARLY SUMMARIES                                                    684A
      WRITE(3,990)TOTR,TOTF,TOTRO,TOTD,YSUMET,TOTDD(IYEAR),TOTWD(IYEAR),   685A
     $TOTFD,TOTWF,SEW(IYEAR),TOSIRR(IYEAR),TPUMPV                    686A
C                                                                     687A
C REINITIALIZATION                                                    688A
      TOTR=0.                                                         689A
      TOTF=0.                                                         690A
      TOTRO=0.                                                        691A
      YSUMET=0.0                                                      692A
      TOTD=0.                                                         693A
      TPUMPV=0.0                                                      694A
      TOTNT=0.                                                        695A
      TOTFD=0.                                                        696A
      TOTWF=0.                                                        697A
      ISKIP=0                                                         698A
      IPOST=0                                                         699A
      JDAY=0                                                          700A
      IK=0                                                            701A
      ISICNT=0                                                        702A
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      IRRDAY=0                                                          703A
      NDAYSI=FDAYSI                                                     704A
      NOIRR1=NR1                                                        705A
      NOIRR2=NR2                                                        706A
C                                                                       707A
      IF(IR.EQ.IEDYR) CALL ORDER(IYEAR)                                 708A
C                                                                       709A
  600 FORMAT(8I10)                                                      710A
  610 FORMAT(3F10.5)                                                    711A
  620 FORMAT(7E10.2)                                                    712A
  625 FORMAT(10F5.2)                                                    713A
  630 FORMAT(F10.2,2I5)                                                 714A
  640 FORMAT(12(F2.0,F3.0))                                            715A
  645 FORMAT(2I3,2I2,3F10.2)                                            716A
  650 FORMAT(6E10.2)                                                    717A
  660 FORMAT(20F4.1)                                                    718A
  670 FORMAT(4I2,2X,F10.2)                                              719A
C                                                                       720A
  790 FORMAT(1H1/1X,'INPUT PARAMETER VALUES USED IN THIS SIMULATION'/)  721A
  800 FORMAT(/1X,'DEPTH TO DRAIN=',F5.1,'CM'/1X,'DEPTH FROM DRAIN TO    722A
     $IMPERMEABLE LAYER=',F5.1,'CM'/1X,'DISTANCE BETWEEN DRAINS =',F7.1,723A
     $'CM'                                                              724A
     $/1X,'MAXIMUM DEPTH OF SURFACE PONDING =',F5.2,'CM'/1X,'DEPTH IMPER725A
     $MEABLE LAYER=',F6.1,'CM'/1X,'NUMBER OF DEPTH INCREMENTS=',F5.0)    726A
  810 FORMAT(1X,'MINIMUM AIR VOL REQUIRED FOR TILLAGE OPERATIONS=',F5.2, 727A
     $'CM'/1X,'MINIMUM AIR VOL REQUIRED WITHOUT PLANT DAMAGE=',F5.2,'CM' 728A
     $/1X,'MINIMUM DAILY RAINFALL TO STOP FIELD OPERATIONS =',F5.2,'CM'/ 729A
     $1X,'MINIMUM TIME AFTER RAIN BEFORE CAN TILL=',F5.0,'DAYS')         730A
  820 FORMAT (1X,'ROOTING DEPTH = ',F5.1,'CM'/1X,'CRITICAL DEPTH WET ZON 731A
     $E=',F5.1,'CM'/1X,'WILTING POINT=',F5.2/1X, 'INITIAL WATER TABLE DE 732A
     $PTH =',F5.1/1X,'WIDTH OF DITCH BOTTOM=',F5.1,                      733A
     $      'CM'/1X,'SIDE SLOPES OF DITCH=',F5.1,':1')                   734A
  822 FORMAT(///8X,'DEPTH',9X,'SATURATED HYDRAULIC CONDUCTIVITY'/)       735A
  828 FORMAT(3X,F7.2,' - ',F7.2,12X,F11.5)                              736A
  830 FORMAT(1X//5X,'DEPTHS OF WIERS FROM THE SURFACE'//1X,'DATE',9X,'1/ 737A
     $',F3.0,3X,'2/',F3.0,3X,'3/',F3.0,3X,'4/',F3.0,3X,'5/',F3.0,3X,'6/' 738A
     $,F3.0,3X,'7/',F3.0,3X,'8/',F3.0,3X,'9/',F3.0,3X,'10/',F3.0,2X,'11/ 739A
     $',F3.0,2X,'12/',F3.0)                                             740A
  835 FORMAT(//1X,'INDICATER FOR DAILY SUMMERY=',I5)                     741A
  840 FORMAT(1X,'WIER DEPTH',12F8.1)                                     742A
  850 FORMAT(1X,'FIRST DAY OF SURFACE IRRIGATION=',I2/1X,                743A
     $' INTERVAL BETWEEN SURFACE IRRIGATION DAYS=',I2/1X,                744A
     $'STARTING HOUR OF SURFACE IRRIGATION=',I3/1X,                      745A
     $'ENDING HOUR OF SURFACE IRRIGATION=',I3/1X,                        746A
     $'NO SURFACE IRRIGATION INTERVAL 1=',I4,2X,I4/1X,                   747A
     $'NO SURFACE IRRIGATION INTERVAL 2=',I4,2X,I4)                      748A
  860 FORMAT(1X,'MINIMUM AIR REQUIRED TO HAVE SURFACE IRRIGATION=',      749A
     $F6.2,'CM'/1X,'AMOUNT OF RAIN TO POSTPONE SURFACE IRRIGATION=',     750A
     $F6.2,'CM'/1X,'SURFACE IRRIGATION FOR ONE HOUR=',F6.2,'CM')         751A
  870 FORMAT(1X,'INDET=',I2,'WHEN INDET.GT. 0 USE READ IN VALUES TO DETE 752A
     2RMINE ET WHEN LIMITED BY SOIL CONDITIONS')                        753A
  900 FORMAT(1H1)                                                        754A
  910 FORMAT(2I10)                                                       755A
  920 FORMAT(//2X,'DAY',3X,'RAIN',3X,'INFIL',6X,'ET',4X,'DRAIN',2X,      756A
     $'AIR VOL',3X,'TVOL',4X,'DDZ',4X,'WETZ',3X,'DTWT',4X,'STOR',        757A
     $1X,'RUNOFF',2X,'WLOSS',3X,'YD',3X,'DRNSTO',2X,'SEW',2X,'DMTSI')    758A
  930 FORMAT(2X,I3,8F8.2 ,8F7.2)                                         759A
  940 FORMAT(1H1,15X,'MONTHLY VOLUMES IN CENTIMETERS FOR YEAR',I6)       760A
  950 FORMAT( 2X,'MONTH',1X,'RAINFALL',1X,'INFILTRATION',1X,'RUNOFF',1X, 761A
     $'DRAINAGE',1X,'   ET   ','DRY DAYS ','  WRK DAYS',1X,'FLOOD D       762A
     $AYS',1X ,'WATER LOSS',4X,'SEW',3X,'MIR',4X,'MCN',1X,'PUMP',2X,'MPT 763A
     3')                                                                 764A
  960 FORMAT(1X,I3,F10.2,F11.2,F10.2,F8.2,F10.2,2F8.2,F11.2,F11.2,F10.2, 765A
     23X,F5.2,I4,F7.3,I4)                                               766A
  990 FORMAT(1H0/1X,'TOTALS',8F9.2,4X,4F9.2)                            767A
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C                                                                              768A
      RETURN                                                                   769A
      END                                                                      770A
C                                                                              771A
C  |------------------------------------------------------------------------|  772A
C  |                        END OF SECTION 9                                 |  773A
C  |                        END OF FORSUB                                    |  774A
C  | RETURN TO MAIN FOR NEW SET OF DATA TO START SIMULATION FOR FIRST MONTH|  775A
C  | OF THE NEXT YEAR.                                                       |  776A
C  |------------------------------------------------------------------------|  777A
C                                                                              778A
C ******************************************************************************  779A
C *                DEFINITION OF TERMS IN SUBROUTINE FORSUB                   *  780A
C *                                                                          *  781A
C *A.  INPUTS TO SUBROUTINE LISTED IN ORDER OF INPUT                         *  782A
C *                                                                          *  783A
C *    FDAYSI: FIRST DAY OF WASTE WATER IRRIGATION (JULIAN DATE).            *  784A
C *    INTDAY: INTERVAL BETWEEN IRRIGATION (DAYS).                           *  785A
C *    IHRSTA: HOUR IRRIGATION STARTS.                                       *  786A
C *    IHREND: HOUR IRRIGATION ENDS.                                         *  787A
C *    NOIRR1: BEGINNING JULIAN DATE OF FIRST NO IRRIGATION INTERVAL.        *  788A
C *    NOIRR2: ENDING JULIAN DATE OF FIRST NO IRRIGATION INTERVAL.           *  789A
C *    NOIRR3: BEGINNING JULIAN DATE OF SECOND NO IRRIGATION INTERVAL.       *  790A
C *    NOIRR4: ENDING JULIAN DATE OF SECOND NO IRRIGATION INTERVAL.          *  791A
C *    REQDAR: AMOUNT OF DRAINED VOLUME OR AIR VOLUME, CM., BEFORE IRRI-     *  792A
C *            GATION OF WASTE WATER IS ALLOWED.                             *  793A
C *    AMTRN : AMOUNT OF RAINFALL REQUIRED TO POSTPONE IRRIGATION TO NEXT    *  794A
C *            DAY.  RAINFALL MUST OCCUR ON FIRST HOUR OF SCHEDULED IRRI-    *  795A
C *            GATION.                                                       *  796A
C *    AMTSI : RATE OF IRRIGATION OF WASTE WATER, CM/HR.                     *  797A
C *    DDRAIN: DEPTH OF DRAIN, CM.                                           *  798A
C *    HDRAIN: EQUIVALENT DEPTH FROM WATER SURFACE IN DRAIN TO IMPERMEABLE   *  799A
C *            LAYER, CM.                                                    *  800A
C *    SDRAIN: DISTANCE BETWEEN TWO DRAINS, CM.                              *  801A
C *    STMAX : MAXIMUM OR AVAILABLE SURFACE DEPRESSION STORAGE, CM.          *  802A
C *    DEPTH : EFFECTIVE DEPTH TO IMPERMEABLE LAYER FROM SOIL SURFACE,CM.    *  803A
C *            EFFECTIVE DEPTH MAY BE SMALLER THAN ACTUAL DEPTH TO ACCOUNT   *  804A
C *            FOR CONVERGENCE NEAR DRAIN TUBES.                             *  805A
C *    XNI   : NUMBER OF DEPTH INCREMENTS.                                   *  806A
C *    DZ(I) : DEPTH TO BOTTOM OF PROFILE LAYER I.                           *  807A
C *    CONK  : LATERAL HYDRAULIC CONDUCTIVITY, CM/HR, OF A PROFILE LAYER.    *  808A
C *            E.G. CONK(2) IS CONDUCTIVITY OF LAYER FROM DZ(1) TO DZ(2).    *  809A
C *    AMINC : MINIMUM AIR VOLUME IN PROFILE IN ORDER NOT TO HAVE CROP       *  810A
C *            DAMAGED, CM.                                                  *  811A
C *    NOPORT: AN INDICATOR TO CONTROL PRINTOUT:                            *  812A
C *            NOPORT = 0 - MONTHLY SUMMARIES                               *  813A
C *            NOPORT .GT. 0 - DAILY SUMMARIES                             *  814A
C *    NMONTH: AN INDICATOR TO CONTROL PRINOUT:                            *A814A
C *            NMONTH = 0 - MONTHLY SUMMARIES                              *B814A
C *            NMONTH .NE. 0 - NO MONTHLY SUMMARIES                        *C814A
C *    DACHNG: THE DAY IN A MONTH WHEN THE WEIR DEPTH IS CHANGED TO DWIER   *  815A
C *            FOR THAT MONTH, I.E., IF DACHNG(3) = 5, THEN THE WEIR DEPTH  *  816A
C *            IS CHANGED TO DWIER(3) ON 5TH DAY OF THE MONTH OF MARCH.     *  817A
C *    DWIER : WEIR DEPTH FROM SURFACE, CM., FOR GIVEN MONTH.  DWIER(2) IS  *  818A
C *            DEPTH OF WEIR IN MONTH 2 (FEB).                             *  819A
C *    BWKDY1 : BEGINNING JULIAN DAY OF FIRST WORK PERIOD.                  *  820A
C *    EWKDY1: ENDING JULAIN DATE OF FIRST WORK PERIOD.                     *  821A
C *    SWKHR1: HOUR TO START WORK DURING PERIOD 1.                         *  822A
C *    EWKHR1: HOUR TO END WORK DURING WORK PERIOD 1.                       *  823A
C *    AMINI : MINIMUM AIR VOLUME OR DRAINED VOLUME REQUIRED TO HAVE FIELD  *  824A
C *            OPERATIONS DURING WORK PERIOD 1.                            *  825A
C *    ROUTA1: RAINFALL REQUIRED TO STOP FIELD OPERATIONS DURING WORK       *  826A
C *            PERIOD 1.                                                    *  827A
C *    ROUTT1: DAYS REQUIRED TO DRAIN OR DRY FIELD SO OPERATIONS CAN CON-   *  828A
C *            TINUE DURING WORK PERIOD 1.                                  *  829A
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C *   BWKDY2: BEGINNING JULIAN DAY OF SECOND WORK PERIOD.              * 830A
C *   EWKDY2: ENDING JULIAN DAY OF SECOND WORK PERIOD.                 * 831A
C *   SWKHR2: HOUR TO START WORK DURING WORK PERIOD 2.                 * 832A
C *   EWKHR2: HOUR TO END WORK DURING WORK PERIOD 2.                   * 833A
C *   AMIN2 : MINIMUM AIR VOLUME OR DRAINED VOLUME REQUIRED TO HAVE FIELD * 834A
C *           OPERATIONS DURING WORK PERIOD 2.                         * 835A
C *   ROUTA2: RAINFALL REQUIRED TO STOP FIELD OPERATIONS DURING WORK   * 836A
C *           PERIOD 2.                                                * 837A
C *   ROUTT2: DAYS REQUIRED TO DRAIN OR DRY FIELD SO OPERATIONS CAN CON- * 838A
C *           TINUE DURING WORK PERIOD 2.                              * 839A
C *   DITCHB: BOTTOM WIDTH OF THE DITCH, CM., WHEN OPEN DITCHS USED FOR * 840A
C *           DRAINS.  EFFECTIVE WIDTH WHICH CONSIDERS STORAGE IN OUTLET * 841A
C *           WHEN DRAIN TUBES USED.                                   * 842A
C *   DITCHS: SIDE SLOPE OF THE DITCH.                                 * 843A
C *   CRITD : CRITICAL DEPTH OF WET ZONE, CM.                          * 844A
C *   WP    : WILTING POINT OR SOIL WATER CONTENT OF SURFACE LAYER AT  * 845A
C *           LOWER LIMIT OF AVAILABILITY TO PLANT.                    * 846A
C *   DTWT  : DEPTH TO WATER TABLE AT BEGINING OF SIMULATION.  NOT IN- * 847A
C *           ITIALIZED AT START OF EACH YEAR.                         * 848A
C *   ISEWMS: MONTH TO START CALCULATING SEW VALUES.  05 MEANS START CAL- * 849A
C *           CULATION IN MAY.                                         * 850A
C *   ISEWDS: DAY OF MONTH TO START CALCULATING SEW.                   * 851A
C *   ISEWME: MONTH TO END SEW CALCULATION.                            * 852A
C *   ISEWDE: DAY OF MONTH TO END SEW CALCULATION.                     * 853A
C *   SEWX  : DEPTH ON WHICH SEW CALCULATION IS BASED, CM., E.G.  SEWX=30 * 854A
C *           MEANS SEW CALCULATED AS DIFFERENCE BETWEEN WATER TABLE DEPTH* 855A
C *           DEPTH AND 30 CM.  IF W.T. = 20 CM., SEW - 30 = 10 CM DAYS * 856A
C *           FOR THAT DAY.                                            * 857A
C *   IDRYMS: MONTH TO START DRY DAY CALCULATION.  05 MEANS START      *A857A
C *           CALCULATION IN MAY.                                      *B857A
C *   IDRYDS: DAY OF MONTH TO START DRY DAY CALCULATION.               *C857A
C *   IDRYME: MONTH TO END DRY DAY CALCULATION.                        *D857A
C *   IDRYDE: DAY OF MONTH TO END DRY DAY CALCULATION.                 *E857A
C *   INDET : INDICATOR VARIABLE.  IF INDET.GT.0, VALUES FOR UPWARD FLUX * 858A
C *           VS. WATER TABLE DEPTH ARE READ IN SUB. PROP TO CALCULATE * 859A
C *           SOIL LIMITED ET.  IF INDET.LE.0, LIMITING DEPTH CONCEPT, * 860A
C *           CRITD, IS USED FOR ET.                                   * 861A
C *   INWIER: INDICATOR TO DETERMINE IF SUBIRRIGATION IS USED.  IF INWIER * 862A
C *           .GE.0, SUBIRRIGATION IS USED AND DEPTH OF WATER IN OUTLET IS* 863A
C *           MAINTAINED AT WIER ELEVATION.  IF INWIER.LE.0 HAVE CONVENT-* 864A
C *           IONAL DRAINAGE OR CONTROLLED DRAINAGE IF DWIER IS ABOVE  * 865A
C *           BOTTOM OF DRAIN.                                         * 866A
C *------------------------------------------------------------------* 867A
C *                                                                    * 868A
C *B.  OTHER PROGRAM VARIABLE IN FORSUB                                * 869A
C *   A     : CONSTANT IN GREEN-AMPT INFILTRATION EQUATION OBTAINED BY * 870A
C *           INTERPOLATION.                                           * 871A
C *   ADRYDY: SUM OF DRY DAYS FOR A GIVEN MONTH OVER ALL PAST YEARS    * 872A
C *           SIMULATED.                                               * 873A
C *   AET   : TOTAL DAILY ET.                                          * 874A
C *   AVOL  : AIR VOLUME OR DRAINED VOLUME IN WET ZONE.                * 875A
C *   AVOL1 : ANOTHER VARIABLE FOR AIR VOLUME IN WET ZONE             * 876A
C *   AWETDY: SUM OF WET DAYS FOR A GIVEN MONTH OVER ALL PAST YEARS    * 877A
C *           SIMULATED.                                               * 878A
C *   AWRKDY: SUM OF WORK DAYS FOR A GIVEN MONTH OVER ALL PAST YEARS   * 879A
C *           SIMULATED.                                               * 880A
C *   B     : CONSTANT IN GREEN-AMPT INFILTRATION EQUATION OBTAINED BY * 881A
C *           INTERPOLATION.                                           * 882A
C *   CHECK : INDEX.                                                   * 883A
C *   CONE  : EFFECTIVE LATERAL HYDRAULIC CONDUCTIVITY, CM/HR.         * 884A
C *   CRITAV: AIR OR DRAINED VOLUME CORRESPONDING TO CRITICAL DEPTH.   * 885A
C *   DAYM  : NUMBER OF DAYS A MONTH, E.G., DAYM(6) = DAYS IN JUNE = 30. * 886A
C *   DAYMT : NUMBER OF DAYS OF THE MONTH.                             * 887A
C *   DDT   : TIME INCREMENT.                                          * 888A
C *   DDZ   : DEPTH OF DRY ZONE, CM.                                   * 889A
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C *   DEBT  : THE AMOUNT OF WATER IN CM THAT HAS BEEN REMOVED FROM DRY    * 890A
C *           ZONE BY ET.                                                 * 891A
C *   DEEPET: DISTANCE FROM BOTTOM OF ROOT ZONE TO IMPERMEABLE LAYER.     * 892A
C *   DELT  : TIME INCREMENT.                                             * 893A
C *   DELTWK: THE FRACTION OF THE DAY WHICH IS SUITABLE FOR WORK.   IE.   * 894A
C *           DELTWK = 0.5 MEANS THIS DAY HAS 0.5 WORK DAYS.              * 895A
C *   DELX  : DEPTH INCREMENT, CM.                                        * 896A
C *   DF    : CHANGE IN INFILTRATION, CM., DURING TIME INCREMENT, DDT.    * 897A
C *   DFLUX : DRAINAGE FLUX, CM/HR.                                       * 898A
C *   DROOT : EFFECTIVE ROOT DEPTH FOR A JULIAN DATE; E.G. DROOT(155) IS  * 899A
C *           ROOT DEPTH FOR DAY 155.                                     * 900A
C *   DRYDAY: A DAY WHEN AMOUNT OF SOIL WATER SUPPLIED TO THE PLANTS IS   * 901A
C *           LESS THAN PET FOR THAT DAY.                                 * 902A
C *   DSTOR : DIFFERENCE IN SURFACE STORAGE FROM ONE HR. TO NEXT OR FROM  * 903A
C *           ONE DAY TO NEXT.                                            * 904A
C *   DT    : TIME INCREMENT, HOUR.                                       * 905A
C *   DTWT  : DEPTH TO WATER TABLE.                                       * 906A
C *   DVOL  : DRAINAGE VOLUME, CM.  SUMMED SO = TO DAILY DRAIN VOLUME AT  * 907A
C *           END OF DAY.                                                 * 908A
C *   DVOL1 : ESTIMATE OF DRAINAGE VOLUME, CM., FOR TIME INCREMENT DT.    * 909A
C *   DVOL2 : ANOTHER ESTIMATE OF DRAINAGE VOLUME, CM., FOR TIME INCRE-   * 910A
C *           MENT DT.                                                    * 911A
C *   DVOLM : TOTAL MONTHLY DRAINAGE VOLUME, CM.                          * 912A
C *   DWRKDY: THE FRACTION OF A WORK DAY IN A GIVEN HOUR.                 * 913A
C *   EDTWT : EFFECTIVE DEPTH TO WATER TABLE - ASSUMING TOTAL AIR VOLUME  * 914A
C *           WAS IN THE WETZ.                                            * 915A
C *   ET    : EVAPOTRANSPIRATION, IN.  ET(2) = ET FOR 2ND DAY OF THE      * 916A
C *           MONTH.                                                      * 917A
C *   F     : INFILTRATION FOR HOUR.  F(2) MEANS INFILTRATION FOR 2ND HOUR* 918A
C *           OF THE DAY, CM.                                             * 919A
C *   F1    : DUMMY VARIABLE FOR F.                                       * 920A
C *   F2    : DUMMY VARIABLE FOR F.                                       * 921A
C *   FRATE : INFILTRATION RATE, CM/HR.  FRATE(6) MEANS INFILTRATION RATE * 922A
C *           IN CM/HR AT THE END OF THE 6TH HOUR OF THE DAY.             * 923A
C *   FVOL  : HOURLY OR DAILY INFILTRATION, CM.                          * 924A
C *   FVOLM : TOTAL MONTHLY INFILTRATION, CM.                            * 925A
C *   H     : PRESSURE HEAD, CM.                                          * 926A
C *   HET   : CALCULATED HOURLY ET, CM.  HET(5) MEANS CALCULATED ET FOR   * 927A
C *           THE 5TH HOUR OF THE DAY.                                    * 928A
C *   HOUR  : HOUR OF THE DAY.                                            * 929A
C *   HOURLY: HOURLY RAINFALL, IN.  HOURLY(54) = HOURLY RAINFALL FOR 54TH * 930A
C *           HOUR OF THE MONTH.                                          * 931A
C *   HSEW  : HOURLY SEW, CM-HRS.                                         * 932A
C *   IAVOL : INTEGER VARIABLE FOR MODIFIED AIR VOLUME, CM, THAT COULD BE * 933A
C *           USED TO FIND WET ZONE DEPTH AS, WETZ = WTD(IAVOL).          * 934A
C *   IDTWT : INITIAL WTD, CM.                                            * 935A
C *           IND = 2 MEANS DAY FALLS WITHIN SECOND WORK PERIOD.          * 936A
C *   IND   : AN INDICATOR.  IND = 1 MEANS DAY FALLS WITHIN FIRST WORK    * 937A
C *           PERIOD.                                                     * 938A
C *   IPOST : NUMBER OF TIMES SCHEDULED SURFACE IRRIGATION IS POSTPONED.  * 939A
C *   IPOSTM: TOTAL MONTHLY TIMES POSTPONE SURFACE IRRIGATION.            * 940A
C *   IR    : CALENDAR YEAR.                                              * 941A
C *   IR1   : INDICES USED TO FIND EACH YEAR.                             * 942A
C *   IR2   : INDICES USED TO FIND EACH YEAR.                             * 943A
C *   IRAIN : FIRST HOUR RAINFALL RECORDED FOR THAT DAY.                  * 944A
C *   IRRDAY: TOTAL DAYS WHEN HAVE SURFACE IRRIGATION.                    * 945A
C *   ISICNM: TOTAL MONTHLY TIMES HAVE SURFACE IRRIGATION.                * 946A
C *   ISICNT: NUMBER OF TIMES HAVE SURFACE IRRIGATION.                    * 947A
C *   ISKIP : NUMBER OF TIMES SCHEDULED SURFACE IRRIGATION IS SKIPPED TO  * 948A
C *           NEXT DAY.                                                   * 949A
C *   ISKIPM: TOTAL MONTHLY TIMES SKIP SURFACE IRRIGATION TO NEXT DAY.    * 950A
C *   IWER  : INDEX = WETZ + 1.                                           * 951A
C *   IEDYR : END YEAR OF SIMULATION.                                     * 952A
C *   IRY   : CALENDAR YEAR.                                              * 953A
C *   IYEAR : NUMBER OF YEARS IN SIMULATION.                              * 954A
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C *   J      : INDEX.                                                  *  955A
C *   JDAY   : JULIAN DAY OR DATE.                                     *  956A
C *   K      : INDEX.                                                  *  957A
C *   KRAIN  : INDEX.                                                  *  958A
C *   L      : INDEX.                                                  *  959A
C *   LOOP   : INDEX TO SKIP THE INPUT AND INITIALIZATION AFTER FIRST TIME * 960A
C *            THROUGH THE SIMULATION.                                 *  961A
C *   LRAIN  : LAST HOUR WHEN IT RAINED DURING THE DAY.               *  962A
C *   MO     : MONTH OF THE YEAR (5 MEANS MAY, ETC.).                 *  963A
C *   NI     : (XNI + 1) NUMBER OF NODE POINTS.                       *  964A
C *   PDEBT  : POTENTIAL DEBT, MAXIMUM WATER THAT CAN BE USED FROM ROOT *  965A
C *            ZONE, CM.                                               *  966A
C *   PET    : POTENTIAL ET.                                           *  967A
C *   PUMPV  : AMOUNT OF SUBIRRIGATION, CM.                            *  968A
C *   PUMPVM : TOTAL MONTHLY SUBIRRIGATION, CM.                        *  969A
C *   R( )   : RAINFALL IN CM HAS DIMENSION 24, INDICATING RAINFALL FOR ANY* 970A
C *            HOUR DURING THAT DAY. E.G., R(4) MEANS RAINFALL BETWEEN *  971A
C *            HOURS OF 3 TO 4 OF THAT DAY.                            *  972A
C *   RAT1   : DUMMY VARIABLE FOR INFILTRATION RATE.                   *  973A
C *   RAT2   : DUMMY VARIABLE FOR INFILTRATION RATE.                   *  974A
C *   RCATE  : INDEX.                                                  *  975A
C *   RDT    : TIME BETWEEN LAST RAINFALL IN PREVIOUS DAY AND FIRST RAIN- *  976A
C *            FALL ON PRESENT DAY, HRS.                               *  977A
C *   RO     : DAILY RUNOFF, CM.                                       *  978A
C *   ROM    : MONTHLY RUNOFF VOLUME, CM.                              *  979A
C *   ROOTD  : ROOT DEPTH, CM. ROOTD(125) IS ROOT DEPTH ON JULIAN DAY 125.*  920A
C *            ROOTD(I) INTERPOLATED FROM DATA READ IN SUBROUTINE ROOT. *  921A
C *   RUNOFF : RUNOFF VOLUME, CM.                                      *  982A
C *   RVOL   : TOTAL DAILY RAINFALL.                                   *  983A
C *   RVOLM  : TOTAL MONTHLY RAINFALL, CM.                             *  924A
C *   SEW    : YEARLY SUM OF EXCESS WATER.                             *  925A
C *   SEWD   : SEW VALUE FOR DAY.                                      *  986A
C *   SEWM   : TOTAL MOMTHLY SEW, CM-DAYS.                             *  927A
C *   SIRRMO : TOTAL MONTHLY SURFACE IRRIGATION, CM.                   *  988A
C *   SPR    : TOTAL WATER AVAILABLE FOR INFILTRATION IN TIME DDT, SUM OF * 989A
C *            STOR + RAINFALL DURING DDT.                             *  990A
C *   STOR   : SURFACE STORAGE, CM.                                    *  991A
C *   STOR1  : TEMPORARY VARIABLE FOR SURFACE STORAGE.                 *  992A
C *   STOR2  : TEMPORARY VARIABLE FOR SURFACE STORAGE.                 *  993A
C *   SUMAET : MONTHLY TOTAL OF ET; SUMAET(10) MEANS TOTAL ET FOR OCTOBER. * 994A
C *   SUMET  : TOTAL YEARLY ET, CM.                                    *  995A
C *   TAV    : TOTAL AIR VOLUME IN SOIL PROFILE; SUM OF AVOL AND DEBT. *  996A
C *   TAVI   : DUMMY VARIABLE FOR TAV.                                 *  997A
C *   TOSIRR : TOTAL YEARLY IRRIGATION.                                *  998A
C *   TOTD   : TOTAL YEARLY DRAINAGE, CM.                              *  999A
C *   TOTDD  : TOTAL YEARLY DRY DAYS.                                  * 1000A
C *   TOTF   : TOTAL YEARLY INFILTRATION, CM.                          * 1001A
C *   TOTFD  : TOTAL YEARLY WATDAYS.                                   * 1002A
C *   TOTNT  : TOTAL YEARLY WET DAYS.                                  * 1003A
C *   TOTR   : TOTAL YEARLY RAINFALL, CM.                              * 1004A
C *   TOTRO  : TOTAL YEARLY RUNOFF, CM.                                * 1005A
C *   TOTWD  : TOTAL YEARLY WORK DAYS.                                 * 1006A
C *   TOTWF  : TOTAL WATER REMOVED FROM FIELD BY SURFACE AND SUBSURFACE * 1007A
C *            DRAINAGE - DOES NOT INCLUDE WATER STORED IN DITCHES THEN * 1008A
C *            SUBIRRIGATED.                                           * 1009A
C *   TPUMPV : TOTAL YEARLY SUBIRRIGATION, CM.                         * 1010A
C *   TVOL   : TOTAL AIR VOLUME IN SOIL.                               * 1011A
C *   TWLOSS : TOTAL MONTHLY WATER LOST FROM SYSTEM.                   * 1012A
C *   UPQ    : MAXIMUM UPWARD FLUX CORRESPONDING TO A GIVEN WET ZONE DEPTH,* 1013A
C *            CM/HR.                                                  * 1014A
C *   UPVOL  : UPWARD FLOW IN GIVEN TIME INCREMENT, CM.                * 1015A
C *   W      : VOLUMETRIC WATER CONTENT, DIMENSIONLESS.                * 1016A
C *   WATER  : VOLUMETRIC WATER CONTENT, DIMENSIONLESS. WATER(9) MEANS * 1017A
C *            WATER CONTENT WHEN PRESSURE HEAD IS 8 CM (FROM SOIL WATER * 1018A
C *            CHARATERISTICS).                                        * 1019A
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C *    WATDAY: A DAY WHEN WATER TABLE IS HIGH ENOUGH TO CAUSE CROP DAMAGE. *1020A
C *    WETDAY: A DAY WHEN IT IS TOO WET TO CONDUCT TILLAGE (WETDAY).       *1021A
C *    WETZ  : DEPTH OF WET ZONE, CM.                                      *1022A
C *    WLO   : ANOTHER VARIABLE FOR WLOSS FOR TIME IF 1HR, 2HR, OR 1 DAY.  *1023A
C *    WLOSS : DAILY WATER LOSS, CM.                                       *1024A
C *    WRKDAY: THE DAYS WHEN TILLAGE CAN BE CONDUCTED (WORKDAY).           *1025A
C *    WTD   : WATER TABLE DEPTH, CM.  WTD(55) MEANS WTD WHEN AIR VOLUME IS*1026A
C *            (55-1)/10 = 5.4 CM.                                         *1027A
C *    X     : DEPTH INCREMENT, CM.                                        *1028A
C *    XV    : REAL VARIABLE FOR IAVOL.                                    *1029A
C *    YEARS : NUMBER OF YEARS SIMULATED; USED TO FIND AVERAGES.           *1030A
C *    YDEBT : DEBT AT END OF PREVIOUS DAY, CM.                            *1031A
C *    YESF  : YESTERDAY'S INFILTRATION, CM.                               *1032A
C *    YSUMET: TOTAL YEARLY ET.                                            *1033A
C ******************************************************************************1034A



C                                                                            1B
         SUBROUTINE PROP(WTD,VOL,WATER,AA,BB,UPFLUX)                          2B
C                                                                            3B
C ***************************************************************************** 4B
C * THIS SUBROUTINE READS IN SOIL WATER CHARACTERISTIC, INTERPOLATES     *  5B
C * VALUES, AND CALCULATES RELATIONSHIP BETWEEN WATER TABLE DEPTH AND    *  6B
C * DRAINAGE VOLUME.                                                     *  7B
C * AS AN ALTERNATIVE CAN READ IN DRAINED VOLUME - WATER TABLE DEPTH     *  8B
C * RELATIONSHIP WHICH MAY ALSO INCLUDE UPWARD FLUX VALUES.              *  9B
C * A TABLE OF CONSTANTS FOR THE GREEN - AMPT INFILTRATION EQUATION FOR  * 10B
C * VARIOUS WATER TABLE DEPTHS IS READ IN AND INTERPOLATED.              * 11B
C * ALL SOIL PROPERTIES ARE STORED IN ARRAYS SO THAT THEY CAN BE EASILY  * 12B
C * RECALLED KNOWING THE WATER TABLE DEPTH.                              * 13B
C ***************************************************************************** 14B
C                                                                           15B
C READ SOIL PROPERTIES AND STORE THE INFORMATION INTO                       16B
C PROPER ARRAYS BY INTERPOLATION                                            17B
         DIMENSION THETA(50),HEAD(50),H(500),WATER(500),VOL(500),WTD(1000)  18B
         DIMENSION D(10),E(10),F(10),AA(500),BB(500)                        19B
         DIMENSION AIA(500),BIB(500)                                        20B
         DIMENSION XVOL(100),X(100)                                         21B
         DIMENSION UPFLUX(500),FLUX(100)                                    22B
C                                                                           23B
C |------------------------------------------------------------------------| 24B
C | THE FOLLOWING SECTION READS IN SOIL WATER CHARACTERISTIC, AND CAL-    | 25B
C | CULATES RELATIONSHIP BETWEEN DRAINED VOLUME AND WATER TABLE DEPTH.    | 26B
C |------------------------------------------------------------------------| 27B
C                                                                           28B
         READ(1,900) NUM,IVREAD                                             29B
         READ(1,905)(THETA(I),HEAD(I),I=1,NUM)                              30B
C        DATA READ IN ORDER OF DECREASING WATER CONTENT                     31B
         DO 5 I = 1,NUM                                                     32B
      5  HEAD(I) = -HEAD(I)+1.0                                             33B
         I=1                                                                34B
         WATER(1)=THETA(1)                                                  35B
         P=WATER(1)                                                         36B
         VOL(1)=0                                                           37B
         DO 10 J = 2,500                                                    38B
         AJ = J                                                             39B
         IF(AJ.GT.HEAD(I+1))I=I+1                                           40B
         AI = I                                                             41B
         AIM=I-1                                                            42B
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         WATER(J) = THETA(I)+(AJ-HEAD(I))/(HEAD(I+1)-HEAD(I))*          43B
       C(THETA(I+1)-THETA(I))                                          44B
         AVG = (WATER(J)+WATER(J-1))/2                                 45B
         VOL(J) = VOL(J-1) + P-AVG                                     46B
      10 CONTINUE                                                      47B
C                                                                      48B
C |----------------------------------------------------------------|  49B
C | THE FOLLOWING READS TABULAR VALUES FOR W.T. DEPTH VS. DRAINAGE VOLUME | 50B
C | AND UPWARD FLUX.                                                |  51B
C | THE NUMBER OF VALUES READ IS IVREAD.                           |   52B
C | IF IVREAD .LE. 0. USE ABOVE W.T.D.-VOL. RELATIONSHIP AND CRITICAL | 53B
C | DEPTH CONCEPT FOR UPWARD FLUX.                                  |  54B
C |----------------------------------------------------------------|  55B
C                                                                      56B
         IF(IVREAD.LE.0) GO TO 14                                      57B
C        IF WATER VOL VS. WATER TAB DEPTH IS READ IN GO TO NEXT STEPS  58B
         READ(1,930)(X(I),XVOL(I),FLUX(I),I=1,IVREAD)                  59B
         DO 12 I=1,IVREAD                                              60B
      12 X(I)=X(I)+1.0                                                 61B
         UPFLUX(1)=FLUX(1)                                             62B
         VOL(1)=XVOL(1)                                                63B
         I=1                                                           64B
         DO 11 L=2,500                                                 65B
         XL=L                                                          66B
         IF(XL.GT.X(I+1)) I=I+1                                        67B
         XI=I                                                          68B
         XIM=XI-1.                                                     69B
         UPFLUX(L)=FLUX(I)+((XL-X(I))/(X(I+1)-X(I)))*(FLUX(I+1)-FLUX(I)) 70B
      11 VOL(L)=XVOL(I)+((XL-X(I))/(X(I+1)-X(I)))*(XVOL(I+1)-XVOL(I))  71B
C                                                                      72B
C |----------------------------------------------------------------|  73B
C | CONVERT TO ARRAY SO CAN DIRECTLY DETERMINE WATER TABLE DEPTH (OR WET | 74B
C | ZONE DEPTH) IF KNOW AIR VOLUME.                                |   75B
C |----------------------------------------------------------------|  76B
C                                                                      77B
      14 CONTINUE                                                      78B
         DO 15 K = 1,500                                               79B
      15 VOL(K) = VOL(K)*10.0+1.0                                      80B
         I = 2                                                         81B
         AI = I                                                        82B
         WTD(1) = 0                                                    83B
         DO 25 L = 2,500                                               84B
         AL = L                                                        85B
         ALM = AL-1.0                                                  86B
         IF(VOL(L).LT.AI) GO TO 25                                     87B
      20 WTD(I) = ALM + (AI-VOL(L-1))/(VOL(L)-VOL(L-1))-1.0            88B
         I = I + 1                                                     89B
         AI = I                                                        90B
         IF(VOL(L).GT.AI) GO TO 20                                     91B
      25 CONTINUE                                                      92B
         WRITE(3,915)                                                  93B
         DO 30 I=1,500                                                 94B
         VOL(I) = 0.1*(VOL(I)-1.0)                                     95B
         XI = I                                                        96B
         AI = 0.1*(XI-1.0)                                             97B
         BI = I-1                                                      98B
         AIA(I)=AI                                                     99B
         BIB(I)=BI                                                    100B
      30 CONTINUE                                                     101B
         DO 50 I=1,500,10                                             102B
      50 WRITE(3,910)AIA(I),WTD(I),BIB(I),WATER(I),VOL(I)            103B
C |----------------------------------------------------------------| 104B
C | READ IN INFILTRATION CONSTANTS FOR GREEN-AMPT EQUATION AND INTERPOLATE| 105B
C |----------------------------------------------------------------| 106B
         READ(1,900)NUMA                                              107B
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      READ(1,920)(D(I),E(I),F(I),I=1,NUMA)                                108B
      AA(1)=0.                                                            109B
      BB(1)=0.                                                            110B
      I=1                                                                 111B
      J=2                                                                 112B
      XJ=J-1                                                              113B
   35 IP=I+1                                                              114B
      RATIO=(XJ -D(I))/(D(IP)-D(I))                                       115B
      AA(J)=E(I)+RATIO*(E(IP)-E(I))                                       116B
      BB(J)=F(I)+RATIO*(F(IP)-F(I))                                       117B
      J=J+1                                                              118B
      XJ=J-1                                                              119B
      IF (XJ.GT.D(IP))I=I+1                                               120B
      IF(I.GE.NUMA)GO TO 45                                               121B
      GO TO 35                                                            122B
   45 CONTINUE                                                            123B
  900 FORMAT(2I2)                                                         124B
  905 FORMAT(E10.2,10X,E10.2)                                             125B
  910 FORMAT(10X,2F20.4,10X,3F20.4)                                       126B
  915 FORMAT(1H1,40X,'SOIL WATER CHARACTERISTICS AND RELATIONSHIP'/       127B
     $ 38X,'BETWEEN WATER TABLE DEPTH AND DRAINED(VOID) VOLUME'//        128B
     $            18X,'VOLUME OF VOIDS',4X,'WATER TABLE DEPTH',           129B
     $19X,'HEAD',12X,'WATER CONTENT',1X,'VOLUME VOIDS ABOVE W.T.')        130B
  920 FORMAT(3E10.2)                                                      131B
  930 FORMAT(3F10.4)                                                      132B
      RETURN                                                              133B
      END                                                                 134B
C ********************************************************************     135B
C *              DEFINITION OF TERMS IN SUBROUTINE PROP          *       136B
C *                                                              *       137B
C *A. INPUTS TO SUBROUTINE LISTED IN   ORDER OF INPUT            *       138B
C *                                                              *       139B
C *   NUM    : NUMBER OF THETA VS. PRESSURE HEAD POINTS READ TO INPUT SOIL * 140B
C *            WATER CHARACTERISTIC.                             *       141B
C *   IVREAD : THE NUMBER OF POINTS TO BE READ IN FOR THE WTD-DRAINAGE    * 142B
C *            VOLUME-UPWARD FLUX RELATIONSHIP.  WHEN CRITICAL DEPTH CON- * 143B
C *            CEPT IS USED, READ 0.0 FOR UPWARD FLUX.           *       144B
C *   THETA  : WATER CONTENT VALUE ON SOIL WATER CHARATERISTIC.  *       145B
C *   HEAD   : PRESSURE HEAD VALUE ON SOIL WATER CHARACTERISTIC, CM. *   146B
C *   X(I)   : WATER TABLE DEPTH IN RELATION OF WTD AND DRAINAGE VOLUME,CM.* 147B
C *   XVOL   : AIR VOLUME OR DRAINED VOL. IN RELATION OF WTD AND DRAINED, * 148B
C *            CM.                                               *       149B
C *   FLUX   : UPWARD FLUX IN RELATION  TO WTD, CM/DAY.          *       150B
C *   NUMA   : NUMBER OF POINTS TO READ IN FOR RELATIONSHIP BETWEEN COEF- * 151B
C *            FICIENTS OF GREEN-AMPT INFILTRATION EQUATION AND WATER TABLE* 152B
C *            DEPTH.                                            *       153B
C *   D(I)   : WATER TABLE DEPTH.                                *       154B
C *   E(I)   : GREEN-AMPT INFILTRATION COEFFICIENT A FOR WTD D(I). *     155B
C *   F(I)   : GREEN-AMPT INFILTRATION COEFFICIENT B FOR WTD D(I). *     156B
C *-------------------------------------------------------------------*  157B
C *B. OTHER PROGRAM VARIABLE IN PROP                             *       158B
C *   AA     : CONSTANT A OF INFILTRATION EQUATION INTERPOLATED FROM E AND * 159B
C *            F VALUES READ IN AND STORED FOR INTEGER WTD FROM TO 500 CM. * 160B
C *            STORED VALUES.                                    *       161B
C *   BB     : CONSTANT B OF INFILTRATION EQUATION INTERPOLATED FROM E AND * 162B
C *            F VALUES READ IN AND STORED FOR INTEGER WTD FROM TO 500 CM. * 163B
C *            STORED VALUES.                                    *       164B
C *   VOL    : AIR VOLUME ABOVE WTD (INTERPOLATED FROM XVOL VS X DATA READ * 165B
C *            IN OR CALCULATED FROM SOIL WATER CHARATERISTIC.   *       166B
C *   WATER  :'VOLUMETRIC WATER CONTENT, INTERPOLATED FROM SOIL WATER  *  167B
C *            CHARATERISTIC FOR INTEGER VALUES OF PRESSURE HEAD FROM 0 TO * 168B
C *            500 CM.                                           *       169B
C *   WTD    : WATER TABLE DEPTH IN CM (FROM 0 TO 500 CM), WTD(1) = 0.0, * 170B
C *            WTD(51) = WATER TABLE DEPTH CORRESPONDING TO AN AIR VOLUME * 171B
C *            OF (51 - 1)/10 = 5.0 CM, ETC.  THEREFORE IF THE AIR VOLUME * 172B
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C *            X CM THE CORRESPONDING WATER TABLE DEPTH WOULD BE WTD(10X+1)*  173B
C *******************************************************************************  174B


C                                                                              1C
        SUBROUTINE SURIRR                                                      2C
C                                                                              3C
C ***************************************************************************    4C
C * THIS SUBROUTINE DETERMINES IF CONDITIONS ARE SUITABLE FOR SURFACE    *     5C
C * IRRIGATION FOR WASTE WATER DISPOSAL.                                 *     6C
C * IT ALSO COUNTS THE NUMBER OF IRRIGATION DAYS, SKIPS, AND             *     7C
C * POSTPONEMENTS.                                                       *     8C
C ***************************************************************************    9C
C                                                                              10C
        COMMON/ICNT/ISICNT, ISKIP, IPOST, IK                                  11C
        COMMON/JCNT/JSICNM, JSKIPM, JPOSTM                                    12C
        COMMON/IDAY/FDAYSI, NDAYSI, INTDAY, NOIRR1, NOIRR2, NOIRR3, NOIRR4    13C
        COMMON/IHR/IHRSTA, IHREND                                             14C
        COMMON/PAR/AVOL, REQDAR, AMTRN, AMTSI, DAMTSI                         15C
        COMMON/RAIN/R(24)                                                     16C
C                                                                              17C
        IF(NDAYSI.GE.NOIRR1.AND.NDAYSI.LE.NOIRR2)GO TO 30                     18C
        IF(AVOL.LT.REQDAR) GO TO 10                                           19C
        IF(R(IHRSTA).GT.AMTRN) GO TO 20                                       20C
        IHRP1=IHRSTA+1                                                        21C
        DO 5 I=IHRP1,IHREND                                                   22C
        R(I)=R(I)+AMTSI                                                       23C
      5 CONTINUE                                                              24C
        DAMTSI=AMTSI*(IHREND-IHRSTA)                                          25C
        JSICNM=JSICNM+1                                                       26C
        ISICNT=ISICNT+1                                                       27C
        GO TO 15                                                              28C
C                                                                              29C
     10 ISKIP=ISKIP+1                                                         30C
        JSKIPM=JSKIPM+1                                                       31C
     15 NDAYSI=FDAYSI+INTDAY*(ISICNT+ISKIP+IK)                               32C
        GO TO 25                                                              33C
C                                                                              34C
     20 NDAYSI=NDAYSI+1                                                       35C
        IPOST=IPOST+1                                                         36C
        JPOSTM=JPOSTM+1                                                       37C
     25 IF(NDAYSI.GE.NOIRR1.AND.NDAYSI.LE.NOIRR2) GO TO 30                    38C
C                                                                              39C
        RETURN                                                               40C
     30 MDAYSI=NDAYSI                                                         41C
        DO 35 I=MDAYSI,NOIRR2,INTDAY                                          42C
        IK=IK+1                                                               43C
        NDAYSI=I+INTDAY                                                       44C
     35 CONTINUE                                                              45C
        NOIRR1=NOIRR3                                                         46C
        NOIRR2=NOIRR4                                                         47C
        RETURN                                                               48C
        END                                                                  49C
C *******************************************************************************  50C
C *                                                                      *     52C
C *              DEFINITION OF TERMS IN SUBROUTINE SURIRR                *     51C
C *  FDAYSI: FIRST DAY (JULIAN) OF SURFACE IRRIGATION.                   *     53C
C *  IHREND: ENDING HOUR OF SURFACE IRRIGATION.                         *     54C
C *  IHRP1 : INDEX = IHREND + 1.                                        *     55C
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C *    IHRSTA: STARTING HOUR OF SURFACE IRRIGATION.                      *  56C
C *    IK   :  INDEX TO KEEP THE COUNT OF DAYS WHEN THERE ARE NO SURFACE *  57C
C *            IRRIGATION INTERVALS (E.G., SOMETIMES NO SURFACE IRRIGATION * 58C
C *            DURING MARCH OR APRIL).                                    *  59C
C *    INTDAY: THE INTERVAL IN DAYS BEFORE THE NEXT DAY SURFACE IRRIGATION * 60C
C *            COMES.                                                     *  61C
C *    IPOST : NUMBER OF POSTPONEMENTS OF SURFACE IRRIGATION, ACCUMULATES *  62C
C *            FOR A YEAR.                                                *  63C
C *    IRRDAY: IRRIGATION DAY, COUNT OF TOTAL DAYS.                       *  64C
C *    ISICNT: NUMBER OF SURFACE IRRIGATION EVENTS ACCUM...TES FOR A YEAR. * 65C
C *    ISKIP : NUMBER OF SKIPS OF SURFACE IRRIGATION EVENTS ACCUMULATES FOR* 66C
C *            A YEAR.                                                    *  67C
C *    JPOSTM: NUMBER OF MONTHLY POSTPONEMENTS OF SURFACE IRRIGATION (SI). * 68C
C *    JSICNM: NUMBER OF MONTHLY SI EVENTS.                              *  69C
C *    JSKIPM: NUMBER OF MONTHLY SKIPS OF SI EVENTS.                     *  70C
C *    MDAYSI: INDEX FOR NDAYSI.                                         *  71C
C *    NDAYSI: NEXT PLANNED DAY FOR SI.                                  *  72C
C *                    OTHER TERMS ARE DEFINED IN FORSUB                 *  73C
C *******************************************************************************  74C


C                                                                           1D
        SUBROUTINE ETFLUX (AVOL,DEBT,FVOL,DVOL,UPVOL,POTET,ACTET,PDEBT)     2D
C                                                                           3D
C *******************************************************************************  4D
C * THIS SUBROUTINE DETERMINES ACTUAL HOURLY OR DAILY ET BASED ON PET AND * 5D
C * UPWARD FLUX FROM THE WATER TABLE.                                     *  6D
C * IF UPWARD FLUX IS INSUFFICIENT TO SUPPLY ET DEMAND, WATER IS REMOVED  *  7D
C * FROM ROOT ZONE TO MAKE UP THE DIFFERENCE.                             *  8D
C * IF ROOT ZONE WATER IS NOT AVAILABLE, ET IS LIMITED.                   *  9D
C *******************************************************************************  10D
C                                                                          11D
        IF(DEBT.GT.0.0) GO TO 30                                           12D
        IF(UPVOL.LT.POTET) GO TO 25                                        13D
        ACTET=POTET                                                        14D
        DEBT=0.0                                                           15D
        AVOL=AVOL+DVOL+ACTET-FVOL                                          16D
        RETURN                                                             17D
   25   DEBT=DEBT-FVOL                                                     18D
        XXD=DEBT+POTET-UPVOL                                               19D
        IF(DEBT.GE.0.0)GO TO 28                                            20D
        ACTET=POTET                                                        21D
        AVOL=AVOL+DVOL+DEBT+ACTET                                          22D
        DEBT=0.0                                                           23D
        RETURN                                                             24D
   28   IF(XXD.GT.PDEBT)GO TO 30                                           25D
        ACTET=POTET                                                        26D
        DEBT=DEBT+POTET-UPVOL                                              27D
        AVOL=AVOL+DVOL+UPVOL                                               28D
        RETURN                                                             29D
   30   ACTET=PDEBT-DEBT+UPVOL                                             30D
        IF(ACTET.GE.0.0) GO TO 31                                          31D
        ACTET=0.0                                                          32D
        DEBT=DEBT-UPVOL                                                    33D
        AVOL=AVOL+DVOL+UPVOL                                               34D
        RETURN                                                             35D
   31   CONTINUE                                                           36D
        DEBT=PDEBT                                                         37D
        AVOL=AVOL+DVOL+UPVOL                                               38D
```

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      RETURN                                                      39D
   50 IF(POTET.GT.UPVOL) GO TO 25                                 40D
      EXCESS=UPVOL -POTET                                         41D
      ACTET=POTET                                                 42D
      IF(DEBT.LT.0.0)GO TO 60                                     43D
      DEBT=DEBT-FVOL                                              44D
      DEBT=DEBT-EXCESS                                            45D
      IF(DEBT.LT.0.0)GO TO 60                                     46D
      AVOL=AVOL+DVOL+UPVOL                                        47D
      GO TO 70                                                    48D
   60 AVOL=AVOL+DVOL+ACTET+DEBT                                   49D
   70 IF(DEBT.LT.0.0)DEBT=0.0                                     50D
      RETURN                                                      51D
      END                                                         52D
C                                                                 53D
C *****************************************************************54D
C *            DEFINITION OF TERMS IN SUBROUTINE ETFLUX        *  55D
C *                                                            *  56D
C *   ACTET : ACTUAL ET FOR TIME PERIOD.                       *  57D
C *   DEBT  : AMOUNT OF WATER REMOVED FROM DRY ZONE .          *  58D
C *   EXCESS: DIFFERENCE BETWEEN AMOUNT OF WATER MOVING UPWARD FROM W.T. * 59D
C *           AND POTET.                                       *  60D
C *   POTET : POTENTIAL ET FOR TIME PERIOD-MAY BE 1 HR OR 1 DAY. * 61D
C *   XXD   : TEMPORARY VALUE FOR DEBT WHICH DEPENDS ON UPWARD FLUX, * 62D
C *           POTET PREVIOUS DEBT.                             *  63D
C * ----------------------------------------------------------*  64D
C *   OTHER TERMS NOT DEFINED ABOVE ARE SAME AS DEFINED IN FORSUB * 65D
C *****************************************************************66D


C                                                                 1E
      SUBROUTINE DRAINS(DTWT,DFLUX)                               2E
C                                                                 3E
C *****************************************************************4E
C * THIS SUBROUTINE FINDS THE EFFECTIVE LATERAL HYDRAULIC CONDUCTIVITY AND* 5E
C * COMPUTES DRAINAGE OR SUBIRRIGATION FLUX.                   *  6E
C *****************************************************************7E
C                                                                 8E
      COMMON/DRABLK/HDRAIN,DEPTH,CONK(5),DZ(5)                    9E
      COMMON/DLK/SDRAIN,DDRAIN                                    10E
      DIMENSION W(20)                                            11E
      Y=DTWT                                                     12E
      ABOVE=0.0                                                  13E
      DO10 I=1,5                                                 14E
      L=DZ(I)                                                    15E
      IF(L.EQ.0) GO TO 15                                       16E
      IF(Y.GT.DZ(I))GO TO 5                                     17E
      W(I)=DZ(I)-Y                                              18E
      X=DZ(I)-ABOVE                                             19E
      IF(W(I).GT.X)W(I)=X                                       20E
      GO TO 10                                                  21E
    5 W(I)=0.0                                                  22E
   10 ABOVE=DZ(I)                                               23E
      N=5                                                       24E
   15 N=I-1                                                     25E
      SUM=0.0                                                   26E
      DEEP=0.0                                                  27E
      DO 25 I=1,N                                               28E
      SUM=SUM+W(I)*CONK(I)                                      29E
```

```
    25  DEEP=DEEP+W(I)                                                          30E
        CONE=SUM/DEEP                                                           31E
        HDMIN=DEPTH-DDRAIN                                                      32E
        IF(HDRAIN.LT.HDMIN) HDRAIN=HDMIN                                        33E
C                                                                               34E
        EM=DEPTH-DTWT-HDRAIN                                                    35E
        DFLUX=4.0*CONE*EM*(2.0*HDRAIN+EM) /SDRAIN**2                            36E
        IF(DFLUX.GT.0.0)RETURN                                                  37E
        DDRANP=DDRAIN-0.10                                                      38E
        IF((DEPTH-HDRAIN).GE.DDRANP)DFLUX=0.                                    39E
        RETURN                                                                  40E
        END                                                                     41E
C                                                                               42E
C ******************************************************************************* 43E
C *                 DEFINITION OF TERMS IN SUBROUTINE DRAINS                *    44E
C *                                                                         *    45E
C *     ABOVE : DEPTH OF TOP OF LAYER CONSIDERED.                           *    46E
C                                                                               47E
C *     CONE  : EFFECTIVE SATURATED LATERAL HYDRAULIC CONDUCTIVITY - BASED  *    48E
C *             ON W.T. DEPTH AND K OF LAYERS.                              *    49E
C *     DDARNP: A VARIBLE USED INDICATING DISTANCE SLIGHTLY LESS THAN       *    50E
C *             DDRAIN, CM.    USED TO PREVENT CALCULATING SUBIRRIGATION    *    51E
C *             WHEN WATER TABLE IS BELOW DRAIN BOTTOM AND NO WATER IN DRAIN*    52E
C *     DEEP  : TOTAL THICKNESS OF SATURATED ZONE.                          *    53E
C *     DEPTH : DEPTH TO IMPERMEABLE LAYER FROM SOIL SURFACE, CM.           *    54E
C *     DFLUX : DRAINAGE FLUX, CM/HR.                                       *    55E
C *     DTWT  : DEPTH TO WATER TABLE FROM SOIL SURFACE, CM.                 *    56E
C *     DZ(I) : THICKNESS OF LAYER I.                                       *    57E
C *     EM    : DISTANCE FROM WATER LEVEL IN THE DRAINS TO WATER TABLE AT   *    58E
C *             MIDPOINT.   EM NEGATIVE DURING SUBIRRIGATION.               *    59E
C *     HDRAIN: DISTANCE BETWEEN THE WATER SURFACE IN THE DRAIN TO THE      *    60E
C *             IMPERMEABLE LAYER, CM.                                      *    61E
C *     SDRAIN: DISTANCE BETWEEN THE DRAINS, CM.                            *    62E
C *     W     : THICKNESS OF SATURATED ZONE IN LAYER CONSIDERED.            *    63E
C *------------------------------------------------------------------------*    64E
C * TERMS NOT DEFINED HERE ARE SAME AS DEFINED IN FORSUB                    *    65E
C ******************************************************************************* 66E



C                                                                               1F
        SUBROUTINE YDITCH(DWIEP,DVOL,YD,RO,WLOSS,B,S)                           2F
C                                                                               3F
C ******************************************************************************* 4F
C * SUBROUTINE TO DETERMINE WATER LEVEL IN OUTLET DITCH BASED ON WIER SET-*      5F
C * ING, DRAINAGE OR SUBIRRIGATION, AND RUNOFF.                           *      6F
C * THE AMOUNT OF WATER LOST FROM THE SYSTEM AND THAT REMAINING IN THE    *      7F
C * DITCH IS CALCULATED.                                                  *      8F
C ******************************************************************************* 9F
C                                                                               10F
C FIND WATER LOSS AND WATER DEPTH IN DRAIN                                       11F
C                                                                               12F
        COMMON/DLK/SDRAIN,DDRAIN                                                13F
        COMMON/DBLK/DRNSTO                                                      14F
C                                                                               15F
        V=DRNSTO+RO+DVOL                                                        16F
        IF(V.LT.0.)V=0.                                                         17F
        CV=V*SDRAIN                                                             18F
        YD=((B/S)**2+4.*CV/S)**0.5/2.-0.5*B/S                                   19F
        IF(YD.GT.(DDRAIN-DWIEP))GO TO 10                                        20F
```

```
      DDSTO=V-DRNSTO                                                   21F
      DRNSTO=V                                                         22F
      WLOSS=0.                                                         23F
      RETURN                                                           24F
C                                                                      25F
   10 YD=DDRAIN-DWIEP                                                  26F
      CV=YD*(B+    S*YD)                                               27F
      V=CV/SDRAIN                                                      28F
      DDSTO=V-DRNSTO                                                   29F
      DRNSTO=V                                                         30F
      WLOSS=RO + DVOL-DDSTO                                            31F
      RETURN                                                           32F
      END                                                             33F
C                                                                      34F
C ****************************************************************** 35F
C *             DEFINITION OF TERMS IN SUBROUTINE YDITCH         *    36F
C *                                                              *    37F
C *    B     : BOTTOM WIDTH OF THE DRAIN, CM.                    *    38F
C *    CV    : TOTAL VOLUME OF WATER COMING TO THE DRAIN, CM.    *    39F
C *    DDSTO : AMOUNT IF WATER STORED IN DRAIN DURING PRESENT TIME INCRE- * 40F
C *            MENT.                                             *    41F
C *    DRNSTO: AMOUNT OF WATER (VOLUME PER UNIT AREA) STORED IN THE DRAIN * 42F
C *            AT THE END OF PREVIOUS TIME INCREMENT, CM.        *    43F
C *            AREA).                                            *    44F
C *    DVOL  : WATER DRAINED THROUGH THE SYSTEM, CM.             *    45F
C *    DWIER : WEIR DEPTH FROM THE SOIL SURFACE, CM.             *    46F
C *    RO    : RUNOFF VOLUME FROM SURFACE, CM.                   *    47F
C *    S     : SIDE SLOPE OF DRAINAGE DITCH, CM/CM.              *    48F
C *    V     : AMOUNT OF WATER (VOL. PER UNIT AREA) THAT COULD BE IN OUTLET* 49F
C *            DITCH AT END OF PRESENT TIME INCREMENT.           *    50F
C *    WLOSS : WATER LOST THROUGH THE DITCH, CM.                 *    51F
C *    YD    : WATER HEIGHT IN THE DRAIN MEASURED FROM BOTTOM OF DITCH. * 52F
C *--------------------------------------------------------------* 53F
C * OTHER TERMS NOT DEFINED ARE SAME AS GIVEN IN FORSUB          *    54F
C ****************************************************************** 55F


C                                                                      1G
      SUBROUTINE ROOT(DROOT)                                           2G
C                                                                      3G
C ****************************************************************** 4G
C * SUBROUTINE TO READ IN TABULAR VALUES OF EFFECTIVE ROOT DEPTH VERSUS * 5G
C * TIME AND INTERPOLATE BETWEEN VALUES SO THAT ROOT DEPTH FOR ANY DAY CAN* 6G
C * BE CALLED DIRECTLY AS A FUNCTION OF THE DAY.                 *    7G
C ****************************************************************** 8G
C                                                                      9G
      DIMENSION DROOT(370), INDAY(50),ROOTIN(50)                      10G
      READ(1,600) NO                                                  11G
  600 FORMAT(I2)                                                      12G
      READ(1,610)(INDAY(I),ROOTIN(I),I=1,NO)                          13G
      J=2                                                             14G
      DROOT(1)=ROOTIN(1)                                              15G
      DO 10 I=2,366                                                   16G
      AI=I                                                            17G
      IF(I.GT.INDAY(J))J=J+1                                          18G
      DROOT(1)=ROOTIN(J-1)+((AI-INDAY(J-1))/(INDAY(J)-INDAY(J-1)))*   19G
     2(ROOTIN(J)-ROOTIN(J-1))                                         20G
   10 CONTINUE                                                        21G
      WRITE(3,615)                                                    22G
```

```
      WRITE(3,620) (DROOT(I),I=1,360,30)                               23G
  615 FORMAT(1H0,10X,'ROOT DEPTHS AS A FUNCTION OF TIME ARE READ IN'/  24G
     211X,'THE FOLLOWING REPRESENT MONTHLY VALUES'/4X,'MONTH   1    2   25G
     3  3    4    5    6    7    8    9   10   11   12')                26G
  620 FORMAT(10X,12F5.0)                                               27G
  610 FORMAT(8(I3,F7.2))                                               28G
      RETURN                                                           29G
      END                                                              30G
C                                                                      31G
C **********************************************************************32G
C *              DEFINITION OF TERMS IN SUBROUTINE ROOT             *  33G
C *                                                                 *  34G
C *A.  INPUTS TO SUBROUTINE ROOT                                    *  35G
C *    N     : NUMBER OF POINTS TO BE READ IN FOR JULIAN DATE - ROOT DEPTH * 36G
C *            RELATIONSHIP.                                        *  37G
C *    INDAY : JULIAN DATE.                                         *  38G
C *    ROOTIN: EFFECTIVE ROOT DEPTH ON INDAY.                       *  39G
C                                                                      40G
C **********************************************************************41G
C *B. DROOT(I): STORED ROOT DEPTH FOR EVERY DAY OF YEAR, I.  DETERMINE BY * 42G
C *             INTERPOLATION FROM ROOTIN - INDAY RELATIONSHIP.     *  43G
C **********************************************************************44G
C                                                                      45G


C                                                                      1H
      SUBROUTINE EVAP(ET,HET,HPET1,TPET)                               2H
C                                                                      3H
C **********************************************************************4H
C * THIS SUBROUTINE DISTRIBUTES DAILY PET OVER 12 HRS. FROM 0600 TO 1800. * 5H
C * WHEN RAINFALL .GT. 0 PET FOR THAT HOUR IS SET=0.               *  6H
C * THEN HOURLY PET SUMMED TO GET DAILY PET.                       *  7H
C **********************************************************************8H
C                                                                      9H
C FIND DAILY EVAPOTRANSPIRATION                                        10H
C                                                                      11H
      COMMON/EVAPO/PET,DDZ,ROOTD                                       12H
      COMMON/RAIN/R(24)                                                13H
      DIMENSION HET(24),HPET1(24)                                      14H
C                                                                      15H
C     FIGURE ET BASED ON 12 HRS                                        16H
      TPET=0.0                                                         17H
      HPET=PET/12.0                                                    18H
      DO 5 I=1,6                                                       19H
      HET(I)=0.0                                                       20H
      HPET1(I)=0.0                                                     21H
    5 CONTINUE                                                         22H
      DO 10 I=7,18                                                     23H
      HET(I)=HPET                                                      24H
      HPET1(I)=HPET                                                    25H
      IF(DDZ.GT.ROOTD)HET(I)=0.0                                       26H
      IF(R(I).GT.0.0)HET(I)=0.0                                        27H
      IF(R(I).GT.0.0)HPET1(I)=0.0                                      28H
   10 CONTINUE                                                         29H
      DO 15 I=19,24                                                    30H
      HET(I)=0.0                                                       31H
      HPET1(I)=0.0                                                     32H
   15 CONTINUE                                                         33H
      ET=0.0                                                           34H
```

```
      DO 20 I=1,24                                                   35H
      ET=ET+HET(I)                                                   36H
      TPET=TPET+HPET1(I)                                             37H
   20 CONTINUE                                                       38H
      RETURN                                                         39H
      END                                                            40H
C                                                                    41H
C ***************************************************************     42H
C *              ALL TERMS DEFINED IN FORSUB AND PROP        *       43H
C ***************************************************************     44H
```

```
C                                                                    1I
      SUBROUTINE WET(DTWT)                                            2I
C                                                                     3I
C ***************************************************************      4I
C * FIND WATER CONTENT AND HEAD DISTRIBUTION IN WET ZONE       *      5I
C ***************************************************************      6I
C                                                                     7I
      COMMON/WHX/WATER(500),W(101),H(101),X(101),NN                   8I
C                                                                     9I
      DO 5 I=1,NN                                                    10I
      H(I)=X(I)-DTWT                                                 11I
      J=-H(I)+1.                                                     12I
      IF(J.LT.1)J=1                                                  13I
      W(I)=WATER(J)                                                  14I
    5 CONTINUE                                                       15I
      RETURN                                                         16I
      END                                                            17I
C ***************************************************************     18I
C *              ALL TERMS DEFINED IN FORSUB AND PROP        *       19I
C ***************************************************************     20I
```

```
C                                                                    1J
      SUBROUTINE SOAK                                                 2J
C                                                                     3J
C ***************************************************************      4J
C * SUBROUTINE TO FIND PARAMETERS IN GREEN-AMPT INFILTRATION EQUATION *  5J
C * BASED ON EFFECTIVE WATER TABLE DEPTH AT BEGINNING OF RAINFALL EVENT. *  6J
C ***************************************************************      7J
C                                                                     8J
      COMMON/ABDT/EDTWT,AA(500),BB(500),A,B                           9J
C                                                                    10J
      I=EDTWT+1                                                      11J
      A=AA(I)                                                        12J
      B=BB(I)                                                        13J
      RETURN                                                         14J
      END                                                            15J
C                                                                    16J
C ***************************************************************     17J
C *              ALL TERMS DEFINED IN FORSUB AND PROP        *       18J
C ***************************************************************     19J
```

```
C                                                                              1K
        SUBROUTINE WORK( IND, J, TAV, DWRK, ACC, DDAY, YTAV)                    2K
C                                                                              3K
C ****************************************************************************  4K
C * THIS SUBROUTINE DETERMINES IF ALL OR ANY PART OF THIS DAY MAY BE       *  5K
C * CONSIDERED A WORK DAY.                                                 *  6K
C ****************************************************************************  7K
        INTEGER SWKHR1, SWKHR2, EWKHR1, EWKHR2                                 8K
        COMMON /RAIN/ R(24)                                                    9K
        COMMON /IWK/ SWKHR1, EWKHR1, SWKHR2, EWKHR2                           10K
        COMMON /WRK/ AMIN1, ROUTA1, ROUTT1, AMIN2, ROUTA2, ROUTT2            11K
        IF(J.LT.0) GO TO 50                                                   12K
        IF( IND.GT. 1) GO TO 25                                               13K
        IF((ACC.GT.ROUTA1).AND. (R(J) .GT. 0.005)) DDAY=0.0                   14K
        IF((J .LE. SWKHR1) .OR. (J .GT. EWKHR1)) GO TO 60                     15K
        IF(TAV.LT. AMIN1) GO TO 60                                            16K
        IF(DDAY .LT. ROUTT1) GO TO 60                                         17K
        DWRK= 1.0/(EWKHR1-SWKHR1)                                             18K
        RETURN                                                                19K
    25  IF((ACC .GT. ROUTA2) .AND. (R(J) .GT. 0.005)) DDAY=0.0               20K
        IF((J .LE. SWKHR2) .OR. (J .GT. EWKHR2)) GO TO 60                     21K
        IF(TAV .LT. AMIN2) GO TO 60                                           22K
        IF(DDAY .LT. ROUTT2) GO TO 60                                         23K
        DWRK= 1.0/(EWKHR2-SWKHR2)                                             24K
        RETURN                                                                25K
    60  DWRK=0.0                                                              26K
        RETURN                                                                27K
    50  IF( IND .GT. 1) GO TO 55                                              28K
        IF(TAV.LT. AMIN1) GO TO 60                                            29K
        IF(DDAY .LT. ROUTT1) GO TO 60                                         30K
        DWRK=1.0                                                              31K
        IF(YTAV .LT. AMIN1) DWRK=(TAV-AMIN1)/(TAV-YTAV)                       32K
        RETURN                                                                33K
    55  IF(TAV .LT. AMIN2) GO TO 60                                           34K
        IF(DDAY .LT. ROUTT2) GO TO 60                                         35K
        DWRK=1.0                                                              36K
        IF(YTAV .LT. AMIN2) DWRK=(TAV-AMIN2)/(TAV-YTAV)                       37K
        RETURN                                                                38K
        END                                                                   39K
C ****************************************************************************  40K
C * ALL TERMS ARE DEFINED IN SUBROUTINE FORSUB                             *  41K
C ****************************************************************************  42K
C                                                                             43K




        SUBROUTINE ORDER( IYEAR)                                               1L
C                                                                              2L
C ****************************************************************************  3L
C * THIS SUBROUTINE DETERMINES THE RANK OF TOTDD, TOTWD, SEW, AND TOSIRR   *  4L
C * AND THEIR AVERAGES DURING THE SIMULATED YEARS.                         *  5L
C ****************************************************************************  6L
C                                                                              7L
        COMMON/ORDR/TOSIRR(50), TOTDD(50), TOTWD(50), SEW(50), IRY(50)         8L
        DIMENSION NRANK1(50), NRANK2(50), NRANK3(50), NRANK4(50)               9L
        DATA SUMWKY, SUMSEW, SUMDDY, SUMIRR/4*0.0/                            10L
        CALL RANK( TOTWD, NRANK1, IYEAR, IRY)                                 11L
        CALL RANK( SEW, NRANK2, IYEAR, IRY)                                   12L
        CALL RANK( TOTDD, NRANK3, IYEAR, IRY)                                 13L
        CALL RANK( TOSIRR, NRANK4, IYEAR, IRY)                               14L
```

```
      WRITE(3,10)                                                        15L
      DO 20 I=1,IYEAR                                                    16L
      WRITE(3,30) I,TOTWD(I),NRANK1(I),SEW(I),NRANK2(I),TOTDD(I),        17L
     1 NRANK3(I),TOSIRR(I),NRANK4(I)                                     18L
      SUMWKY=SUMWKY+TOTWD(I)                                             19L
      SUMSEW=SUMSEW+SEW(I)                                               20L
      SUMDDY=SUMDDY+TOTDD(I)                                             21L
   20 SUMIRR=SUMIRR+TOSIRR(I)                                            22L
C CALCULATE AVERAGES                                                     23L
      AVGWKY=SUMWKY/IYEAR                                                24L
      AVGSEW=SUMSEW/IYEAR                                                25L
      AVGDDY=SUMDDY/IYEAR                                                26L
      AVGIRR=SUMIRR/IYEAR                                                27L
      WRITE(3,40) AVGWKY,AVGSEW,AVGDDY,AVGIRR                            28L
   10 FORMAT('1',14X,'RANK',3X,'WORK DAYS',2X,'YEAR',10X,'SEW',6X,'YEAR' 29L
     1,8X,'DRY DAYS',3X,'YEAR',7X,'IRRIGATION',2X,'YEAR'/)               30L
   30 FORMAT(15X,I4,4(F11.2,I7,5X))                                      31L
   40 FORMAT('0',11X,'AVERAGE',4(F12.2,11X))                            32L
      RETURN                                                             33L
      END                                                                34L
C                                                                        35L
C ************************************************************************ 36L
C *              DEFINITION OF TERMS IN SUBROUTINE ORDER              *   37L
C *                                                                   *   38L
C *   SUMDDY: SUM OF DRY DAYS FOR THE YEARS SIMULATED.                *   39L
C *   SUMIRR: SUM OF IRRIGATION FOR THE YEARS SIMULATED.              *   40L
C *   SUMSEW: SUM OF SEW DAYS FOR THE YEARS SIMULATED.                *   41L
C *   SUMWKY: SUM OF WORK DAYS FOR THE YEARS SIMULATED.               *   42L
C *   AVGIRR: AVERAGE OF IRRIGATION FOR THE YEARS SIMULATED.          *   43L
C *   AVGDDY: AVERAGE OF DRY DAYS FOR THE YEARS SIMULATED.            *   44L
C *   AVGSEW: AVERAGE SEW FOR YEARS SIMULATED.                        *   45L
C *   AVGWKY: AVERAGE OF WORK DAYS FOR THE YEARS SIMULATED.           *   46L
C *   NRANK1: RANK FOR TOTAL YEARLY WORK DAYS.                        *   47L
C *   NRANK2: RANK FOR YEARLY SUM OF EXCESS WATER.                    *   48L
C *   NRANK3: RANK FIR TOAL YEARLY DRY DAYS.                          *   49L
C *   NRANK4: RANK FOR TOTAL YEARLY IRRIGATION.                       *   50L
C *------------------------------------------------------------------* 51L
C   OTHER TERMS NOT DEFINED ABOVE ARE SAME AS DEFINED IN FORSUB      *   52L
C ************************************************************************ 53L


C                                                                        1M
      SUBROUTINE RANK(BAF,NK,IYEAR,IR)                                   2M
C                                                                        3M
C ************************************************************************ 4M
C * THIS SUBROUTINE DETERMINES THE RANK FOR AN ARRAY.                *   5M
C ************************************************************************ 6M
      DIMENSION NK(50),BAF(50),IR(50)                                    7M
      DO 10 I=1,IYEAR                                                    8M
      NK(I)=IR(I)                                                        9M
      IF(I.EQ.1) GO TO 10                                               10M
      K=I-1                                                             11M
C REARRANGE ARRAY BAF FROM MAX TO MIN                                   12M
      DO 20 J=1,K                                                       13M
      M=K-J+1                                                           14M
      IF(BAF(M+1).LE.BAF(M)) GO TO 10                                   15M
      NN=NK(M+1)                                                        16M
      NK(M+1)=NK(M)                                                     17M
      NK(M)=NN                                                          18M
```

```
      AF = BAF( M+ 1)                                                           19M
      BAF( M+ 1) = BAF( M)                                                      20M
      BAF( M) = AF                                                             21M
  20  CONTINUE                                                                  22M
  10  CONTINUE                                                                  23M
      RETURN                                                                    24M
      END                                                                       25M
C                                                                               26M
C  ************************************************************************      27M
C  *              DEFINITION OF TERMS IN SUBROUTINE RANK               *        28M
C*                                                                      *        29M
C  *   BAF   : VARIABLE ARRAY TO BE ARRANGED FROM MAX TO MIN.          *        30M
C  *   NK    : YEARLY ARRAY TO BE ARRANGED FROM MAX TO MIN.            *        31M
C  ************************************************************************      32M


    DRAIMOD: PROCEDURE( PARM) OPTIONS( MAIN) ;                                   1N
    /************************************************************************     2N
    * THIS MAIN PROGRAM WRITTEN IN PL1 READS HOURLY PRECIP AND DAILY MAX AND*   3N
    * MIN TEMPERATURES FROM HISARS FILES. DETERMINES PET USING THORNTHWAITE *    4N
    * METHOD, AND TRANSFERS MONTHLY, HOURLY PRECIP AND DAILY PET VALUES TO  *    5N
    * FORSUB.                                                               *    6N
    ************************************************************************/**   7N
    DECLARE( RHOU, RTEM) FILE KEYED RECORD ENV( INDEXED INDEXAREA GENKEY) ;      8N
    DECLARE FORSUB ENTRY OPTIONS( FORTRAN NOMAP INTER) ;                         9N
    DECLARE PARM CHAR( 100) VAR;                                                10N
    /*  THE PARAMETER IS GIVEN BY USING AN EXECUTE CARD IN THE FORM            11N
    //   EXEC PLOCLC, PARM. G=' /317604/010103/197701/197801/3456/064'    */    12N
    /*     WHERE 317604 IS STATID  FOR HOURLY RAINFALL,                        13N
          010103 IS  STATION ID FOR  TEMPERATURE,                             14N
          197701  IS THE BEGINNING  YEAR AND MONTH                            15N
          197801 IS THE ENDING  YEAR AND MONTH                                16N
          3456   IS THE  LATITUDE OF  TEMPERATURE STATION                     17N
          064   IS THE HEAT INDEX                        */                   18N
    DECLARE ( ET( 31), HOURLY( 744)) FLOAT DEC( 6) ALIGNED;                     19N
    DECLARE SET( 12) FLOAT DEC( 6) INIT( .03, .05, .08, .11, .14, .17, .16, .14, 20N
      .11, .08, .04, .02) ;                                                     21N
     DECLARE DAYBEG( 12) FIXED BIN( 15) INIT( 0, 31, 60, 91, 121, 152, 182, 213, 22N
       244, 274, 305, 335) ;                                                    23N
     DECLARE LATT CHAR( 6) ;                                                    24N
    DECLARE ( IYR, MO, LOOP, IEDYR) FIXED BIN( 31) ALIGNED;                     25N
    DECLARE KYB CHAR( 14), ( KYBI CHAR( 8), KYBD CHAR( 6) POS( 9)) DEF KYB;     26N
    DECLARE ( OYR PIC '9999' POS( 9), OMO PIC '99' POS( 13)) DEF KYB;           27N
    DECLARE KYE CHAR( 14), ( KYEI CHAR( 8), KYED CHAR( 6) POS( 9)) DEF KYE;     28N
    DECLARE KYZH CHAR( 16), ( KYZ CHAR( 14), HDAY PIC '99' POS( 15)) DEF KYZH;  29N
    DECLARE 1 SHOU BASED( PTS),                                                 30N
       2 ( HNDY, HOD) BIT( 8) ALIGNED, 2 HKEY CHAR( 16),                        31N
       2 HTOT FIXED BIN( 15), 2 HOUR( 24) CHAR( 4) ;                            32N
     DECLARE 1 STEM ALIGNED EXT, 2 ( TNDY, TOD) BIT( 8), 2 TID PIC '999999',    33N
       2 TBLK CHAR( 2), 2 TATE CHAR( 6), 2 ( TAX, TIN, TET)( 31) BIT( 8),       34N
       2 TTOT BIT( 24) ;                                                        35N
     DECLARE E( 200:440), REL( 366) ;                                           36N
    DECLARE 1 HOR BASED( PHR),                                                  37N
       2 ( DAY, CODE) BIT( 8) ALIGNED, 2 XRD FIXED BIN( 15) ;                   38N
    DECLARE ID CHAR( 8), ( START, END) CHAR( 6) ;                              39N
         DCL ( ID1, ID2)   CHAR( 8) ;                                           40N
    ON ENDFILE( RHOU) BEGIN; NSWA=1; GO TO S254; END;                          41N
    /*  INPUT CONTROL PARAMETERS THAT MUST BE GIVEN  */                        42N
       ID=' 319476 ' ;       START=' 196201' ; END=' 196512'  ;                43N
```

```
LATT='3543'; HET=79;   /* FUNCTION OF STATION */             44N
IF PARM = '' THEN; ELSE DO;                                   45N
ID1=SUBSTR(PARM,1,6); ID2=SUBSTR(PARM,8,6);                   46N
START=SUBSTR(PARM,15,6); END=SUBSTR(PARM,22,6);              47N
LATT=SUBSTR(PARM,29,4);HET=SUBSTR(PARM,34,3);                48N
END;   IEDYR=SUBSTR(END,1,4);                                 49N
OPEN FILE(RHOU) SEQUENTIAL INPUT;                            50N
 RLAT=0.0174533*SUBSTR(LATT,1,2)+0.0002909*SUBSTR(LATT,3,2);  51N
 SINLAT=SIN(RLAT);COSLAT=COS(RLAT);XI=HET;                    52N
    DO ND=1 TO 366;                                           53N
              XM=0.0172264*(-6E-1+ND);                        54N
    XLAM=4.874239+XM+0.0334762*SIN(XM)+0.0003502*SIN(XM+XM);  55N
    YD=0.397900*SIN(XLAM); XD=SQRT(1.-YD*YD); D=ATAN(YD,XD);  56N
    XD=(-0.014544-(SINLAT*SIN(D)))/(COSLAT*COS(D));           57N
    YD=SQRT(1.-XD*XD); REL(ND)=0.0111111*ATAND(YD,XD); END;   58N
Y=LOG(XI); F=49239E-5+XI*(1792E-5+XI*(-771E-7+XI*675E-9));    59N
DO NT=1 TO 124;                                               60N
    X=-3863357E-6+F*(1021651E-6+LOG(NT)-Y); ETEMP=EXP(X);     61N
    IF ETEMP<24E-2 THEN E(NT+264)=ETEMP; ELSE E(NT+264)=24E-2; END; 62N
DO NT=200 TO 264; E(NT)=0; END;                              63N
DO NT=389 TO 440; E(NT)=24E-2; END;                         64N
/*                                                            65N
   END EVAPOTRANSPIRATION COMPUTATION */                     66N
           KYBD=START; KYED=END;                              67N
SUBSTR(ID1,7,2)='  '; SUBSTR(ID2,7,2)='  ';                 68N
LOOP=0;                                                      69N
KYBI,KYEI=ID1;                                               70N
READ FILE(RHOU) SET(PTS) KEY(KYB);                          71N
KYBI=ID2;                                                    72N
 READ FILE(RTEM) INTO (STEM) KEY(KYB);                      73N
KYZH=HKEY; GO TO S255;                                       74N
S252:READ FILE(RHOU) SET(PTS) KEYTO(KYZH);                  75N
 KYBI,KYEI=ID1;                                              76N
    IF KYZ > KYE THEN DO; NSWA=1; GO TO S254; END;           77N
S253:IF KYZ = KYB THEN GO TO S256; NSWA=0;                  78N
   /*  MONTH IS COMPLETE  */                                 79N
S254:                                                        80N
   IYR=OYR; MO=OMO;                                          81N
  LOOP=LOOP+1;                                               82N
  NDY=UNSPEC(TNDY); NBEG=DAYBEG(MO);                         83N
  DO K=1 TO NDY;                                             84N
    NT=TAX(K)+TIN(K);                                        85N
    IF NT>200 THEN ET(K)=E(NT)*REL(NBEG+K);                  86N
          ELSE ET(K)=SET(MO);                                87N
   END;                                                      88N
 CALL FORSUB(IYR,MO,ET,HOURLY,LOOP,IEDYR);                  89N
    IF NSWA > 0 THEN GO TO PK;                               90N
 READ FILE(RTEM) INTO (STEM);                                91N
S255:KYB=KYZ; HOURLY=0;                                      92N
S256:I=HDAY; II=24*(I-1);                                    93N
   IF HOD >= '10000000'B THEN;                               94N
   ELSE DO; NDY=UNSPEC(HNDY);                                95N
     DO K=1 TO NDY;                                          96N
       PHR=ADDR(HOUR(K)); J=UNSPEC(DAY);                     97N
       IF XRD > 0 THEN HOURLY(II+J)=1E-2*XRD; END; END;      98N
   GO TO S252;                                               99N
PK:CLOSE FILE(RHOU);                                        100N
END DRAIMOD;                                                101N
```

Input Data

Input data for the example presented in Chapter 4 are given in Table A1 as card images arranged in the order that they are fed into the computer. The variable names are "penciled in" to assist the user in arranging the input data. Recall that the simulation in this example is for a surface-subsurface drainage system on a Wagram soil. No surface irrigation is applied.

Simulation Results - Examples of Program Output

Examples of the simulation results for a relatively wet year were given in Chapter 4 (Tables 5 and 6). Daily summaries for July, 1961, a relatively dry year are given in Table A2. Yearly summaries for 1961 are given in Table A3. In these summaries, all values are given in cm except SEW which has units of cm days. Note that predicted depth to the water table (DTWT) increases gradually through the month of July with small reversals due to rainfall on days 7 and 17. Much greater fluctuation of the water table was predicted in 1959 because of large and frequent amounts of rainfall.

Simulations were also conducted as an example for irrigation of waste water. Irrigation (sprinkler) of 2.5 cm was scheduled once per week when soil water and rainfall conditions would permit. The only changes in the input data (Table A1) are in card 10 where 7 should be substituted for 365 and in card 11 where the value 1.25 should be typed for AMTSI. Then water would be applied for two hours (1000 to 1200 hours - card 10) at the rate of 1.25 cm/hr on every 7th day (NDTDAY).

Examples of the computer output are shown in Table A4 for daily summaries for July 1961. Note that the last column in Table A4 gives the waste water application for each day. Applications were scheduled on days 1 and 8 but were skipped because the air volume was below REQDAR = 3.5 cm at the time of irrigation. It should also be noted that the daily values given in Tables A2, A4 and in Chapter 4 represent conditions at the end of the day. Monthly summaries for 1961 are given in Table A5. A total of 65 cm was irrigated during 1961. If the drains had been spaced closer or deeper such that scheduled irrigations would not

have skipped because of wet soil conditions, 130 cm could have been irrigated that year. Notice that only 2.5 cm could be irrigated in January, 0.0 in February, etc. Therefore the model can be used to determine time of year when storage is necessary - see Chapter 6 for more discussion on this point. Yearly summaries and ranking are given in Table A6 for this example. The 4th lowest yearly total irrigation is 57.5 cm so this would represent the 5 year recurrence interval (20/4 = 5). Therefore, on the average, we could expect to apply at least 57.5 cm of irrigation water in 4 out of 5 years on this soil with the given drainage system.

Table A1. Example input data for DRAINMOD.

CARD
NO.

JOB CARD
//HVL1V1 JOB NCS.BAE.B4430,SKAGGS,T=(2,00),P=100,PRTY=1,M=1,R=250K

1 //*PW=WATER — PASSWORD

2 //JOBLIB DD DSN=NCS.BAE.I2025.TANG.MODELD,DISP=SHR — *PG. CALLED FROM STORAGE*

3 // EXEC PGM=DRAIMOD,PARM='/319476/319476/195201/197112/3547/075' — *EXECUTE CARD*
   K, RAIN STA. TEMP. STA. YEAR/MO YEAR-MO STA. HEAT
                             START   END   LATT. INDEX

4 //SYSPRINT DD SYSOUT=A — *JOB CONTROL*

5 //FT03F001 DD SYSOUT=A — *JOB CONTROL*

6 //RHOU DD DSN=NCS.BAE.BE747.WISER.HOURRAIN,DISP=SHR — *CALLS HOURLY RAINFALL RECORDS FROM STORAGE*

7 //RTEM DD DSN=NCS.BAE.BE747.WISER.TEMPTU-E,DISP=SHR — *CALLS DAILY TEMP. RECORDS FROM STORAGE*

8 //FT01F001 DD * — *JOB CONTROL*

9 1   365   10   12   0   0 *NOIRR2* 0 *NOIRR3* 0 *NOIRR4*
   FDAVSI INTDAY   IHRSTA IHREND   NOIRR1   *IRRIGATION CARD*

10 7.0   0.5   0.0   *SOIL & RAINFALL CONDITIONS CONTROLING IRRIGATION*
   REQDAR AMIAN   AMTSI

11 100.   68.0   4500.0   0.25   168.0   33.   *— DRAINAGE SYSTEM PARAMETERS*
   DDRAIN HDRAIN   SDRAIN   STMAX   DEPTH   XNE

12 168. 6.0   *HYDRAULIC CONDUCTIVITY (K) CARD*
   DZ(1) CONK(1)

13 1.0   0   0   *PRINTOUT : NOPORT ≠0 — DAILY SUMMARIES*
   -AMINC NOPORT NMONTH *CONTROLS : NMONTH =0 — MONTHLY ; NMONTH≠0 — YEARLY SUMS.*

14 100 100 100 100 100 100 100 100 100 100 100 100 *WEIR DEPTH CARD*
   DACHNG(I), DWIER(I)

15 0761050820 3.7   1.25   1.0   076 - BWKDY1 ; 08 - SWKHR1 *TRAFFICABILITY*
              AMIN1   ROUTA1   ROUTT1   105 - EWKDY1 ; 20 - EWKHR1 *PARAMETERS - SPRING*

16 3683680820 3.0   0.50   1.0   368 - BWKDY2 ; 08 - SWKHR2 *TRAFFICABILITY*
              AMIN2   ROUTA2   ROUTT2   368 - EWKDY2   20 - EWKHR2 *PARAMETERS —FALL*

17 60.0   0.50   30.0   75.0   0.05   0.0   *DITCH DIMENSIONS, ROOT*
   DITCHB DITCHS   ROOTD   CRITD   WP(θLL) DTWT   *DEPTH, ETC.*

18 04150815 30.0   ISEWMS, ISEWDS, ISEWME, ISEWDE (4I2) *PARAMETERS FOR TIME TO START*
            SEWX   *AND STOP SEW COMPUTATION.*

19 04150815 04 = IDRYMS ; 15 = IDRYDS ; 08=IDRYME ; 15 = IDRYDE ; *DATES TO START & STOP DRY DAY COUNT*

20 3900   *IF INDET >0, VALUES FOR UPWARD FLUX VS. WTD. READ IN & USED; IF*
   INDET INWIER *INDET.LE.0, USE LIMITING DEPTH CONCEPT (CRITD) ;*

21 3014   *IF INWIER >0 USE SUBIRRIGATION ; IF INWIER≤0 HAVE DRAINAGE*
   NUM IVREAD *OR CONTROLED DRAINAGE*

22 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

NUM = NO. OF h(Θ) POINTS TO BE READ IN.

IVREAD = NO. OF POINTS FOR WTD-DRAIN VOL - UPWARD FLUX TO BE READ IN.

Table A1. Continued.

CARD NO.	θ	K (not used here)	h	NEXT 30 (NUM) CARDS ARE READ	
22	0.302	5.94	-0.0	FOR SOIL WATER CHARACTERISTIC h(θ)	1
23	0.301	5.42	-3.0		2
24	0.300	4.77	-7.0	θ = volumetric water content (cm³/cm³)	3
25	0.299	4.31	-10.	h = soil water pressure head (cm of water)	4
26	0.298	4.03	-12.	— data obtained from pressure plate	5
27	0.293	3.50	-16.	measurements —	6
28	0.285	3.01	-20.		7
29	0.274	2.54	-24.		8
30	0.261	2.12	-28.		9
31	0.247	1.74	-32.		10
32	0.233	1.39	-36.		11
33	0.218	1.07	-40.		12
34	0.203	0.78	-44.		13
35	0.190	0.52	-48.		14
36	0.177	0.28	-52.		15
37	0.165	0.09	-56.		16
38	0.154	0.03	-60.		17
39	0.144	0.025	-64.0		18
40	0.136	0.019	-68.0		19
41	0.128	0.016	-72.0		20
42	0.117	0.014	-80.0		21

43
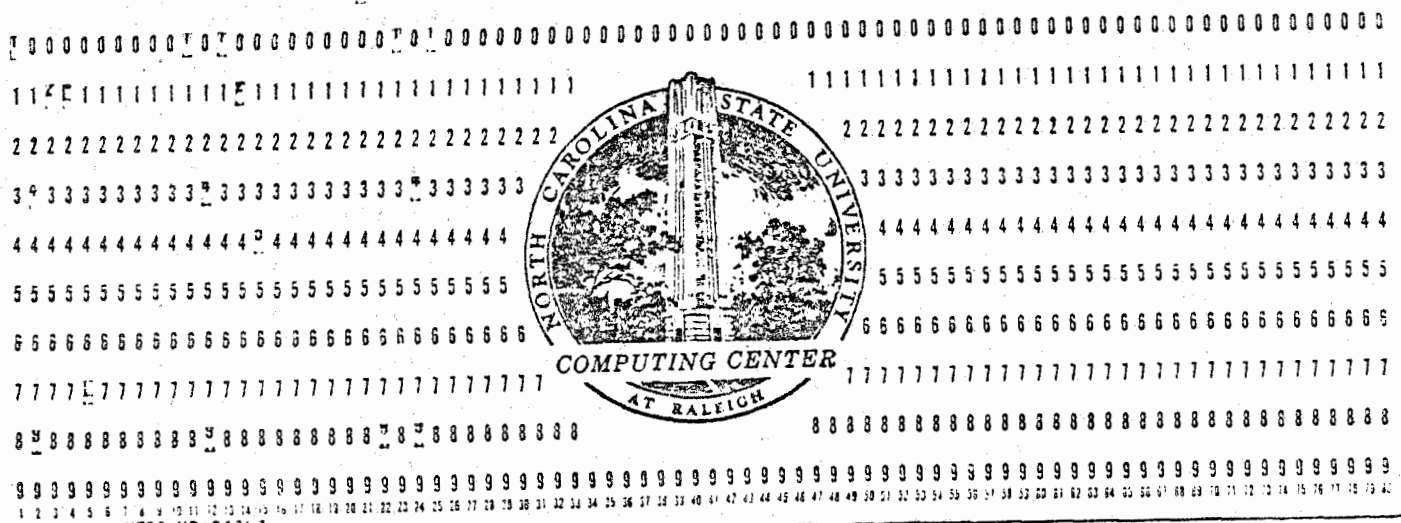
Table A1. Continued.

0.108	0.012	-90.0	2:
0.103	0.011	-100.	2
0.087	0.010	-150.	24
0.072	0.008	-200.	25
0.055	0.005	-400.	26
0.047	0.003	-600.	27
0.046	0.002	-800.	28
0.045	0.001	-999.	29
0.04	0.0002	-2000.	30

←— LAST CARD FOR θ vs h —→

WTD(I)	XVOL(I)	FLUX(I)	
0.0	0.0	3.0	1
10.0	0.10	2.0	2
20.0	0.25	1.0	3
30.0	0.50	0.50	4
50.0	1.40	0.146	5
40.0	0.80	0.30	6
50.0	2.80	0.035	7
70.0	4.60	0.0150	8
80.0	7.10	0.009	9
100.0	12.80	0.003	10
110.	16.24	0.0020	11
120.	19.68	0.001	12
150.0	30.0	0.00001	13

WTD(I) = WATER TABLE DEPTH

XVOL(I) = AIR VOLUME OR DRAINAGE VOL.
(ASSUMING HYDROSTATIC CONDITIONS
ABOVE WATER TABLE)

FLUX(I) = STEADY STATE UPWARD FLUX
AT GIVEN WTD WITH LARGE
SOIL WATER SUCTION AT SURFACE.

510.

52.0   LAST CARD FOR: WTD(I), XVOL(I), FLUX(I)   14

406   NUMA = C6 = NUMBER OF VALUES FOR IUFIL. PARAMETERS

50.   WTD(1) 0.0 A(1) 0.10 B(1)

100.   3.0   1.0

100.   5.50   2.0

150.   8.70   3.0

200.   11.50   3.0

200.   WTD(6) 25.0 A(6) 3.0 B(6)

14   NO = 14 = NUMBER OF PTS. TO READ FOR EFFECTIVE ROOT DEPTH VS. JULIAN DATE

001 4.0   106 4.0   116 5.0   126 8.0   136 16.0 146 21.0 156 23.0 166 26.0   A & B ARE PARAMETERS IN GREEN-AMPT
DUMMY(I)   DUMMY(4) ROOTIN(I)

176 28.0 186 30.0 196 30.0 226 30.0 256 4.00   366 4.00   INFIL. EQUATION $f = \dfrac{A}{F} + B$
     DUMMY(4) ROOTIN(4)   DUMMY(4) ROOTIN(14)

28,

JCL – LAST CARDS

NORTH CAROLINA STATE UNIVERSITY
COMPUTING CENTER
AT RALEIGH

NCSCCMP-24267

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Table A2. Example simulation output for a relatively dry year. Daily summaries, Wagram soil, no irrigation. All values given in cm.

1961

DAY	RAIN	INFIL	ET	DRAIN	AIR VOL	TVOL	DDZ	WETZ	DTWT	STOR	RUNOFF	WLOSS	YD	DRNSTO	SEW	DMTSI
1	0.0	0.0	0.54	0.12	5.48	5.77	1.15	73.51	74.66	0.0	0.0	0.12	0.0	0.0	0.0	0.0
2	0.0	0.0	0.55	0.11	5.89	6.42	2.13	75.14	77.27	0.0	0.0	0.11	0.0	0.0	0.0	0.0
3	0.91	0.91	0.40	0.10	6.02	6.02	0.0	75.66	75.66	0.0	0.00	0.10	0.0	0.0	0.0	0.0
4	0.0	0.0	0.50	0.10	6.39	6.62	0.90	77.16	78.06	0.0	0.0	0.10	0.0	0.0	0.0	0.0
5	0.91	0.91	0.51	0.09	6.73	7.22	1.93	78.52	80.45	0.0	0.00	0.09	0.0	0.0	0.0	0.0
6	0.0	0.0	0.50	0.08	6.89	6.89	0.0	79.14	79.14	0.0	0.0	0.08	0.0	0.0	0.0	0.0
7	1.50	1.50	0.30	0.09	5.77	5.77	0.0	74.69	74.69	0.0	0.00	0.09	0.0	0.0	0.0	0.0
8	0.48	0.48	0.40	0.11	5.81	5.81	0.0	74.84	74.84	0.0	0.0	0.12	0.0	0.0	0.0	0.0
9	0.0	0.0	0.37	0.10	6.21	6.29	0.32	76.43	76.75	0.0	0.0	0.11	0.0	0.0	0.0	0.0
10	0.0	0.0	0.36	0.09	6.57	6.75	0.69	77.89	78.58	0.0	0.0	0.10	0.0	0.0	0.0	0.0
11	0.0	0.0	0.34	0.09	6.91	7.18	1.08	79.24	80.32	0.0	0.00	0.09	0.0	0.0	0.0	0.0
12	0.20	0.20	0.26	0.09	7.11	7.33	0.88	80.02	80.90	0.0	0.00	0.09	0.0	0.0	0.0	0.0
13	0.0	0.0	0.53	0.07	7.39	7.94	2.15	81.03	83.18	0.0	0.0	0.07	0.0	0.0	0.0	0.0
14	0.0	0.0	0.56	0.06	7.66	8.56	3.56	81.98	85.54	0.0	0.0	0.06	0.0	0.0	0.0	0.0
15	0.0	0.0	0.58	0.05	7.92	9.19	5.05	82.87	87.93	0.0	0.0	0.05	0.0	0.0	0.0	0.0
16	0.0	0.0	0.56	0.04	8.14	9.79	6.49	83.71	90.20	0.0	0.0	0.04	0.0	0.0	0.0	0.0
17	1.07	1.07	0.57	0.04	8.29	9.34	4.15	84.17	88.32	0.0	0.00	0.04	0.0	0.0	0.0	0.0
18	0.76	0.76	0.47	0.05	8.43	9.09	2.61	84.67	87.29	0.0	0.00	0.05	0.0	0.0	0.0	0.0
19	0.0	0.0	0.46	0.05	8.66	9.59	3.70	85.47	89.17	0.0	0.00	0.05	0.0	0.0	0.0	0.0
20	0.66	0.66	0.50	0.04	8.79	9.48	2.72	85.94	88.66	0.0	0.00	0.04	0.0	0.0	0.0	0.0
21	0.86	0.86	0.45	0.05	9.11	9.11	0.0	87.06	87.06	0.0	0.00	0.05	0.0	0.0	0.0	0.0
22	0.0	0.0	0.59	0.04	9.32	9.74	1.67	87.79	89.45	0.0	0.0	0.04	0.0	0.0	0.0	0.0
23	0.0	0.0	0.58	0.03	9.51	10.36	3.34	88.47	91.81	0.0	0.0	0.03	0.0	0.0	0.0	0.0
24	0.0	0.0	0.59	0.02	9.69	10.96	5.04	89.09	94.13	0.0	0.0	0.02	0.0	0.0	0.0	0.0
25	0.23	0.23	0.57	0.01	9.86	11.57	6.79	89.67	96.46	0.0	0.00	0.01	0.0	0.0	0.0	0.0
26	0.05	0.05	0.54	0.01	9.94	11.92	7.85	89.97	97.82	0.0	0.00	0.01	0.0	0.0	0.0	0.0
27	0.0	0.0	0.53	0.00	10.02	12.42	9.51	90.25	99.75	0.0	0.0	0.00	0.0	0.0	0.0	0.0
28	0.0	0.0	0.58	0.0	10.16	12.95	11.07	90.73	101.80	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.58	0.0	10.29	13.53	12.32	91.21	104.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.60	0.0	10.42	14.12	14.60	91.66	106.34	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.0	0.61	0.0	10.55	14.73	16.56	92.12	108.68	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A3. Example of monthly summary output for a relatively dry year. Wagram soil, no irrigation.

MONTHLY VOLUMES IN CENTIMETERS FOR YEAR 1961

MONTH	RAINFALL	INFILTRATION	RUNOFF	DRAINAGE	ET	DRY DAYS	WRK DAYS	FLOOD DAYS	WATER LOSS	SEW	MIR	MCN	PUMP	MPT
1	6.73	6.73	0.00	3.71	0.68	0.0	0.0	0.0	3.71	0.0	0.0	0.0	0.0	0
2	14.10	11.98	2.11	6.87	1.82	0.0	0.0	0.00	8.98	0.0	0.0	0.0	0.0	0
3	11.73	11.73	0.00	7.11	4.01	0.0	3.92	3.00	7.11	0.0	0.0	0.0	0.0	0
4	8.13	8.13	0.00	6.96	4.43	0.0	0.0	3.00	6.96	0.0	0.0	0.0	0.0	0
5	10.06	10.06	0.00	4.37	8.46	0.0	0.0	2.00	4.37	0.0	0.0	0.0	0.0	0
6	15.32	15.32	0.00	1.60	12.31	0.0	0.0	0.0	1.62	0.0	0.0	0.0	0.0	0
7	7.65	7.65	0.00	1.77	15.59	0.0	0.0	0.0	1.77	0.0	0.0	0.0	0.0	0
8	11.07	11.07	0.00	0.00	12.96	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0
9	3.45	3.45	0.00	0.00	1.85	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0
10	2.06	2.06	0.00	0.0	3.19	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0
11	6.17	6.17	0.00	0.09	1.92	0.0	0.0	0.0	0.10	0.0	0.0	0.0	0.0	0
12	3.97	3.97	0.00	2.16	1.03	0.0	0.0	0.0	2.16	0.0	0.0	0.0	0.0	0
TOTALS	105.44	103.32	2.11	34.65	68.14	0.0	3.92	8.00	36.78	0.0	0.0	0.0	0.0	0

Table A4. An example of output for daily summaries when waste water application is scheduled at 2.5 cm, once per week. Note the last column is amount of waste water applied. Under drier conditions, 2.5 cm of water would have been applied on days 1 and 8, but these application were skipped because of insufficient drained volume (TVOL) at the scheduled time of application.

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DAY	RAIN	INFIL	ET	DRAIN	AIR VOL	TVOL	DDZ	WETZ	DTWT	STOR	RUNOFF	WLOSS	YD	DRNSTO	SEW	DMTSI
1	0.0	0.0	0.54	0.21	3.02	3.02	0.0	61.22	61.22	0.0	0.0	0.21	0.0	0.0	0.0	0.0
2	0.0	0.0	0.55	0.18	3.75	3.75	0.0	65.28	65.28	0.0	0.0	0.18	0.0	0.0	0.0	0.0
3	0.91	0.91	0.40	0.17	3.41	3.41	0.0	63.39	63.39	0.0	0.00	0.17	0.0	0.0	0.0	0.0
4	0.0	0.0	0.50	0.17	4.08	4.08	0.0	67.12	67.12	0.0	0.0	0.17	0.0	0.0	0.0	0.0
5	0.0	0.0	0.51	0.15	4.66	4.74	0.31	70.25	70.56	0.0	0.0	0.15	0.0	0.0	0.0	0.0
6	0.91	0.91	0.50	0.14	4.47	4.47	0.0	69.28	69.28	0.0	0.00	0.14	0.0	0.0	0.0	0.0
7	1.50	1.50	0.30	0.14	3.41	3.41	0.0	63.38	63.38	0.0	0.0	0.14	0.0	0.0	0.0	0.0
8	0.48	0.48	0.40	0.18	3.51	3.51	0.0	63.95	63.95	0.0	0.00	0.18	0.0	0.0	0.0	0.0
9	0.0	0.0	0.37	0.17	4.05	4.05	0.0	66.93	66.93	0.0	0.0	0.17	0.0	0.0	0.0	0.0
10	0.0	0.0	0.36	0.15	4.56	4.56	0.0	69.77	69.77	0.0	0.0	0.15	0.0	0.0	0.0	0.0
11	0.0	0.0	0.34	0.14	5.04	5.04	0.0	71.76	71.76	0.0	0.0	0.14	0.0	0.0	0.0	0.0
12	0.20	0.20	0.26	0.13	5.23	5.23	0.0	72.52	72.52	0.0	0.00	0.13	0.0	0.0	0.0	0.0
13	0.0	0.0	0.53	0.12	5.66	5.88	0.86	74.26	75.12	0.0	0.0	0.12	0.0	0.0	0.0	0.0
14	0.0	0.0	0.56	0.10	6.06	6.55	1.93	75.85	77.78	0.0	0.0	0.10	0.0	0.0	0.0	0.0
15	2.50	2.50	0.48	0.12	4.66	4.66	0.0	70.22	70.22	0.0	0.00	0.12	0.0	0.0	0.0	2.50
16	0.0	0.0	0.56	0.13	5.13	5.35	0.86	72.12	72.98	0.0	0.0	0.13	0.0	0.0	0.0	0.0
17	1.07	1.07	0.57	0.13	4.98	4.98	0.0	71.51	71.51	0.0	0.0	0.13	0.0	0.0	0.0	0.0
18	0.76	0.76	0.47	0.13	4.81	4.81	0.0	70.86	70.86	0.0	0.00	0.13	0.0	0.0	0.0	0.0
19	0.0	0.0	0.46	0.13	5.29	5.40	0.44	72.76	73.20	0.0	0.0	0.13	0.0	0.0	0.0	0.0
20	0.66	0.66	0.50	0.13	5.37	5.37	0.0	73.08	73.08	0.0	0.00	0.13	0.0	0.0	0.0	0.0
21	0.86	0.86	0.45	0.12	5.08	5.08	0.0	71.92	71.92	0.0	0.00	0.12	0.0	0.0	0.0	0.0
22	2.50	2.50	0.49	0.15	3.23	3.23	0.0	62.38	62.38	0.0	0.00	0.16	0.0	0.0	0.0	2.50
23	0.0	0.0	0.58	0.17	3.99	3.99	0.0	56.60	66.60	0.0	0.0	0.17	0.0	0.0	0.0	0.0
24	0.0	0.0	0.58	0.15	4.59	4.72	0.51	69.96	70.47	0.0	0.0	0.15	0.0	0.0	0.0	0.0
25	0.0	0.0	0.59	0.13	5.10	5.44	1.36	71.99	73.35	0.0	0.0	0.13	0.0	0.0	0.0	0.0
26	0.23	0.23	0.57	0.12	5.39	5.91	2.07	73.15	75.22	0.0	0.00	0.12	0.0	0.0	0.0	0.0
27	0.05	0.05	0.54	0.11	5.64	6.51	3.42	74.18	77.60	0.0	0.00	0.11	0.0	0.0	0.0	0.0
28	0.0	0.0	0.53	0.09	6.03	7.13	4.36	75.72	80.08	0.0	0.0	0.09	0.0	0.0	0.0	0.0
29	2.50	2.50	0.48	0.11	5.22	5.22	0.0	72.48	72.48	0.0	0.00	0.11	0.0	0.0	0.0	2.50
30	0.0	0.0	0.60	0.12	5.65	5.93	1.11	74.21	75.32	0.0	0.0	0.12	0.0	0.0	0.0	0.0
31	0.0	0.0	0.61	0.10	6.05	6.64	2.34	75.80	78.13	0.0	0.0	0.10	0.0	0.0	0.0	0.0

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Table A5. An example of output for monthly summaries when waste water application is scheduled at 2.5 cm, once per week on a Wagram loamy sand.

MONTHLY VOLUMES IN CENTIMETERS FOR YEAR 1961

MONTH	RAINFALL	INFILTRATION	RUNOFF	DRAINAGE	ET	DRY DAYS	WRK DAYS	FLOOD DAYS	WATER LOSS	SEW	MIR	MCN	PUMP	MPT
1	9.23	8.62	0.61	7.74	0.66	0.0	0.0	4.00	8.35	0.0	2.50	1	0.0	0
2	14.10	11.16	2.94	8.34	1.82	0.0	0.0	9.00	11.28	0.0	0.0	2	0.0	0
3	14.23	13.19	1.05	8.33	4.00	0.0	0.0	9.00	9.37	2.50	2.50	4	0.0	0
4	8.13	8.13	0.00	7.17	4.43	0.0	1.17	6.00	7.17	0.0	0.0	5	0.0	0
5	15.06	14.62	0.44	6.36	8.39	0.0	0.0	7.00	6.80	5.00	5.00	3	0.0	0
6	22.82	19.66	3.16	5.95	12.09	0.0	0.0	2.00	9.11	7.50	7.50	3	0.0	0
7	15.15	15.15	0.00	4.31	15.20	0.0	0.0	3.00	4.31	10.00	7.50	4	0.0	0
8	15.15	15.15	0.00	4.86	12.74	0.0	0.0	0.0	4.86	10.00	10.00	4	0.0	0
9	21.07	21.07	0.00	5.02	11.19	0.0	0.0	0.0	5.02	12.50	12.50	5	0.0	0
10	15.95	15.95	0.00	6.31	5.26	0.0	0.0	0.0	6.31	10.00	10.00	4	0.0	0
11	12.06	12.06	0.00	7.04	3.23	0.0	0.0	3.00	7.35	5.00	5.00	2	0.0	0
12	11.17	10.86	0.31	9.03	1.03	0.0	0.0	0.00	10.91	2.50	2.50	1	0.0	0
TOTALS	170.44	160.05	10.39	80.46	80.05	0.0	1.17	39.00	90.85	50.23	65.00	0.0	0.0	0

Table A6. Example of yearly summaries and ranking for 20 years of simulation for waste water application of 2.5 cm, once per week on a Wagram loamy sand.

RANK	WORK DAYS	YEAR	SEW	YEAR	DRY DAYS	YEAR	FLOOD DAYS	YEAR	IRRIGATION	YEAR
1	7.20	1952	199.67	1959	0.0	1951	4.00	1951	82.50	1954
2	7.12	1953	197.22	1966	0.0	1952	9.00	1952	77.50	1951
3	6.75	1967	188.24	1967	0.0	1953	9.00	1953	77.50	1955
4	6.67	1965	174.47	1968	0.0	1954	7.00	1970	70.00	1970
5	6.25	1955	149.50	1965	0.0	1955	6.80	1954	67.50	1968
6	6.18	1968	104.98	1969	0.0	1956	3.00	1955	67.50	1952
7	5.69	1966	93.62	1963	0.0	1957	3.00	1956	65.00	1953
8	4.98	1963	86.91	1958	0.0	1958	0.0	1957	65.00	1957
9	4.40	1960	85.94	1960	0.0	1959	0.0	1958	65.00	1961
10	4.17	1964	76.01	1951	0.0	1960	0.0	1959	65.00	1965
11	3.11	1969	66.50	1962	0.0	1961	0.0	1960	65.00	1969
12	2.26	1951	60.63	1955	0.0	1962	0.0	1961	62.50	1956
13	1.54	1956	58.62	1957	0.0	1963	0.0	1962	62.50	1960
14	1.27	1959	50.23	1961	0.0	1964	0.0	1963	62.50	1966
15	1.17	1961	49.69	1956	0.0	1965	0.0	1964	60.00	1967
16	1.07	1954	39.11	1951	0.0	1966	0.0	1965	60.00	1958
17	1.06	1962	31.23	1964	0.0	1967	0.0	1966	57.50	1963
18	1.03	1970	15.95	1954	0.0	1968	0.0	1967	57.50	1964
19	0.17	1957	0.0	1952	0.0	1969	0.0	1968	55.00	1962
20	0.0	1958	0.0	1970	0.0	1970	0.0	1970	50.00	1959
AVERAGE	3.56		86.38		0.0		0.0		64.50	

APPENDIX B
SOIL PROFILE DESCRIPTIONS

1. Cape Fear Loam

     Tidewater Research Station, Plymouth, N.C.

     Field: M-3 (near center of field)

     Soil Family Name: Typic Umbraquult, clayey, mixed, thermic

                    Profile Description

Depth, M	Description
0 - .25	Very dark brown (10 YR 2/2) loam or very fine sandy loam; clear boundary -
0.25 - 0.9	Dark grayish brown (10 YR 4/2; 5/2 and 5/6) smooth stiff clay with common fine yellowish red (5 YR 4/8) mottles; common fine mica; grades -
0.9 - 1.3	Very pale to pale brown (10 YR 7/3 - 6/3) with brownish yellow (10 YR 6/6) mottles; sandy clay loam; bedded clayey and sandy material grading to light sandy loam at 1.1 to 1.3 m; grades -
1.3 - 2.6	Gray (10 YR 6/1) medium sandy loam - loamy sand; grading to gray (5 Y 5/1).
2.6 - 5.2	Gray (5 Y 5/1) fine light sandy loam grading to gray (10 Y 5/1) at about 4 m; few grits to 4 mm in lower .3 m. Base of Pamlico Begin small
5.2 - 10.4 m	5 GY 5/1 mealy feeling light loam grades gradually to 5 GY 4/1 tough stiff clay loam; fossil fragments became common and coarser.

2. Goldsboro Sandy Loam

     Lower Coastal Plains Tobacco Research Station, Lenoir County, near Kinston, N.C.

     Described by: R. D. Daniels and E. E. Gamble

     Attitude: About 21 m MSL

     Soil Family Name: Aquic Paleudult, fine-loamy, siliceous, thermic.

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Profile Description

Depth, m	Description
0 - 0.3	Ap horizon -- sandy loam -
0.3 - 1.1	B horizon -- brownish yellow (10 YR 6/6) fine clay loam to sandy clay loam; clear -
1.1 - 2.6	Mottled light red (2.5 YR 6/6), reddish yellow (5 YR 6/8), and very pale brown (10 YR 7/3) tough medium fine clay loam; gradual -
2.6 - 3.0	Light yellowish brown (10 YR 6/4) medium sandy loam; clear -
3.0 - 3.8	Reddish yellow (7.5 YR 6/6) very coarse sand to loamy sand; abrupt - Base of Wicomico MSU. Begin Cretaceous Pee Dee.
3.8 - 4.4	Reddish yellow (5 YR 6/8 and 7.5 YR 7/8) medium to medium fine loam to sandy loam; abrupt -
4.4 - 5.2	Dark greenish gray (10 Y 4/1) fine loam; one 3 cm angular phosphate pebble; gradual -
5.2 - 8.5	Dark gray (5 Y 4/1) medium coarse loam to sandy clay loam; grades to very dark greenish gray (darker than 5 G 4/1) tough calcareous light loam. Base of hole at 8.5 m.

3. Lumbee Sandy Loam (mixed minerology taxajunt of Lumbee)
   H. C. Austin Farm near Aurora, N.C.
   Soil Family Name: Typic Ochraquult, fine loamy, silicebus, thermic.

Profile Description

Depth, m	Description
0 - 0.25	Gray to dark gray friable sandy loam, abrupt boundary -
0.25-0.4	Gray sandy loam mottled with dark brown, grades to
0.4 - 1.0	Gray mottled with yellow friable to firm sandy clay or sandy clay loam, some small pockets of medium sand or loamy sand intermixed, grades to
1.0 - 1.6	Gray sandy loam to loamy sand, sometimes light gray, bottom of this layer at 1.35 m for lower surface elevations, 1.6 m for higher surface elevations.

| 1.6 - 2.5 | Dark gray loamy sand or sandy loam with shell fragments to 5 mm mixed in marl like material with some clay, density increase with depth, |
| 2.5 - 2.8 | Dark gray, hard, tight fine sand with some clay, doesn't appear saturated. |

4. Ogeechee Loam

McArne Bay, McNair Seed Co. Farm near Laurinburg, N.C.

Soil Family Name: Typic Ochraquult over sandy, siliceous, thermic.

Profile Description

Depth, m	Description
0 - 0.20	Gray, friable loam or sandy loam -
0.2 - 1.2	Clay loam or sandy clay, abrupt to -
*1.2 - 2.4	Light gray loamy sand with bodies of sandy loam Depth of top of this layer varies from 1 to 2 m, thickness varies from 0.5 to 1.2 m depending on location -
2.4 -	Sandy clay sediments, tight, massive structure, firm consistence. Thickness of this layer was not determined.

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*Note: When sandy layer doesn't exist or occurs at depths > 2 m the soil is classified as a Coxville. The sandy layer was discontinuous in the experimental site with some areas of Coxville. The sand layer occurred closer to the surface than 1.2 m in some areas and would be classified as Lumbee.

APPENDIX C

ROOTING DEPTHS FOR EXPERIMENTAL SITES

Table C1. Rooting depths for experimental sites at Aurora and Plymouth, N.C.

Julian Date	Root Depth	Crop	Julian Date	Root Depth	Crop
Aurora - 1973, 1974*			Aurora - 1976		
001	3 cm	fallow	001	5	wheat
069	3	plant potato	041	9	wheat
089	5	potato	075	15	wheat
106	12	potato	106	25	wheat
136	25	potato	140	25	wheat
172	25	harvest potato	168	8	wheat harvest
173	3	fallow	169	4	wheat stubble
199	3	plant soybean	175	4	plant soybean (notil)
220	10	soybean			
232	20	soybean			
240	25	soybean	195	10	soybeans
275	25	soybean	210	20	soybeans
290	20	soybean	217	25	soybeans
308	10	harvest soybean	265	25	soybeans
			280	20	soybeans
319	3	fallow	314	10	soybeans
365	3	fallow	320	3	harvest beans
Aurora - 1975			366	3	fallow
001	3	fallow			
112	3	plant corn	Aurora - 1977		
130	4	corn	001	3	fallow
143	15	corn	119	3	plant corn
157	25	corn			
177	30	corn	137	4	corn
205	30	corn	150	15	corn
230	20	corn ready to harvest	165	25	corn
			179	30	corn
248	10	harvest	205	30	corn
249	3	fallow	232	20	corn
316	3	plant wheat	248	10	harvest corn
330	5	wheat			
365	5	wheat	249	3	fallow
			365	3	fallow

*Crops grown on the Aurora site in 1973 and 1974 were the same with only slight differences in potato harvesting dates and soybean harvesting dates. In 1974 potatoes were harvested on day 167, beans planted on day 192 and harvested on day 332.

Table C1. Continued. Rooting depths for experimental sites.

Julian Date	Root Depth	Crop	Julian Date	Root Depth	Crop
Plymouth - 1973, 1974, 1975			Plymouth - 1977		
001	3	fallow	001	5	wheat
106	3	plant corn	041	6	wheat
124	4	corn	075	12	wheat
137	15	corn	106	18	wheat
151	25	corn	125	25	wheat
171	30	corn	150	25	wheat
199	30	corn	168	8	harvest
232	20	corn			wheat
267	10	harvest	169	3	fallow
268	3	fallow	175	3	plant
266	3	fallow			soybean
			195	10	soybean
Plymouth - 1976			210	20	soybean
001	3	fallow	217	25	soybean
106	3	plant corn	265	25	soybean
124	4	corn	280	25	soybean
137	15	corn	314	10	harvest
151	25	corn			soybean
171	30	corn	320	3	fallow
199	30	corn	365	3	fallow
232	20	corn			
267	10	harvest			
268	3	fallow			
315	3	plant			
		wheat			
366	5	wheat			

APPENDIX D

DAILY RAINFALL AND OUTLET WATER LEVEL ELEVATIONS FOR EXPERIMENTAL SITES

Table D1. DAILY RAINFALL IN INCHES AT THE PLYMOUTH SITE

1973   MONTH

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.273	0.000	2.260	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.899	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	2.280	0.000	0.410	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.010	0.290	0.000	0.610	0.000	0.030	0.340
6	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.040	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.030	0.000	0.000	0.000	0.050	0.000	2.544
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.190	0.000	0.010	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.460	0.030	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	2.000	0.180	0.000	0.000	0.000	0.070
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.390	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.000	0.000	0.579	0.000	0.040	0.000	0.000	0.000	0.599
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100	0.400	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.000	0.000	0.340	1.070	0.000	0.000	0.000	0.040
16	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.890	0.000	0.000	0.000	1.210
17	0.000	0.000	0.000	0.000	0.000	0.060	0.040	0.000	0.000	0.000	0.000	0.050
18	0.000	0.000	0.000	0.000	0.000	0.940	0.000	1.400	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.140	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.770	0.000	0.000	0.000	0.458
21	0.000	0.000	0.000	0.000	0.000	0.100	0.000	0.700	0.000	0.000	0.000	0.681
22	0.000	0.000	0.000	0.000	0.000	0.280	0.601	0.020	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.000	1.441	0.000	0.000	0.000	0.000	0.000	0.000
24	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000
25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.089
26	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27	0.000	0.000	0.000	0.000	0.000	0.000	0.430	0.000	0.000	0.000	0.000	0.000
28	0.000	0.000	0.000	0.000	0.000	0.000	2.900	0.000	0.000	0.000	0.400	0.000
29	0.000	0.000	0.000	0.000	0.000	0.770	0.000	0.000	0.000	0.720	0.000	0.000
30	0.000	0.000	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.000	0.000	0.000
31	0.000	0.000	0.000	0.000	0.000	0.000	0.060	0.000	0.000	0.040	0.000	0.000

Table D1. DAILY RAINFALL IN INCHES AT THE PLYMOUTH SITE

1974   MONTH

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.170	0.000	0.000	0.000	0.000	0.130	0.000	0.000	0.040	0.000	0.000	0.770
2	0.000	1.150	0.000	0.000	0.310	0.950	0.000	0.990	0.280	0.000	0.000	0.000
3	0.040	0.380	0.000	0.000	0.000	0.070	0.000	0.000	0.010	0.000	0.000	0.000
4	0.200	0.000	0.000	0.010	0.000	0.000	0.000	1.480	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.920	0.230	0.000	1.110	0.130	0.130	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.110	0.520	0.980	0.000	0.000	0.000
7	1.190	0.070	0.000	0.000	0.000	0.000	0.540	0.280	0.000	0.040	0.020	0.070
8	0.000	0.150	0.000	0.020	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.500
9	0.140	0.000	0.000	0.700	0.180	0.000	0.000	0.430	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.010	0.000	0.190	0.040	0.000	0.000	0.000	0.000
11	0.000	0.000	0.080	0.000	0.000	0.000	0.090	0.010	0.000	0.000	0.000	0.000
12	0.000	0.000	0.380	0.000	0.170	0.020	0.000	0.000	0.000	0.000	0.130	0.100
13	0.000	0.000	0.040	1.830	0.000	0.020	0.000	0.060	0.000	0.300	0.000	0.010
14	0.000	0.080	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100
16	0.000	1.150	1.270	0.070	0.000	0.010	0.000	0.330	0.070	0.080	0.000	0.130
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.890	0.590	0.000	0.010
18	0.030	0.000	0.000	0.000	0.670	0.000	0.000	0.620	0.000	0.000	0.280	0.000
19	0.000	0.550	0.500	0.000	0.220	0.000	0.000	0.310	0.000	0.640	0.030	0.010
20	0.000	0.000	0.010	0.000	0.000	0.150	0.000	0.000	0.000	0.000	0.590	0.400
21	0.720	0.020	0.040	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.020	0.590
22	0.000	0.320	0.000	0.000	0.000	0.000	0.000	0.020	0.160	0.000	0.000	0.010
23	0.000	0.000	0.190	0.200	0.210	0.510	0.000	0.390	0.000	0.000	0.000	0.050
24	0.120	0.000	0.180	0.100	0.000	0.150	0.000	0.620	0.000	0.000	0.000	0.000
25	0.300	0.000	0.690	0.000	0.130	0.000	1.190	0.000	0.000	0.000	0.000	0.000
26	0.480	0.000	0.010	0.000	1.160	0.000	0.000	0.000	0.000	0.000	0.250	0.000
27	0.000	0.000	0.064	0.000	1.800	1.120	1.210	0.000	0.160	0.000	0.000	0.400
28	0.340	0.000	0.010	0.600	0.000	0.000	0.000	0.020	0.010	0.000	0.000	0.250
29	0.060	0.000	1.120	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30	0.040	0.000	0.110	0.000	0.070	0.000	0.600	0.000	0.000	0.000	0.020	0.000
31	0.000	0.000	0.000	0.000	0.000	0.000	0.410	0.020	0.000	0.000	0.000	0.000

Table D1. DAILY RAINFALL IN INCHES AT THE PLYMOUTH SITE

1975   MONTH

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.070	0.040	0.000	0.120	0.730	0.090	0.000	0.000	0.930	0.310	0.060	0.250
2	0.000	0.440	0.290	0.000	0.030	0.000	0.000	0.000	0.600	0.000	0.000	0.000
3	0.000	0.000	0.000	0.320	0.010	0.000	0.000	0.000	0.000	0.200	0.000	0.000
4	0.610	0.000	0.000	0.000	0.100	0.000	0.620	0.000	0.000	0.000	0.000	0.000
5	0.000	0.530	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100	0.000	0.000
6	0.140	0.000	0.000	0.000	0.000	0.000	0.000	0.680	0.000	0.010	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.980	0.320	2.010	0.000	0.000	0.340
8	0.310	0.000	0.000	0.000	0.000	0.000	0.010	0.930	0.010	0.160	0.000	0.900
9	0.000	0.000	0.000	0.280	0.000	0.000	0.000	0.000	0.010	0.080	0.000	0.410
10	0.000	0.000	0.150	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.000	0.000
11	0.570	0.000	0.010	0.610	0.000	0.000	2.990	0.000	0.000	0.000	0.000	0.000
12	0.370	0.040	0.000	0.000	0.000	0.340	0.440	0.000	0.170	0.000	0.000	0.000
13	0.930	0.000	0.410	0.000	0.000	0.000	1.360	0.000	0.000	0.000	0.040	0.000
14	0.000	0.000	0.970	0.020	0.000	0.000	0.110	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	3.660	0.030	0.000	0.020	0.000	0.000	0.000	0.000	0.030
16	0.000	1.500	0.460	0.000	0.350	0.000	2.410	0.000	0.000	0.810	0.000	0.050
17	0.000	0.000	0.430	0.000	0.130	0.010	0.620	0.000	0.000	0.270	0.000	0.450
18	0.020	0.010	0.000	0.000	0.010	0.000	0.020	0.000	0.020	1.330	0.000	0.100
19	0.000	0.310	2.030	0.260	0.010	0.000	0.010	0.000	0.610	0.010	0.000	0.000
20	0.920	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.820	0.000	0.000	0.000
22	0.000	0.000	0.020	0.000	0.000	0.200	0.020	0.000	0.150	0.000	0.000	0.000
23	0.000	0.000	0.000	0.110	0.000	0.000	0.450	0.000	1.040	0.000	1.120	0.000
24	0.500	0.530	0.250	0.000	0.000	0.000	0.030	0.000	0.020	0.100	0.120	0.000
25	0.440	0.000	0.000	0.000	0.200	0.660	1.760	0.000	0.270	0.010	0.000	0.000
26	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.420	1.020	0.000	0.560
27	0.000	0.000	0.000	0.000	0.000	0.300	0.000	0.000	0.200	0.000	0.000	0.000
28	0.000	0.000	0.000	0.000	0.010	1.210	0.000	0.000	0.000	0.000	0.000	0.000
29	0.950	0.000	0.000	0.000	0.000	0.640	0.000	0.000	0.050	0.000	0.000	0.000
30	0.000	0.000	0.110	0.000	0.000	0.000	0.000	0.000	0.010	0.040	0.000	0.000
31	0.000	0.000	0.000	0.000	0.100	0.000	0.020	0.000	0.700	0.000	0.000	0.000

Table D1. DAILY RAINFALL IN INCHES AT THE PLYMOUTH SITE

1976   MONTH

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.000	1.110	0.000	0.270	0.110	0.000	3.370	0.000	0.000	0.000	0.000	0.000
2	0.000	0.030	0.000	0.000	0.460	1.540	0.010	0.000	0.770	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.010	0.380	0.290	0.240	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.060	0.000	0.640	0.620	0.100	0.000	0.040	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.700	0.000	0.000	0.000	0.150	0.000	0.500	0.000	0.000	0.000
7	0.580	0.000	0.000	0.000	0.630	0.000	0.340	0.000	0.000	0.000	0.000	0.440
8	0.260	0.000	0.000	0.210	0.000	0.000	0.000	0.220	0.000	0.100	0.000	0.530
9	0.000	0.000	0.960	0.000	0.000	0.000	0.000	0.650	0.000	0.010	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.040	1.260	0.000	0.000	0.000
11	0.070	0.000	0.000	0.000	0.310	0.000	0.010	0.000	0.200	0.000	0.210	0.170
12	0.010	0.000	0.000	0.000	0.000	0.110	0.000	0.000	0.000	0.000	0.000	0.520
13	0.000	0.000	0.040	0.000	1.560	0.000	0.000	0.000	0.000	0.000	0.000	0.050
14	0.100	0.370	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.120	0.000	0.220	0.000	0.080	0.000	2.360	0.000	1.340	0.620
16	0.380	0.000	0.460	0.000	0.000	0.530	0.000	0.000	0.000	0.000	0.050	0.480
17	0.160	0.000	0.000	0.000	0.250	0.000	0.120	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.100	0.020	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	1.510	0.000	0.020	0.000	0.000	0.000	0.140
21	0.010	0.000	0.000	0.000	0.000	0.350	0.000	0.180	0.040	0.000	0.000	0.000
22	0.000	0.160	0.000	0.000	0.000	0.740	0.080	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.000	2.960	0.000	0.000	0.000	0.000	0.000	0.000
24	0.000	0.000	0.000	0.000	0.170	0.260	0.000	0.000	0.000	0.000	0.000	0.000
25	0.000	0.000	0.000	0.190	0.000	0.000	0.280	0.000	0.000	0.000	0.000	0.000
26	0.110	0.000	0.460	0.000	0.000	0.000	0.000	0.700	0.000	0.000	0.000	0.000
27	0.860	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.210	0.000
28	0.190	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.190	0.000	0.420	0.000
29	0.000	0.000	0.000	0.000	3.290	0.000	0.000	0.000	0.000	0.200	0.130	0.000
30	0.000	0.000	0.240	0.000	0.000	0.000	0.630	0.000	0.150	0.000	0.000	0.000
31	0.000	0.000	0.470	0.000	0.000	0.000	0.100	0.000	0.000	0.070	0.000	0.000

Table D1. DAILY RAINFALL IN INCHES AT THE PLYMOUTH SITE

	1977					MONTH						
DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.000	0.000	0.000	0.000	0.000	0.350	1.480	0.000	0.000	0.000	0.069	0.000
2	0.000	0.000	0.000	0.000	0.000	1.100	0.000	0.110	0.000	0.770	0.070	0.000
3	0.110	0.000	0.000	0.000	0.210	0.000	0.000	0.410	0.040	0.040	0.000	0.000
4	0.100	0.000	0.640	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.510	0.070
5	0.100	0.000	0.000	0.140	0.200	0.000	0.000	0.000	0.000	0.000	0.020	0.020
6	0.040	0.000	0.550	0.000	0.000	0.510	0.000	0.000	0.000	0.000	0.070	0.000
7	0.550	0.000	0.530	0.000	1.270	0.010	0.000	0.000	0.030	0.000	0.340	0.000
8	0.000	0.000	0.360	0.000	0.000	0.000	0.000	0.000	1.270	0.020	0.000	0.000
9	0.650	0.000	0.000	0.000	0.000	0.931	0.240	0.000	0.000	0.660	0.000	0.010
10	1.051	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.280	0.000	0.000
13	0.000	0.080	1.120	0.000	0.000	0.000	0.000	0.120	0.000	0.329	0.000	0.000
14	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.891	0.000	0.331	0.000	1.091
15	0.000	0.000	0.000	0.000	0.000	0.020	0.000	0.111	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.040	0.000	0.000	0.000	4.360	0.000	0.020	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.180	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.620	0.000	3.211	0.000	0.000	0.000	0.771
19	0.000	0.050	0.000	0.800	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.000
20	0.000	0.000	0.590	0.100	0.000	0.000	0.000	0.000	0.140	0.000	0.000	0.250
21	0.000	0.000	0.000	0.000	0.000	0.000	1.160	0.000	0.000	0.000	0.000	0.320
22	0.000	0.000	0.620	0.000	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.020	0.800	0.070	0.850	0.000	0.000	0.000	0.000	0.030	0.000
24	0.020	0.700	0.000	0.910	5.201	0.200	0.000	0.190	0.000	0.000	0.000	0.000
25	0.010	0.000	0.000	0.570	0.700	0.000	0.000	0.600	0.000	0.190	0.070	0.110
26	0.000	0.000	0.000	0.040	0.030	0.130	0.130	0.150	0.000	0.980	0.000	0.000
27	0.000	0.510	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.030	0.000	0.000
28	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.400	0.000	0.000
29	0.000	0.000	0.000	0.030	0.000	0.070	0.000	0.000	0.000	0.360	0.000	0.000
30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.020
31	0.000	0.000	0.000	0.000	0.330	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table D2. DAILY RAINFALL IN INCHES AT THE AURORA SITE

	1973					MONTH						
DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.240	0.000	0.000	2.760	0.000	0.000	0.300	0.000	0.000	0.000	0.000	0.000
2	0.190	0.010	0.060	0.670	0.000	0.000	0.000	1.400	0.000	0.200	0.000	0.000
3	0.000	1.000	0.170	0.060	0.210	0.000	0.000	0.950	0.000	0.200	0.000	0.000
4	0.250	0.000	0.290	0.040	0.210	0.000	0.020	0.280	0.000	0.000	0.000	0.000
5	0.000	0.000	0.150	0.020	0.000	0.000	0.100	0.020	0.000	0.100	0.000	0.150
6	0.140	0.000	0.080	0.000	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000
7	0.000	0.120	0.040	0.000	0.300	0.000	0.000	0.000	0.010	0.200	0.000	0.000
8	0.030	0.000	0.010	1.360	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.210
9	0.250	0.000	0.000	0.000	0.371	0.000	0.000	0.000	0.310	0.000	0.020	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.000	0.000	0.000	0.000
11	0.000	1.100	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020
12	0.000	0.000	0.220	0.000	0.010	0.000	0.000	0.400	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.000	0.000	0.170	0.010	0.000	0.000	0.000	0.000	0.540
14	0.000	0.000	0.000	0.000	0.110	0.050	0.000	0.000	0.120	0.000	0.000	0.000
15	0.000	0.740	0.000	0.000	0.119	0.000	0.170	0.060	0.000	0.000	0.000	0.000
16	0.000	0.050	0.000	0.000	0.000	0.000	0.000	0.230	0.000	0.000	0.010	0.000
17	0.090	0.000	0.000	0.000	0.000	0.000	0.020	0.040	0.000	0.000	0.000	0.000
18	0.000	0.000	0.660	0.000	0.010	0.170	0.000	0.030	0.700	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.390	0.000
20	0.190	0.000	0.000	0.000	0.200	0.560	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.300	0.000	0.000	0.460	0.000	0.010	0.000	0.000	0.000	0.000
22	0.000	0.000	0.210	0.000	0.000	0.070	0.000	0.000	0.000	0.000	0.000	0.000
23	0.470	0.000	0.000	0.000	0.120	1.550	0.220	0.160	0.000	0.000	0.000	0.000
24	0.000	0.000	0.000	0.000	0.420	0.000	0.000	0.150	0.000	0.000	0.000	0.000
25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26	0.000	0.010	0.260	0.280	0.000	0.100	0.000	0.170	0.000	0.000	0.000	0.000
27	0.220	0.290	0.060	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28	0.000	0.010	0.000	0.000	0.000	0.000	1.750	0.000	0.000	0.000	0.050	0.000
29	0.220	0.000	0.000	0.000	0.010	2.177	0.000	0.000	0.000	0.030	0.000	0.000
30	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000
31	0.000	0.000	0.060	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000

Table D2. DAILY RAINFALL IN INCHES AT THE AURORA   SITE

| | | 1974 | | | | MONTH | | | | | | |
DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.249	0.000	0.000	0.000	0.000	1.090	0.000	0.570	1.120	0.000	0.000	1.300
2	0.020	0.150	0.000	0.000	0.150	0.340	0.000	0.240	0.080	0.000	0.000	0.000
3	0.060	0.540	0.000	0.000	0.000	0.000	0.000	0.000	0.600	0.000	0.000	0.000
4	0.070	0.000	0.000	0.020	0.000	0.000	0.000	0.760	0.010	0.000	0.000	0.000
5	0.080	0.000	0.000	0.650	0.490	0.040	0.130	0.720	0.000	0.000	0.010	0.000
6	0.000	0.020	0.000	0.100	0.000	0.000	0.130	0.320	0.300	0.000	0.010	0.650
7	0.030	0.130	0.000	0.000	0.000	0.100	0.120	0.900	0.320	1.030	0.000	0.770
8	0.000	0.040	0.000	0.070	0.000	0.010	0.380	0.020	0.000	0.000	0.000	0.000
9	0.080	0.000	0.000	0.580	0.480	0.000	0.000	2.850	0.000	0.000	0.000	0.000
10	0.020	0.000	0.000	0.000	0.010	0.000	0.000	0.010	0.000	0.000	0.000	0.000
11	0.080	0.000	0.170	0.000	0.330	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.250	0.000	0.480	0.000	0.000	0.000	0.000	0.000	0.100	0.080
13	0.000	0.000	0.080	0.830	0.000	0.030	0.000	0.000	0.000	0.000	0.000	0.010
14	0.000	0.140	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.070	0.000	0.000	0.000	0.000	0.000	0.120	0.000	0.000	0.000	0.000
16	0.000	0.390	0.520	0.000	0.000	0.050	0.640	0.000	0.000	2.120	0.000	0.090
17	0.000	0.810	0.000	0.000	0.000	0.230	0.010	0.000	0.920	0.000	0.000	0.040
18	0.040	0.000	0.000	0.000	0.150	0.010	0.000	0.000	0.600	0.000	0.730	0.000
19	0.160	0.720	0.230	0.010	0.020	0.000	0.000	0.770	0.000	0.610	0.000	0.010
20	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.520	0.940
21	0.250	0.000	0.130	0.000	0.000	0.000	0.140	0.130	0.000	0.000	0.000	0.190
22	0.020	0.220	0.000	0.000	0.000	0.000	0.630	0.050	0.090	0.000	0.000	0.010
23	0.000	0.000	0.010	0.150	0.230	0.590	0.000	0.650	0.600	0.000	0.000	0.000
24	0.000	0.000	0.000	0.000	0.350	0.010	0.000	0.000	0.000	0.000	0.000	0.000
25	0.000	0.000	0.610	0.000	0.200	0.250	0.140	1.130	0.000	0.000	0.000	0.020
26	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.140	0.000
27	0.000	0.000	0.010	0.000	1.490	2.060	0.630	1.000	0.040	0.000	0.000	0.260
28	0.140	0.000	0.040	0.000	0.000	0.010	0.000	0.000	0.190	0.000	0.000	0.360
29	0.560	0.000	0.730	0.000	0.000	0.020	0.000	0.000	0.000	0.000	0.000	0.000
30	0.240	0.000	0.020	0.000	0.460	0.000	0.000	0.000	0.000	0.000	0.000	0.000
31	0.010	0.000	0.000	0.000	0.010	0.000	0.150	0.640	0.000	0.000	0.000	0.000

Table D2. DAILY RAINFALL IN INCHES AT THE AURORA   SITE

| | | 1975 | | | | MONTH | | | | | | |
DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.020	0.000	0.000	0.380	0.230	0.000	0.000	0.000	0.180	0.000	0.000	0.000
2	0.000	0.380	0.000	0.710	0.220	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.090	0.000	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.420	0.990	0.000	0.000	0.000	0.000	1.260	0.000	0.000	0.600	0.000	0.000
5	0.500	0.270	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.420	0.000	0.000
6	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.200	0.000	0.040	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.430	0.380	0.000	0.000	0.000	0.070
8	0.280	0.000	0.020	0.000	0.000	0.000	0.070	0.000	0.000	0.030	0.120	0.540
9	0.000	0.000	0.000	0.120	0.000	0.000	0.550	0.210	0.000	0.040	0.030	0.200
10	0.000	0.000	0.000	0.000	0.000	0.000	0.090	0.000	0.000	0.000	0.000	0.000
11	1.360	0.000	0.030	0.650	0.090	0.000	1.140	0.000	0.000	0.000	0.000	0.000
12	0.480	0.010	0.010	0.150	0.270	0.000	0.700	0.000	0.510	0.000	0.000	0.000
13	0.560	0.000	0.060	0.000	0.000	0.000	0.510	0.000	0.020	0.000	0.590	0.000
14	0.000	0.000	1.330	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	1.130	0.010	0.000	0.000	0.000	0.000	0.000	0.040	0.000
16	0.000	0.500	0.000	0.000	1.870	0.000	0.710	0.000	0.860	0.000	0.000	0.350
17	0.000	0.000	0.500	0.000	0.010	0.000	0.670	0.440	0.000	0.190	0.000	1.170
18	0.080	0.010	0.000	0.000	0.000	0.000	0.160	0.030	0.030	1.900	0.000	0.000
19	0.000	0.650	0.390	0.000	0.300	0.000	0.000	0.000	0.360	0.000	0.000	0.000
20	0.540	0.000	0.000	0.620	0.000	0.000	0.140	0.000	0.000	0.000	0.000	0.040
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020
22	0.000	0.000	0.120	0.000	0.000	0.000	0.000	0.000	0.300	0.000	0.000	0.000
23	0.060	0.000	0.000	0.000	2.120	0.000	0.000	0.000	1.100	0.000	0.000	0.000
24	0.300	0.260	0.020	0.000	0.000	0.000	0.000	0.000	0.180	0.130	0.630	0.000
25	0.750	0.000	0.000	0.000	0.490	0.000	0.040	0.000	0.970	0.350	0.000	0.040
26	0.000	0.000	0.000	0.000	0.000	0.000	0.190	0.000	0.430	0.350	0.000	1.270
27	0.000	0.000	0.000	0.000	0.000	1.340	0.000	0.000	0.020	0.000	0.000	0.000
28	0.000	0.020	0.000	0.000	0.000	1.310	0.000	0.000	0.000	0.000	0.000	0.000
29	0.000	0.000	0.060	0.000	0.000	0.080	0.000	0.000	0.210	0.000	0.000	0.000
30	0.000	0.000	0.000	0.000	0.200	0.000	0.000	0.000	0.010	0.000	0.000	0.690
31	0.000	0.000	0.000	0.000	0.000	0.000	0.140	0.000	0.000	0.000	0.000	0.000

Table D2.　DAILY RAINFALL IN INCHES AT THE AURORA SITE

1976 MONTH

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.000	0.900	0.000	0.110	0.000	0.000	0.250	0.010	0.000	0.000	0.000	0.000
2	0.000	0.060	0.000	0.000	0.000	0.000	0.080	0.280	0.290	0.000	0.000	0.000
3	0.000	0.000	0.000	0.060	0.060	1.000	1.110	1.150	0.000	0.000	0.000	0.000
4	0.130	0.000	0.000	0.000	0.000	0.160	0.060	0.010	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.540	0.000	0.000	0.000	0.000	0.000
7	0.050	0.000	0.000	0.000	0.260	0.000	1.010	0.000	0.000	0.000	0.000	0.360
8	0.590	0.000	0.000	0.700	0.050	0.000	0.010	3.160	0.000	0.000	0.000	0.380
9	0.020	0.000	0.470	0.000	0.000	0.000	0.450	0.240	0.000	0.550	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.150	0.000	0.830	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.030	0.000	0.000	0.060	0.000	0.000	0.000	0.180
12	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.820
13	0.000	0.000	0.090	0.000	0.160	0.220	0.000	0.000	0.000	0.000	0.000	0.070
14	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.080	0.000	0.000	0.270	0.010	0.000	2.570	0.000	1.700	1.190
16	0.120	0.000	0.590	0.000	0.270	0.010	0.010	0.270	0.000	0.000	0.000	0.410
17	0.140	0.000	0.000	0.000	0.760	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.020	0.910	0.000	0.000	0.000	0.000	0.510	0.000	0.000
19	0.000	0.000	0.000	0.000	0.800	0.040	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.680	0.000	0.230	0.000	1.640	0.000	0.080
21	0.060	0.110	0.000	0.000	0.000	1.130	0.000	0.470	0.160	0.000	0.000	0.010
22	0.000	0.260	0.000	0.000	0.000	1.200	0.660	0.000	0.030	0.000	0.000	0.000
23	0.000	0.120	0.000	0.000	0.000	0.000	0.850	0.000	0.000	0.000	0.000	0.000
24	0.000	0.000	0.000	0.000	0.380	0.210	0.160	0.000	0.000	0.000	0.000	0.000
25	0.000	0.000	0.000	0.000	0.000	0.000	0.090	0.000	0.000	0.010	0.000	0.030
26	0.290	0.000	0.000	0.000	0.000	0.430	0.000	0.000	0.000	0.160	0.240	0.000
27	0.060	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.260	0.000
28	0.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.760	0.000
29	0.000	0.000	0.000	0.080	4.170	0.000	0.000	0.000	0.000	0.000	0.060	0.000
30	0.000	0.000	0.180	0.070	0.000	0.540	0.030	0.000	0.510	0.000	0.000	0.000
31	0.000	0.000	0.020	0.000	0.000	0.000	0.480	0.000	0.000	0.830	0.000	0.000

Table D2.　DAILY RAINFALL IN INCHES AT THE AURORA SITE

1977 MONTH

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.000	0.000	0.000	0.000	0.000	0.560	1.500	0.330	0.000	0.200	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.090	0.630	0.000	0.000	0.000	0.000
3	0.190	0.000	0.000	0.000	0.000	0.000	0.000	1.820	0.010	0.000	0.000	0.000
4	0.020	0.000	0.300	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.090	0.000	0.000	0.200	0.280	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.731	0.000	0.000	0.270	0.280	0.000	0.000	0.000	0.000	0.000
7	0.430	0.000	0.880	0.000	0.510	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.321	0.060	0.000	0.000
9	0.490	0.000	0.000	0.000	0.000	0.400	0.000	0.000	0.240	0.090	0.000	0.000
10	0.410	0.000	0.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	1.220	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.080	0.840	0.000	0.000	0.000	0.000	0.070	0.000	0.000	0.000	0.000
14	0.730	0.000	0.600	0.000	0.000	0.050	0.000	0.290	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.000	0.090	0.000	0.060	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.330	0.000	0.000	0.000	0.190	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.390	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.350	0.000	1.800	0.000	0.000	0.000	0.000
19	0.000	0.050	0.000	0.000	0.000	0.210	0.000	0.370	0.270	0.000	0.000	0.000
20	0.000	0.060	1.150	0.000	0.120	0.210	0.440	0.000	0.040	0.000	0.000	0.000
21	0.000	0.000	0.470	0.130	0.010	0.000	0.000	0.005	0.150	0.000	0.000	0.000
22	0.000	0.000	0.271	0.000	0.000	0.000	0.630	0.000	0.050	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.020	0.270	0.000	0.000	0.060	0.000	0.000	0.000
24	0.301	0.779	0.000	0.000	4.021	0.010	0.000	0.000	0.100	0.000	0.000	0.000
25	0.060	0.000	0.000	0.300	0.250	0.130	0.000	0.000	0.000	0.000	0.000	0.000
26	0.000	0.000	0.000	0.270	0.000	0.010	0.690	0.000	0.000	0.000	0.000	0.000
27	0.000	0.650	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29	0.000	0.000	0.080	0.070	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30	0.000	0.000	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
31	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table D3. DAILY RAINFALL IN INCHES AT THE LAURINBURG SITE

1976

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.420	0.390	0.000	0.030	0.790	0.210	0.000	0.480	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.560	0.000	0.000	0.500	0.030	0.630	0.000	0.000
3	0.000	0.000	0.000	0.000	0.590	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.050	0.000	0.000	0.000	0.950	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.360	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.200	0.000	0.000	0.700	0.000	0.040	0.000	0.000	0.000	0.000
7	0.020	0.000	0.000	0.000	0.000	0.000	0.570	0.200	0.000	0.000	0.000	0.010
8	0.850	0.000	0.000	0.000	0.000	0.000	0.370	0.000	0.000	0.000	0.000	0.670
9	0.010	0.000	0.250	0.000	0.210	0.000	0.380	0.000	0.000	0.000	0.000	0.150
10	0.021	0.000	0.250	0.000	0.270	0.000	0.000	0.574	0.000	0.040	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.160
13	0.010	0.000	0.040	0.000	0.010	0.085	0.000	0.000	0.000	0.000	0.000	0.390
14	0.000	0.000	0.030	0.000	0.320	0.210	0.000	0.000	0.100	0.000	0.240	0.040
15	0.000	0.000	0.000	0.000	0.450	0.020	0.000	0.000	0.590	0.000	1.999	0.000
16	0.020	0.000	0.000	0.000	0.550	0.850	0.030	0.000	0.000	0.000	0.670	0.000
17	0.020	0.000	0.800	0.000	0.150	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.450	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.070	0.000	0.000	0.000	0.710	0.010	0.000	0.000	0.020	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.470	2.330	0.010	0.000	0.020
21	0.000	0.110	0.000	0.000	0.000	0.000	0.000	0.070	0.470	0.330	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.430	0.500	0.000	0.000
23	0.000	0.000	0.000	0.040	0.000	0.000	0.700	0.000	0.000	0.670	0.000	0.000
24	0.010	0.000	0.000	0.000	0.000	0.035	0.000	0.000	0.000	0.000	0.000	0.000
25	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100	0.000	0.000	0.000
26	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.100	0.290	0.000	0.000
27	0.410	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.510	0.000	0.270	0.000
28	0.860	0.000	0.000	0.000	0.110	0.100	0.000	0.000	0.000	0.000	0.000	0.000
29	0.000	0.000	0.000	0.000	0.180	0.490	0.000	0.000	0.000	0.000	0.020	0.000
30	0.000		0.250	0.000	0.000	0.020	0.010	0.000	0.000	0.000	0.000	0.000
31	0.000		0.250		0.190		0.000	0.000		0.050		0.000

Table D4. DRAIN OUTLET WATER LEVEL ELEVATIONS (ABOVE DATUM) AT THE PLYMOUTH SITE

1973

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.0	0.0	0.0	0.0	19.5	19.8	19.8	58.3	18.6	21.0	33.6	27.9
2	0.0	0.0	0.0	0.0	20.0	19.4	19.4	56.0	18.4	35.5	32.8	27.6
3	0.0	0.0	0.0	0.0	20.5	18.5	37.0	66.5	18.2	39.3	32.2	27.3
4	0.0	0.0	0.0	0.0	21.5	17.7	66.0	74.5	19.0	35.0	32.0	27.1
5	0.0	0.0	0.0	0.0	21.4	17.4	77.5	72.1	19.3	33.9	32.0	27.0
6	0.0	0.0	0.0	0.0	20.5	17.1	74.0	54.1	18.5	36.0	32.0	27.0
7	0.0	0.0	0.0	0.0	19.5	29.6	69.5	29.6	18.5	33.0	31.9	27.0
8	0.0	0.0	0.0	0.0	19.6	17.0	64.2	21.6	18.0	38.0	31.8	39.0
9	0.0	0.0	0.0	0.0	19.2	16.5	64.2	22.2	18.0	51.0	31.8	27.0
10	0.0	0.0	0.0	0.0	20.5	16.5	59.0	21.5	18.0	74.5	31.7	52.0
11	0.0	0.0	0.0	0.0	20.8	16.5	69.5	21.0	18.0	86.1	31.5	0.0
12	0.0	0.0	0.0	0.0	20.4	15.3	78.2	21.0	17.7	92.5	31.4	0.0
13	0.0	0.0	0.0	0.0	20.1	14.9	80.5	21.5	16.9	98.0	31.3	0.0
14	0.0	0.0	0.0	0.0	19.4	19.0	73.5	22.0	16.3	102.0	31.1	0.0
15	0.0	0.0	0.0	0.0	19.5	18.5	65.8	21.3	16.3	101.5	31.0	0.0
16	0.0	0.0	0.0	0.0	19.6	16.5	58.6	20.5	16.8	104.0	30.8	0.0
17	0.0	0.0	0.0	0.0	19.2	15.5	56.3	20.5	16.4	107.0	30.6	0.0
18	0.0	0.0	0.0	0.0	19.0	15.5	54.0	21.4	15.4	100.9	30.5	0.0
19	0.0	0.0	0.0	18.9	18.8	14.5	54.0	23.5	15.4	67.5	30.3	0.0
20	0.0	0.0	0.0	18.9	19.7	16.5	59.0	24.0	14.8	30.1	30.1	0.0
21	0.0	0.0	0.0	18.4	19.2	16.5	69.5	24.5	14.1	40.2	29.9	0.0
22	0.0	0.0	18.2	18.8	19.0	18.5	73.0	24.5	13.0	36.6	29.5	0.0
23	0.0	0.0	18.8	18.3	19.4	15.9	80.5	24.0	13.3	35.0	29.1	0.0
24	0.0	0.0	18.7	20.4	19.5	18.5	77.5	22.2	13.6	33.9	28.8	0.0
25	0.0	0.0	18.7	21.4	19.3	18.5	57.1	20.2	13.3	32.7	28.4	0.0
26	0.0	0.0	16.6	22.0	20.4	21.5	61.7	20.2	13.2	32.5	28.0	0.0
27	0.0	20.0	18.3	22.0	19.9	19.5	61.7	19.8	13.5	32.7	27.7	0.0
28	0.0	21.2	18.6	21.0	19.9	19.3	61.3	19.6	13.0	31.6	27.3	0.0
29	0.0		19.6	21.0	18.6	19.3	61.9	19.5	13.0	31.3	27.1	0.0
30	0.0		19.1	20.3	18.9	19.0	67.4	19.2	13.0	34.0	27.6	0.0
31	0.0		19.5		18.7		61.5	18.7		34.3		0.0

Table D4. DRAIN OUTLET WATER LEVEL ELEVATIONS (ABOVE DATUM) AT THE PLYMOUTH SITE

1974   MONTH

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	9.7	9.8	8.3	6.2	4.1	5.5	5.0	7.5	6.6	5.6	5.5	5.9
2	9.7	9.8	8.1	5.7	4.1	5.2	4.8	7.3	6.5	5.4	5.4	6.6
3	9.8	9.8	7.8	5.4	4.2	6.3	4.6	8.8	6.6	5.2	5.4	6.6
4	9.8	9.8	7.6	5.4	4.2	5.8	4.5	8.4	6.6	5.1	5.2	6.5
5	9.8	9.8	7.4	6.0	4.2	5.4	4.4	10.4	6.5	5.0	5.0	6.5
6	9.6	9.8	7.2	5.8	4.9	5.2	5.6	10.4	6.5	4.9	5.0	6.3
7	10.7	9.8	7.0	5.5	4.9	4.8	5.6	10.4	7.1	4.8	4.8	6.2
8	10.4	10.0	6.8	5.2	4.9	5.0	6.1	7.3	7.0	4.7	4.6	6.7
9	10.2	9.8	6.6	5.8	4.8	5.0	7.8	7.2	7.0	4.6	4.5	7.1
10	10.2	9.6	6.4	5.6	4.8	5.0	9.2	7.2	6.9	4.4	4.4	7.0
11	9.9	9.4	6.2	5.4	4.8	4.9	9.2	7.1	6.9	4.3	4.3	6.9
12	9.7	9.2	6.4	5.1	4.7	4.8	9.2	7.0	6.6	4.2	4.2	6.8
13	9.4	8.8	6.7	4.8	4.7	4.7	8.6	7.0	6.6	4.2	4.2	6.8
14	9.2	8.6	6.6	7.2	4.6	4.6	8.6	6.9	6.4	4.1	4.1	6.7
15	9.2	8.8	6.4	6.5	4.5	4.5	7.8	6.9	6.2	4.0	4.0	6.6
16	9.0	8.6	6.3	5.9	4.4	4.4	6.6	6.8	6.2	4.0	3.9	6.7
17	8.7	10.4	9.1	5.6	4.4	4.3	6.2	8.6	6.5	4.8	3.8	6.8
18	8.6	10.0	6.0	5.3	4.3	4.1	5.8	8.6	6.8	5.6	3.8	6.7
19	8.4	10.6	4.0	5.0	5.0	3.9	6.2	10.6	6.8	5.8	3.9	6.5
20	8.4	10.3	5.4	4.9	5.0	3.7	6.9	10.8	6.8	6.4	3.9	6.8
21	8.2	10.0	5.8	4.7	5.0	3.5	6.1	7.2	6.6	6.5	4.2	7.5
22	9.6	9.8	5.6	4.6	4.9	3.4	5.2	7.2	6.6	6.4	4.8	8.2
23	9.5	10.0	5.2	4.6	4.8	3.2	5.1	7.2	6.5	6.3	5.0	8.1
24	9.2	9.6	5.2	4.5	4.8	3.4	5.4	7.1	6.4	6.2	5.0	7.9
25	9.8	9.5	5.2	4.4	4.7	3.5	5.9	7.0	6.2	6.1	5.0	7.9
26	9.8	9.0	6.4	4.4	4.6	3.4	6.2	7.0	6.0	6.0	5.1	7.7
27	10.2	8.9	6.1	4.3	7.4	3.6	7.3	7.0	6.0	5.9	5.2	7.6
28	10.0	8.9	5.8	4.3	6.7	5.0	7.0	6.9	5.8	5.8	5.2	8.2
29	10.0	0.0	5.6	4.2	6.1	5.1	6.6	6.9	5.8	5.7	5.2	8.5
30	10.0	0.0	7.1	4.2	5.8	5.1	7.2	6.8	5.8	5.6	5.1	8.4
31	10.0	0.0	6.9	0.0	5.6	0.0	7.2	6.8	0.0	5.5	0.0	8.2

Table D4. DRAIN OUTLET WATER LEVEL ELEVATIONS (ABOVE DATUM) AT THE PLYMOUTH SITE

1975   MONTH

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	80.5	78.0	42.5	37.0	36.0	37.0	53.5	59.0	28.5	72.5	41.5	40.5
2	78.5	81.0	42.5	36.5	36.5	36.5	51.0	56.5	28.5	71.0	41.0	40.5
3	82.0	83.5	42.0	37.0	37.0	36.0	48.5	54.0	28.5	68.5	40.5	40.0
4	85.5	85.0	42.0	36.0	36.0	34.5	47.5	52.5	28.5	66.5	40.0	40.0
5	83.0	89.5	42.0	35.0	35.0	32.0	48.0	50.5	28.5	65.0	40.0	39.5
6	84.0	87.5	42.0	34.0	34.0	30.5	47.0	48.5	28.5	65.0	40.0	39.0
7	84.5	85.5	41.0	33.0	34.0	25.0	47.5	48.5	36.0	63.5	40.0	39.5
8	87.5	83.5	40.5	33.0	36.5	29.5	51.0	48.0	46.5	62.0	39.5	45.0
9	85.0	81.5	40.5	33.5	38.5	29.5	52.0	47.0	54.5	61.5	39.5	52.5
10	87.0	79.5	42.5	33.5	38.5	29.0	50.5	45.5	53.0	61.5	39.5	51.0
11	89.5	78.0	40.0	33.5	38.0	29.0	67.0	44.0	51.5	60.5	39.5	45.5
12	93.5	77.5	38.0	34.0	38.0	29.0	85.5	43.0	49.5	59.0	41.0	43.5
13	92.5	76.5	36.5	33.0	38.0	29.0	90.0	42.0	47.5	57.5	39.5	43.0
14	89.5	75.0	38.5	32.5	37.5	29.0	87.5	40.5	45.5	56.5	38.5	43.0
15	87.5	74.0	39.0	56.0	37.5	29.0	84.0	39.0	44.0	55.0	38.5	43.5
16	85.5	84.0	45.5	47.0	38.0	45.5	95.5	37.5	48.0	54.0	37.5	43.0
17	84.5	93.0	43.5	43.0	37.5	51.5	95.5	35.5	54.5	53.5	37.5	44.0
18	83.5	90.5	50.5	43.0	37.5	55.0	81.5	32.0	54.5	66.5	37.0	45.5
19	87.5	92.0	17.0	41.0	37.5	63.5	65.5	24.5	54.0	79.0	36.5	45.5
20	89.0	90.5	28.0	41.5	37.0	57.0	63.5	29.0	52.5	78.0	36.0	44.5
21	87.0	87.5	30.0	40.0	36.5	56.0	63.0	28.5	52.0	76.0	35.5	44.0
22	86.0	86.5	30.5	38.5	36.0	50.5	62.0	28.5	59.5	73.0	35.5	43.5
23	87.0	86.5	30.5	37.5	35.5	57.5	62.0	28.5	72.0	70.5	38.0	43.0
24	90.5	86.0	24.5	36.5	35.0	60.0	62.0	28.5	77.5	69.0	41.0	43.0
25	89.0	87.5	35.5	36.0	36.0	52.5	68.5	28.5	75.5	68.0	41.0	42.5
26	86.0	67.5	38.0	35.5	37.5	54.5	65.0	28.5	78.5	74.5	40.5	49.0
27	84.5	47.0	37.5	35.5	37.5	23.5	63.0	28.5	81.0	82.5	40.5	59.0
28	82.5	44.0	37.5	36.0	37.0	23.0	62.0	28.5	78.5	80.5	40.0	48.0
29	81.0	0.0	37.5	35.0	37.0	58.5	61.5	28.5	76.0	62.5	40.0	47.0
30	79.5	0.0	37.0	34.5	37.0	56.5	60.5	28.5	74.0	44.5	40.0	51.5
31	79.0	0.0	37.0	0.0	37.5	0.0	59.5	28.5	0.0	42.5	0.0	55.0

Table D4. DRAIN OUTLET WATER LEVEL ELEVATIONS (ABOVE DATUM) AT THE PLYMOUTH SITE

DAY	JAN	FEB	1976 MAR	APR	MAY	MONTH JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	56.5	55.0	39.0	41.5	29.0	57.0	69.0	46.0	29.5	44.5	37.7	62.5
2	50.5	57.5	39.0	41.0	31.5	64.0	84.0	45.5	29.5	44.0	37.0	60.5
3	49.5	53.0	39.0	40.5	34.2	67.5	75.0	45.0	29.5	43.0	36.5	59.5
4	48.5	50.5	39.0	39.5	33.5	62.5	66.0	46.0	29.5	42.5	35.7	58.7
5	48.0	49.5	38.5	39.5	31.7	59.7	57.0	45.0	29.5	42.5	34.7	57.7
6	47.0	48.0	41.0	39.2	30.0	58.7	48.0	43.5	29.5	41.5	33.5	56.5
7	48.0	47.0	41.0	38.7	29.5	57.7	38.0	42.5	29.5	41.0	32.7	57.0
8	52.0	46.5	41.0	38.7	30.5	57.0	38.5	41.5	29.5	40.0	31.5	63.5
9	50.5	45.0	45.5	38.7	29.7	56.7	37.5	45.5	29.5	41.0	30.5	70.0
10	49.5	45.0	44.5	38.2	30.0	56.2	38.0	49.0	34.0	44.0	29.5	70.0
11	48.0	44.5	43.5	37.7	30.0	55.7	39.0	49.5	40.5	43.5	29.5	74.0
12	47.5	44.5	43.0	36.7	30.5	55.0	40.0	47.0	41.0	43.0	29.5	82.2
13	46.5	44.5	42.5	36.2	37.0	54.0	41.5	46.0	41.5	42.2	29.7	82.5
14	46.0	46.0	42.0	35.2	44.5	54.5	43.5	45.5	41.0	41.5	29.5	83.5
15	45.5	44.5	41.5	34.7	44.0	54.0	42.5	45.2	48.0	40.0	40.0	83.5
16	46.5	44.0	44.0	33.5	43.5	54.0	42.0	45.0	53.0	39.0	54.0	90.5
17	48.5	43.5	43.5	33.0	48.0	55.0	40.0	44.0	50.5	38.5	55.5	88.5
18	48.0	43.5	43.0	32.5	47.0	54.0	38.5	43.5	49.5	38.5	56.5	86.0
19	47.5	42.7	42.0	32.0	45.7	54.0	38.0	41.5	48.5	37.5	56.0	85.5
20	47.0	42.5	41.7	30.5	45.2	53.0	37.0	40.5	47.5	39.0	55.5	68.0
21	48.0	42.0	41.5	30.5	44.5	52.0	36.0	40.0	46.0	42.7	55.0	51.0
22	48.0	42.5	41.0	30.0	43.7	51.0	39.0	39.0	45.0	42.6	54.0	49.5
23	47.5	42.0	40.5	30.0	43.0	50.0	48.0	37.7	44.5	42.5	53.5	47.5
24	47.0	42.0	40.5	29.5	42.5	49.5	46.0	35.5	43.7	41.7	52.7	46.5
25	46.0	41.5	40.5	30.0	45.0	47.0	45.5	32.0	42.5	41.5	50.5	46.0
26	47.0	41.0	40.5	29.2	48.0	46.5	44.5	30.0	42.0	41.0	52.0	47.5
27	51.0	40.5	40.0	29.0	52.0	46.0	44.0	30.0	40.5	39.0	54.0	49.5
28	53.5	40.0	39.7	29.0	56.0	45.0	45.5	29.5	41.0	38.5	53.0	47.5
29	50.5	39.5	39.5	29.0	60.0	44.5	45.0	29.5	40.5	38.0	58.0	56.5
30	49.5	0.0	40.5	29.0	60.0	43.5	46.0	29.5	42.5	37.0	60.5	57.0
31	47.5	0.0	41.5	0.0	60.0	0.0	47.5	29.5	0.0	37.5	0.0	57.5

Table D4. DRAIN OUTLET WATER LEVEL ELEVATIONS (ABOVE DATUM) AT THE PLYMOUTH SITE

DAY	JAN	FEB	1977 MAR	APR	MAY	MONTH JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	53.5	73.1	54.7	39.7	30.9	41.8	49.5	30.3	37.5	30.0	46.1	42.3
2	52.9	60.6	54.2	39.5	29.5	50.0	49.5	30.1	37.4	30.0	45.3	41.5
3	52.8	49.8	53.8	39.3	29.5	51.2	44.5	32.4	36.0	30.0	44.9	41.5
4	52.6	50.5	55.5	39.1	29.5	46.1	42.9	36.1	33.7	30.0	47.3	41.5
5	52.4	49.5	57.2	39.5	29.5	44.3	41.6	36.7	31.7	30.0	49.4	42.1
6	52.1	48.0	58.4	38.8	29.5	43.5	40.8	33.5	31.0	30.0	79.8	42.7
7	54.0	48.1	63.4	38.3	36.8	44.3	40.0	30.6	31.0	30.0	98.5	42.2
8	53.0	49.1	62.7	37.8	41.5	43.1	39.3	30.0	43.8	30.0	80.0	42.0
9	52.8	49.5	54.0	37.2	38.3	47.0	38.5	30.0	53.1	30.5	66.7	41.8
10	54.0	49.8	46.0	36.3	37.3	48.0	38.3	30.0	46.5	30.5	54.6	41.5
11	47.3	50.0	44.3	34.7	36.5	45.1	38.3	30.0	42.9	30.0	48.4	41.3
12	56.6	50.3	42.8	32.9	35.8	43.4	39.3	40.8	41.2	34.7	46.2	41.1
13	68.9	50.3	47.3	31.1	35.1	42.1	38.6	41.5	40.3	41.2	44.9	41.0
14	79.6	50.3	49.0	29.9	33.9	41.1	36.8	35.9	39.8	46.3	44.0	45.5
15	87.3	49.8	46.1	29.6	32.3	40.6	34.0	35.2	39.0	45.8	43.9	50.0
16	89.1	49.5	44.5	29.5	31.1	40.0	31.7	73.5	38.2	42.5	43.6	48.0
17	89.7	49.6	43.8	29.5	30.3	43.5	31.5	90.8	37.3	40.8	43.3	46.0
18	89.8	49.7	42.8	29.5	30.0	45.1	30.8	91.0	36.7	39.8	43.1	52.5
19	89.3	49.7	41.8	29.8	30.0	45.1	44.3	93.7	35.6	39.3	42.8	57.1
20	79.1	49.8	42.5	29.7	30.0	42.8	42.6	74.2	33.2	38.8	42.5	52.3
21	68.2	49.9	43.7	29.5	30.0	40.6	46.8	64.0	30.8	38.3	42.3	51.0
22	65.7	49.9	45.4	29.5	30.0	39.4	54.0	57.5	30.0	38.0	42.1	53.3
23	63.6	49.8	45.4	29.5	30.0	40.1	54.3	53.5	30.0	37.8	42.8	50.0
24	63.4	51.8	44.0	31.3	56.6	41.8	50.3	53.5	30.0	37.5	43.5	46.4
25	65.4	54.8	43.9	35.5	74.5	40.7	46.2	55.2	30.0	37.3	43.9	45.6
26	71.3	54.6	42.8	37.0	55.5	39.9	43.5	52.7	30.0	49.8	44.3	45.0
27	76.7	54.6	41.5	36.8	47.1	39.3	41.5	49.2	30.0	53.6	43.8	44.3
28	78.7	54.8	40.9	35.5	44.1	38.8	39.2	45.8	30.0	52.3	43.4	43.8
29	78.2	0.0	40.5	34.7	42.8	38.3	37.1	43.1	30.0	63.8	43.1	43.4
30	76.3	0.0	40.2	33.3	41.5	38.0	34.1	40.1	30.0	53.8	43.0	51.8
31	74.6	0.0	39.9	0.0	40.8	0.0	31.2	37.5	0.0	48.3	0.0	56.3

Table D5. DRAIN OUTLET WATER LEVEL ELEVATIONS (ABOVE DATUM) AT THE LAURINBUR SITE

DAY	JAN	FEB	1976 MAR	APR	MAY	MONTH JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	80.5	73.0	59.5	60.0	43.0	51.0	56.0	56.0	9.0	9.0	33.5	55.0
2	80.5	79.5	59.5	58.5	43.0	52.5	56.0	56.0	9.0	9.0	32.0	54.0
3	80.5	78.5	59.0	58.0	43.0	53.5	56.0	56.0	9.0	9.0	31.0	53.0
4	80.5	78.0	59.0	57.5	43.0	58.5	56.0	56.0	9.0	9.0	30.0	51.5
5	80.5	76.0	59.0	56.0	43.0	58.5	56.0	14.5	9.0	9.0	28.5	51.0
6	80.5	75.5	60.0	55.5	43.0	58.5	56.0	12.0	9.0	9.0	28.5	53.5
7	80.5	74.0	59.0	55.0	43.0	58.5	56.0	10.5	9.0	9.0	27.5	58.0
8	80.5	73.0	58.5	54.5	43.0	58.5	56.0	13.5	9.0	9.0	26.5	59.0
9	77.0	72.0	59.0	54.0	43.0	58.5	56.0	11.5	9.0	9.0	26.5	58.5
10	75.0	71.0	59.0	53.0	43.0	58.5	56.0	11.0	9.0	9.0	25.0	57.5
11	74.0	70.0	56.0	52.0	43.0	58.5	56.0	10.5	9.0	9.0	24.5	68.0
12	73.0	69.0	56.0	51.5	43.0	58.5	56.0	10.0	9.0	9.0	22.0	68.5
13	72.0	68.5	57.5	51.0	43.0	58.5	56.0	9.0	9.0	9.0	21.0	65.5
14	70.5	68.0	56.5	50.5	41.5	58.5	56.0	9.0	9.0	15.0	21.0	65.5
15	69.0	67.5	56.5	49.0	62.5	58.5	56.0	9.0	9.0	21.0	56.0	71.0
16	69.0	67.0	57.0	48.5	72.0	58.5	56.0	9.0	9.0	27.0	70.0	76.0
17	68.5	67.0	71.0	47.5	66.0	58.5	56.0	9.0	9.0	31.0	62.5	74.0
18	67.5	66.5	69.0	47.0	61.5	58.5	56.0	9.0	9.0	39.0	59.0	72.0
19	67.0	66.5	68.0	47.0	59.0	58.5	56.0	9.0	9.0	45.0	57.0	70.0
20	67.0	65.5	67.5	47.0	56.0	58.5	56.0	9.0	9.0	52.0	55.0	67.0
21	67.0	65.0	67.0	46.0	55.0	58.5	56.0	9.0	9.0	75.0	54.0	65.5
22	66.0	65.5	66.5	46.0	54.0	58.5	56.0	9.0	9.0	52.0	52.0	65.0
23	65.5	64.5	65.5	45.5	52.5	58.5	56.0	9.0	9.0	45.0	51.0	65.0
24	65.0	63.5	64.5	44.0	51.0	58.5	56.0	9.0	12.0	41.5	50.0	64.5
25	64.5	62.0	64.0	43.5	50.0	58.5	56.0	9.0	15.0	39.5	50.0	63.5
26	65.0	61.0	63.5	43.5	49.0	58.5	56.0	9.0	18.0	41.5	49.5	66.0
27	72.0	60.5	63.0	42.0	48.0	58.5	56.0	9.0	24.0	41.5	50.0	67.0
28	79.0	60.5	62.0	41.0	47.5	58.5	56.0	9.0	18.0	37.0	51.0	66.0
29	76.0	60.0	60.5	41.0	47.0	58.5	56.0	9.0	12.0	36.0	56.0	66.0
30	74.5	0.0	60.0	41.0	48.5	58.5	56.0	9.0	9.0	35.0	55.5	66.0
31	74.0	0.0	60.5	0.0	49.5	0.0	56.0	9.0	0.0	35.0	0.0	66.0