Hydrologic simulation of depressional watersheds

Kenneth Leonard Campbell

Iowa State University

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by

Kenneth Leonard Campbell

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INTRODUCTION

Millions of acres of agricultural land in the Midwest have been drained artificially since the early 1900s to accelerate the removal of excess water from the soil surface (surface drainage) and the crop root zone (subsurface drainage). The effects of man on floods through this artificial land drainage have been debated for years. Woodward and Nagler (1929) concluded from their study that agricultural drainage has had a negligible effect upon either the total flow or maximum discharge of floods. However, others have stated that agricultural drainage has greatly increased flood peaks due to faster removal of surface runoff water. Two examples of the latter point of view are an article in Engineering News-Record (Anonymous, 1969) and one by Heins (1965). Linsley and Franzini (1972) indicate that land-drainage operations tend to increase floods by accelerating runoff of soil water and by eliminating natural water storage in ponds and swamps. However, they also contend that a full reservoir may accelerate flood flows. This could also apply to surface depressions in a drainage watershed. If so, draining the depressions would be preferable. In addition, drained soils and surface depressions provide considerable storage capacity and could contain much of the potential storm runoff and release it at a relatively slow rate.
Hollander (1968) discussed the role of subsurface drainage systems in the management of cornbelt agricultural lands. He indicated that during periods of excessive rainfall the surface depressions characteristic of north central Iowa topography (Figure 1) hold large volumes of runoff. The underground tile lines which serve as outlets for these depressions release the water at a controlled rate and thus serve an important secondary function of flood detention.

On the other hand, Sokolovskii (1971) indicated that drainage of swamps in regions with adequate or excess moisture does not reduce the annual runoff, but as a result of a more intensive discharge of floods leads to a considerable increase in the peaks of spring and rainfall floods with a simultaneous reduction in the duration of flooding.

One possible explanation for part of the disagreement on the effects of drainage on floods is that many times the type of drainage (surface or subsurface) is not specified. Surface drainage of depressions almost completely eliminates the surface storage capacity while subsurface drainage removes the water stored on the surface over a longer period of time.

Haan and Johnson (1968a) developed a mathematical model to investigate the effect of depression drainage on flood peaks. They found that for long-duration, low intensity runoff events the peak flow increased with increasing depression drainage. They also found that for storms with
Figure 1. Storage of water in surface depressions in East Fork Hardin Creek Watershed
relatively high intensities and large volumes of runoff the peak flow was unchanged by drainage. DeBoer (1969) developed a hydrologic mathematical watershed model for drainage watersheds with depressional storage. He found that subsurface tile drainage has a minor effect on major flood peak discharges, however, for smaller storms undrained watershed flows were smaller and of longer duration than drained watershed flows. Such results indicate there is no simple answer to the question of the effect of agricultural drainage on flood flows.

The Upper Mississippi River Comprehensive Basin Study (UMRCBS Coordinating Committee, 1970) indicates that research in this area is needed. This study states:

Another aspect of land development is the probable effect of agricultural drainage on flood flows and water yield. To date the available research shows no significant effects. This inability to discern the possible effects does not mean that there are none. In this area, understanding is limited by the knowledge and technical ability to properly account for the beneficial and adverse effects and the relative importance of each. Traditionally, land drainage and channel improvements have been viewed by the general public as flood producers. The complex interplay of water storage in the soil profile and on the land surface does influence the time-discharge relationship. The net effect of past and expected further land development for land drainage is not well understood. There are, however, positive as well as negative aspects to be considered relative to the water resource when such projects are undertaken on a large scale for the development of land for agricultural purposes.

Additional research is needed in this subject matter, particularly in the northern areas where snow accumulation is a significant factor relative to major flood events.
Iowa State Water Resources Research Institute Advisory Board personnel pointed out related research needs (Iowa State Water Resources Research Institute, 1970, 1971). The U.S. Corps of Engineers suggested studies on (1) effect of agricultural drainage practices on tributary peak discharges and (2) continued studies of hydrology of small watersheds. The Iowa Natural Resources Council suggested research in hydrology and planning with emphasis given to the smaller (150 sq. mi. or less) drainage areas.

Watersheds with large amounts of surface storage and subsurface drainage are representative of most of north central Iowa and southern Minnesota. Large areas of Illinois, Indiana, Ohio, and Michigan also have extensive surface and subsurface drainage. There is need in these areas for design information for surface drainage and drainage district tile systems. The complexity of water movement through these drainage watersheds with depressional storage requires the development of mathematical models to simulate the physical processes taking place within the watershed. A deterministic mathematical watershed model of the type being developed by this research may provide this design information. The model should be able to simulate the various hydrologic processes, the movement of excess water through the drainage watershed, and the soil moisture status of the crop root zone on a continuous basis. As this is accomplished and the climatic variable,
soil moisture, and crop response relationships are better understood, the problem of drainage economics for watersheds and individual farms can be examined.

There is need today for a better understanding of nutrient movement through the soil within the hydrologic system. Future work concerning nutrient movement within agricultural watersheds will require a knowledge of the patterns of water flow by surface and subsurface drainage for water quality studies. These patterns can be determined by use of a mathematical watershed model such as that developed by this research. As we further develop expertise in the modeling of hydrologic systems sub-models can be added to the basic hydrologic model to determine plant nutrient loads delivered in drainage waters.

In flat-land watershed modeling a relatively deterministic simulation approach is needed to include the effects of the range of possible drainage practices which may be carried out in watersheds with depressional storage. Such an approach is being used in the development of the ISU hydrologic model. The primary objective of this research is to develop a mathematical model for drainage watersheds which will continuously simulate the soil moisture level throughout the

\footnote{ISU hydrologic model is hereafter used to refer to the model developed by Agricultural Engineering staff at Iowa State University for the recently glaciated regions of north central Iowa, Minnesota and Illinois.}
crop root zone and provide a continuous simulation of watershed discharge during the crop season.
The objectives of this research are as follows:

1. To improve the determination of the piezometric head at each depression within an elemental watershed,

2. To investigate a branched flow system as compared with the existing ISU hydrologic model's approximation of the branched flow system,

3. To develop a continuous simulation of watershed discharge with the ISU hydrologic model,

and

4. To verify the ISU hydrologic model with field discharge measurements and independent data from the East Fork Hardin Creek Watershed.
REVIEW OF HYDROLOGIC WATERSHED MODELING

There has been much emphasis on the development of hydrologic watershed models during the past 10 years. One reason for this emphasis has been the use of the river basin as a unit for natural resources planning. The present concern for environmental quality is another reason for this emphasis on hydrologic modeling. Since water is a transporting medium for many pollutants, comprehensive hydrologic watershed models are necessary to predict changes in water quality due to man's activities. Hydrologic models are also required in studying and predicting the effects of watershed modifications. Eagleson (1970) indicated a growing need for physically realistic simulations of hydrologic system behavior. He pointed out that optimization of the design and operation of systems of hydraulic structures, as well as real-time forecasting, often requires the complete time history of the response of a hydrologic system. This involves the dependent (output) variables of a nonlinear hydrologic-hydraulic system, the parameters of which are increasingly subject to change by man. To obtain these desired output variables it becomes convenient to pass the independent (input) variables of the hydrologic-hydraulic system through a simulation or model of the system dynamics.

Woolhiser (1971) investigated several existing watershed
models regarding their potential for use in predicting water quality changes. Mathematical models may be subdivided into theoretical models and empirical models. Empirical models are developed from data and cannot be used to predict if conditions change. Theoretical models, however, are similar to the real world system and may be helpful in prediction if conditions change. He concluded that empirical, lumped-system models will be useful tools for predictions involving substances naturally present in the environment and currently being monitored. On the other hand, to evaluate the environmental effect of new substances before release or changes in the transport system itself, theoretical models appear to be the only possible approach.

Larson (1971) discussed the use of hydrologic models in determining the effects of modifying small watersheds. Since past records cannot be directly used for future prediction if the watershed is being modified, his discussion is concerned only with deterministic watershed modeling. This type of watershed model is composed of many component models, each of which represents one of the hydrologic processes, e.g., infiltration and evapotranspiration. In general, models in which all parameters are physical characteristics of the watershed are preferred for applications involving watershed modifications. However, this requires a good understanding of the processes involved and a complete set of physical data.
describing the system. If a conceptual type watershed model in which some parameters are determined by fitting is to be useful in predicting effects of watershed modification, some other means of determining the modified parameter values is necessary since these parameters will not be measurable. He concluded that if the parameters of the various model components are physical watershed characteristics that can be measured for the present condition, they can probably be estimated for the future condition, so that the effects of watershed modification can be predicted without difficulty.

In modeling the effect of watershed modifications, Onstad and Jamieson (1970) concluded that the simulation model should be able to show the sensitivity of the hydrologic response to the extent of watershed modification as reflected in the modified parameters of the model. This implies the assumption that the parameters have physical significance and indicates the need for a realistic conceptual model.

It appears that a deterministic mathematical model, based on theoretical processes, which uses physical characteristics of the watershed as parameters is preferable for prediction of watershed modification effects and impact of movement of substances not presently monitored through the hydrologic system. However, until our modeling expertise develops sufficiently to allow this, it is realistic to assume that conceptual models with some empirically determined
parameters will necessarily be used in modeling some hydrologic processes. This literature review is concerned with some of the recent deterministic mathematical watershed modeling developments.

Some Recently Developed Hydrologic Models

One of the first general watershed models developed was the Stanford Model (Crawford and Linsley, 1966). This model has been developed and improved over the past ten years and is the best known hydrologic watershed model in current use. Linsley, Crawford and associates have made some changes and refinements in the Stanford Model and are presently using it in a consulting business. Haan (1967) and DeBoer (1969) have reviewed the Stanford Model in some detail. Also included in their reviews of mathematical modeling are several other hydrologic models developed during the 1960s.

Dawdy (1969) presented a comprehensive discussion of the role of mathematical modeling in hydrology. Recent developments in hydrology have been mainly mathematical in nature. He stated that the use of mathematical tools in hydrology has provided new possibilities for solution of water resources problems and concluded that a knowledge of these new tools is a necessity for the modern hydrologist. Larson (1971), Woolhiser (1971) and Dawdy (1969) include rather extensive
bibliographies of hydrologic watershed models that have been developed during the past ten years. Several different models are reviewed in these papers.

Holtan and Lopez (1971) described the USDAHL-70 model of watershed hydrology. This model was developed with a multidisciplinary approach including meteorology and climate, soils and vegetation, hydraulics, hydrogeology, and watershed hydrologic systems. It is the beginning of an effort to express watershed hydrology as a continuum. The model is currently empirical in nature, however, these empiricisms are to be replaced by logical explanations of the physical processes as the continuum is developed for practical use. The model was designed to help bridge the gap between theory and practice by providing a framework in which new basic knowledge can be applied to watershed modeling. It is structured to allow addition of improved subroutines without disturbing other routines in the model as each component of the hydrologic process is improved through research.

One example of component testing within a watershed model is reported by England and Coates (1971). They used the USDAHL-70 model of watershed hydrology to predict evapotranspiration and percolation in lysimeters at Coshocton, Ohio. The model is constructed so that output can be obtained from individual component processes within the hydrologic system. This allows for multiple uses for the model or various parts
of it, as well as providing means for testing and continued improvement of each individual component of the model.

Bird and McCorquodale (1971) developed a computer simulation of agricultural tile drainage systems. Their mathematical model was based on an existing available soil moisture model and an empirical drainage model. The water balance model considered two soil moisture storage phases - the available soil moisture and the gravitational or ground water. Their mathematical water balance model predicted the performance of a tile system by predicting the tile runoff hydrographs.

Freeze (1972) has investigated the mechanism of base flow generation and the nature of watershed response in base flow dominant streams with a deterministic mathematical model. The model couples together three-dimensional, transient, saturated-unsaturated subsurface flow (Freeze, 1971) and one-dimensional, gradually varied, unsteady channel flow. The model is based on numerical solutions to the coupled boundary value problems expressed by the differential equations of subsurface and channel flow. Due to the size and complexity of the subsurface portion of the model, it is presently best suited to simulation of individual hydrologic events on a subwatershed scale, i.e., on individual slopes feeding single streams. The goal is development of a rigorous, physically-based mathematical model of the complete hydrologic system (Freeze
and Harlan, 1969). As growth in computer capacity continues and our understanding of physical hydrologic processes grows this may become possible.

Moore and Claborn (1971) developed a modified version of the Stanford Watershed Model IV. They developed new components for depression storage, infiltration, soil moisture storage, and soil moisture movement based on unsaturated flow theory which conform more realistically to soil physics principles. Their simulation model emphasized surface storage, infiltration, and soil moisture phases as significant in determining the stream flow. However, the time distribution of runoff is still treated very simply by a distribution graph technique used in the Stanford Watershed Model IV.

Most Watershed models available for use today still have at least some components that are empirical in nature since our understanding of the hydrologic processes and modeling expertise have not developed to the point that all parameters are measurable watershed characteristics. Due to this fact some better means of evaluating parameters which must be determined by fitting is needed. This has led to research involving the development of computerized optimization techniques (Decoursey and Snyder (1969) and James (1970)) to determine parameters of watershed models which are not directly measurable physical characteristics. Hopefully this should
permit more successful hydrologic modeling as these techniques are refined.

Many other things can limit simulation accuracy. The combined effects of differences in time distribution of rainfall and spatial variability of rainfall volume over a watershed limit the possible accuracy of simulation results. The transfer of errors from rainfall to runoff depends on the regional rainfall variability and the amount of averaging of errors achieved by the particular watershed hydrology. Dawdy and Bergmann (1969) found that the use of a single rain gage in their particular 9.7 sq. mi. watershed could be expected to predict peak discharge within about 20 percent. They concluded that the limiting factor for accuracy in most rainfall-runoff simulation studies will be the random errors of rainfall measurement. Also, errors in potential evapotranspiration input data can influence simulation accuracy significantly. Parmele (1972) studied this effect on nine watersheds ranging in size from 3.1 sq. mi. to 296 sq. mi. using three different hydrologic models. He found that a constant bias of 20 percent in the potential evapotranspiration input data had a cumulative effect and resulted in considerable error in the computed peak discharges and recession characteristics. However, the influence of a random error in the potential evapotranspiration input data on simulated streamflow was generally not measurable for the watersheds and
models studied. From the two preceding studies it appears that the quality of the input data is very important in achieving reasonably accurate simulation results no matter how well the various hydrologic model parameters may be estimated.

Iowa State University Hydrologic Watershed Model

The basic concept of the ISU hydrologic model was devised by Haan (1967). The basic approach was similar to that used by Machmeier and Larson (1967) in which a watershed is divided into elemental watersheds (Figures 2 and 3). The assumption of this approach is that each elemental watershed can be modeled separately and the outflows combined through channel flood routing techniques to produce the total watershed discharge hydrograph. This procedure simplifies calculations required by allowing a very few basic types of elemental watersheds to be used repeatedly in making up the complete watershed.

A basic assumption of the model is that the elemental watersheds can be represented by a series of depressions (potholes), each with its contributing watershed area as shown in Figure 3. This assumption was investigated during this research and will be discussed later. The hydraulic model (Haan and Johnson, 1968b) utilized excess rainfall as
Figure 2. Model watershed divided into elemental watersheds

Figure 3. Typical elemental watershed
input to the elemental watershed. This excess water was routed to the outlet by use of the basic continuity equation:

\[ I(t) - O(t) = \frac{d[S(t)]}{dt} \]  \hspace{1cm} (1)

where

- \( I(t) \) is the inflow to a depression
- \( O(t) \) is the outflow from a depression
- \( S(t) \) is the storage in a depression,

and

- \( t \) is time.

The excess water was routed from one depression to the next through a surface inlet in the bottom of the depression and through an overland channel when the water surface elevation in the depression reached the overflow elevation as is shown in Figure 4. The basic routing relationship was applied in sequence to each depression in the elemental watershed beginning with the upper depression and ending at the drainage ditch.

The discharge from the elemental watersheds was routed down the drainage ditch by use of the kinematic flood routing method developed by Brakensiek (1967). This simplified routing procedure seems sufficiently accurate for this application. It solves the continuity equation

\[ \frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \]  \hspace{1cm} (2)
Figure 4. Cross-section of an elemental watershed
and a rating function

\[ Q = Q(A) \]  

where

- \( Q \) is the flow rate
- \( A \) is the flow area
- \( q \) is the lateral inflow (+) or outflow (-)
- \( x \) is the distance along the channel,

and

- \( t \) is time.

Equations 2 and 3 were solved for the downstream flow area of each stream reach at the end of a routing time interval by using finite difference techniques. In this manner the flow was routed downstream to the watershed outlet.

The hydraulic model made use of drained and undrained elemental watersheds or a combination of them in watershed simulation. The drained elemental watersheds had surface inlets in all depressions while the undrained had none. This model provided for the removal of drainage water only through the surface inlets and therefore did not simulate the removal of excess water which moves through the soil to the water table.

The model did not contain an overland flow routing process. The travel time of water from the time it enters the depression until it reaches the watershed outlet was
assumed to be much longer than the travel time from rainfall impact until it reaches the depression. Therefore, overland flow time was ignored.

Haan (1967) also developed a mathematical model to generate synthetic elemental watersheds typical of north-central Iowa. These elemental watersheds were used in his hydraulic simulation model. A study of the physical characteristics of north-central Iowa by Haan and Johnson (1967) was used as a basis for generating the elemental watersheds. Haan (1967) developed a relationship for the size distribution of depressions, a volume-surface area relationship, a volume-depth relationship, and a depression contributing area-surface area relationship which were used in the watershed generation model. Elemental watershed parameters required included the average land slope, tile slope, depth of drainage ditch, drainage coefficient, initial water depth in a depression, and the three parameters of the Weibull probability density function used to describe the depression size distribution.

DeBoer (1969) presents a critical analysis of Haan's hydraulic watershed model. He pointed out that the model simulates the hydraulic aspects of a drainage watershed but does not simulate the hydrologic aspects of a watershed since it uses excess rainfall as input rather than precipitation. He also suggested that the omission of an overland flow
routing routine could be critical in some cases, such as where the outflow hydrograph is desired from only one or two depressions in series.

The second major phase of research on the ISU hydrologic model was conducted by DeBoer (1969). He refined portions of the original model and added land phase components of the hydrologic cycle to expand the model's applicability. The model uses hydrologic relationships, with precipitation as input, to derive depressional-area and tile-main inputs (excess water) for the hydraulic model. Figure 5 is a schematic diagram of the conceptual model developed by DeBoer and Johnson (1971) that uses precipitation as input. The combined model simulated the hydrology of a drainage watershed from precipitation input to a watershed outflow hydrograph on an individual storm basis.

Interception storage was not included in the model. Precipitation that reached the soil surface was stored on the surface and infiltrated, evaporated or allowed to leave as surface runoff.

The infiltration component of the model used the approach proposed by Holtan (1961) and modified by Huggins and Monke (1968) in the following form:

\[ f = f_c + A \left[ \frac{S-F}{P} \right]^P \]  

(4)
Figure 5. Schematic diagram of conceptual watershed model
where

\[ f \] is infiltration capacity

\[ f_c \] is steady-state infiltration capacity

A and P are coefficients

S is total storage potential of a soil above an impeding layer

F is total volume of water infiltrated,

and

\[ P \] is total porosity of the soil above the impeding layer

This method has a provision for infiltration recovery, however soil parameter values required for its use are scarce.

The movement and storage of infiltrated water within the soil profile was included in the model; this component was a simple approximation of the process. Evapotranspiration was provided for only in the upper part of the soil profile and at a constant rate. No means of soil moisture redistribution was provided. This component was satisfactory for simulating a single storm event, but would not be adequate for continuous simulation over a period of days or weeks.

The subsurface drainage system as used in the model is shown in Figure 6. The approach used is that of Toksoz and Kirkham (1961) as shown in the following equation:

\[ H = \frac{S}{K} \left[ \frac{R}{1-R/K} \right] F(r/S,d/S) \] (5)
Figure 6. Schematic of model subsurface drainage system
where

- \( H \) is the maximum height of the water table above the level of the drain centers
- \( K \) is the hydraulic conductivity of the soil
- \( R \) is the average rate of seepage to the water table as well as tile outflow
- \( S \) is the drain spacing
- \( r \) is the radius of drains
- \( d \) is the distance to an impermeable layer below the drain centers,

and

\[
F(r/S, d/S) = \frac{1}{\pi} \left[ \ln \frac{S}{\pi r} + \sum_{m=1}^{\infty} \frac{1}{m} \left( \cos \frac{2m\pi r}{S} - \cos m\pi \right) \left( \cosh \frac{2md}{S} - 1 \right) \right].
\]

Lateral tile discharges and water table elevations were simulated by a solution to the two-dimensional problem of the seepage of steady rainfall into a homogeneous soil drained by tile (Equation 5) and the continuity equation (Equation 1). This approach used the assumption that the lateral and sub-main tile lines have sufficient capacity to carry all discharges without being under pressure.

A schematic summary of the model simulation of water movement from precipitation down to the water table and out the lateral tile line is shown in Figure 7. Water that moves from groundwater storage through the soil and emerges as base flow in the drainage ditch was not considered in the
Figure 7. Schematic diagram of water movement through the soil profile to the lateral tile.
model. The subsurface drainage systems produce the base flow discharges for the model.

The ISU hydrologic model as developed by DeBoer and Johnson (1971) has four drainage options which can be used for an elemental watershed. They are: (1) no drains, (2) subsurface drains, (3) surface-inlet drains, or (4) surface-inlet-and-subsurface drains. The soil parameters that control the hydrologic processes can also be different for each elemental watershed. The model was developed for use in drainage watersheds with extensive depressional storage and its application should be confined to areas with similar topography.

An important feature of a comprehensive watershed model is the ability to generate a continuous synthetic hydrologic record from continuous input data. It should be noted that DeBoer and Johnson's model permits simulation only on an individual storm basis. Therefore, to make the model more useful it should be further developed to allow continuous simulation. To permit this a more extensive soil moisture component needs to be developed to continuously simulate the soil moisture content in zones as affected by infiltration, evapotranspiration, percolation to the water table, and soil moisture redistribution. The model also needs to be modified to allow seepage of ponded water from the surface depressions into the soil profile.
Evapotranspiration and Soil Moisture Models

An important component of any comprehensive hydrologic watershed model is a soil moisture model that will adequately simulate moisture movement into, out of, and within the soil profile. The physical processes involved in modeling this segment are perhaps the least understood of any in the hydrologic cycle. For this reason many empirical relations are common even though the basic approach to developing the model may be based on a mathematical expression of the physical processes as they are presently understood. Considerable work has been done recently in developing soil moisture models to be used for various purposes. Some of this research will be reviewed here.

Vaigneur and Johnson (1966) developed design criteria for tile drain spacing in agricultural soils. Their method was based on a moisture balance in which excess moisture in the soil profile was determined by use of a water balance. This excess moisture accretion was then used to calculate daily water table heights. A similar study by Young and Ligon (1972) resulted in the development of a computer model to calculate daily water table height and soil moisture content in the root zone.

Jones and Verma (1971) developed a soil moisture model, however their model did not simulate evapotranspiration from
plants. Only infiltration into and evaporation from a bare soil surface were simulated by the model.

Jensen, Wright, and Pratt (1971) developed a soil moisture depletion model for use in irrigation scheduling. Their model used climatic data as well as soil and crop data as input to determine the evapotranspiration from the soil profile. This model was designed for use in arid areas in the management of irrigation farms.

Hanks, Klute, and Bresler (1969) described a method for estimating one-dimensional infiltration, redistribution, evaporation, and drainage of water from soil. Their method used numeric procedures to solve the nonlinear partial differential equation of water flow in one dimension through porous media. The removal of water from the soil profile by plants through evapotranspiration was not considered.

Shaw (1963) developed an empirical method for estimation of soil moisture in the root zone under row crops. His method was based on open-pan evaporation as a measure of the potential for evapotranspiration. The pan evaporation was adjusted for the stage of crop development and moisture stress conditions which might exist due to high atmospheric demand. The evapotranspiration thus determined was withdrawn from the soil profile at various depths according to the plant root distribution for the time of year. During the spring period water loss by evaporation and transpiration from the
top 6 inches was assumed to average 0.1 inch per day. After October 1, evaporation was assumed to be 35 percent of pan evaporation, and after November 1, 0.1 inch per week. This method included no procedure for redistribution of soil moisture within the root zone soil profile over time.

Saxton (1972) developed a mathematical model to simulate the soil moisture in the crop root zone on a day-to-day basis. The three major components of his soil moisture model are (1) calculation of the actual evapotranspiration (ET) and extraction from the soil profile, (2) addition of infiltration to the soil profile, and (3) redistribution of the soil moisture within the soil profile.

The first component involved the separation of the energy used in each major part of the evapotranspiration process. A flow chart of the processes involved in the conversion of energy from potential ET to actual ET is shown in Figure 8. The first use of potential ET was in evaporation of interception from the plant and soil surfaces if precipitation occurred. The remaining energy was separated into energy used in soil evaporation and plant transpiration. Actual soil evaporation was a function of the moisture content in the top 6 inches. A portion of the unused energy for soil evaporation was transferred to the plant canopy for use in transpiration. The remaining energy was transferred to energy sinks such as soil heat.
Figure 8. Flow chart of the potential to actual ET energy conversions (Saxton, 1972, p. 48)
The potential energy available for plant transpiration was reduced by a factor determined by the plant's phenological state which represented its ability to transpire. The remaining energy was divided among the 6 inch soil zones according to the root distribution of the plant. Reductions in actual transpiration due to plant moisture stress were then applied to each soil zone. The soil moisture crop stress was a function of the moisture content in the soil zone and the level of atmospheric demand. The calculated actual ET was then the sum of the actual transpiration from each soil zone, actual soil evaporation from the upper zone, and interception evaporation. This amount was withdrawn from the moisture in the soil profile according to the calculated actual ET from each 6 inch soil zone.

The second component of Saxton's model involved the addition of daily infiltration to the soil profile. He used the difference between average watershed precipitation minus interception storage and watershed runoff in inches for an infiltration amount and assumed no time distribution. Infiltration was considered to be stored in the upper soil zones as required without exceeding 0.9 of saturation.

The final component of Saxton's soil moisture prediction model was the vertical soil moisture redistribution within the soil profile. He used the one-dimensional Darcy equation for unsaturated flow which uses moisture-tension and moisture-conductivity relationships in the following form:
\[ q = K \frac{\partial (H+Z)}{\partial Z} \Delta T \]  

where

- \( q \) is vertical water movement, \( \text{cm}^3/\text{cm}^2 \)
- \( K \) is unsaturated conductivity, \( \text{cm/min} \)
- \( H \) is soil moisture tension head, \( \text{cm} \)
- \( Z \) is elevation head, \( \text{cm} \)
- \( \Delta T \) is time increment, \( \text{min} \)

The moisture content of two adjacent 6 inch soil zones determined their respective tensions and average conductivity, which were used to calculate the amount and direction of soil moisture movement between adjacent zones. Moisture contents for each zone were adjusted for this moisture movement after each time increment and new tensions and conductivities determined for the next period. The moisture content of the soil directly below the soil profile was held constant and percolation to or from the profile was allowed.

The calculations described above in the three components of the model were performed in the order discussed and thus established the soil moisture profile conditions for the next day's calculations.
HYDRAULIC HEAD CALCULATION METHOD

Basic Approach

The method developed to calculate the hydraulic head or piezometric head in the main tile at each surface inlet utilizes a basic continuity equation approach. The point at which each surface inlet is connected to the main tile line is used as a junction about which the inflow must equal the outflow as shown in Figure 9. This approach requires an iterative solution since the head at any inlet becomes dependent upon the head at inlets both above and below it along the main tile line.

The initial head in the main tile at each inlet is assumed equal to the elevation of the water surface in the main tile during a period of low flow. Calculation of the head at each inlet for successive time increments begins at the outlet using the head for the preceding time increment as an approximation for the present head at the next upstream inlet along the main tile. After the head in the main tile has been calculated in this manner at each inlet, the calculated head at each inlet is compared with the approximation used in the calculations. If any of these values are not within a specified tolerance the heads are all recalculated using the previously calculated heads as approximations for the new calculations.
At each inlet there are two possible types of flow which may control the flow rate depending upon the magnitude of the hydraulic head and water depth in the depression. Weir flow is a function of water depth expressed as

\[ Q_2 = KLD^{1.5} \]  
(7)

where

Q2 is water flow rate into inlet  
K is a weir coefficient  
L is circumference of inlet,  
and  
D is water depth in depression

Short tube flow is described by the equation for a standard short tube

\[ Q_2 = CA\left[ 2g(E-H) \right]^{0.5} \]  
(8)

where

Q2 is water flow rate into inlet  
C is an orifice coefficient for short tube  
A is cross-sectional area of inlet  
g is acceleration of gravity  
E is water surface elevation in depression,  
and  
H is hydraulic head in main tile at inlet.

Weir flow occurs when the following conditions are satisfied:
1. Water surface elevation in the depression is greater than the hydraulic head in the main tile at the inlet,

2. Water depth in the depression is less than the diameter of the surface inlet, and

3. The weir flow rate is less than the short tube flow rate for the same water depth and hydraulic head.

If any one or more of these conditions is not satisfied, short tube flow occurs.

The flow in the main tile line is calculated by use of Manning's equation for full pipe flow

\[ Q = \frac{0.463}{n} D^{8/3} \left( \frac{H_i - H_{i+1}}{L} \right)^{1/2} \]  

where

- \( Q \) is water flow rate in main tile
- \( n \) is roughness coefficient for tile
- \( D \) is tile diameter
- \( H \) is hydraulic head at inlets \( i \) and \( i+1 \),

and

- \( L \) is main tile length between inlets

Since the slope used in Equation 9 is the hydraulic grade line in the main tile between two inlets, flow under pressure may occur in the tile main as is actually the case in many field situations.
Comparison with Previous Method

The computational technique used in the above method of hydraulic head calculation is more firmly based on hydraulics than that of DeBoer (1969). However, it requires more iteration to arrive at an acceptable solution and is therefore more expensive to use than DeBoer's (1969) SUBROUTINE HEAD. DeBoer's SUBROUTINE does not allow the reverse flow through inlets into depressions which sometimes occurs in actual field situations. This situation is included in the present SUBROUTINE HEAD.

Newton's Method (Henrici, 1964) is used in the iterative solution for the hydraulic head at each inlet. An attempt was made to use Bailey's Iterative Method (McCalla, 1967) since it has faster convergence, but in certain flow situations the discharge vs. head function resulted in extremely large values of the second derivative which caused stability and convergence problems in the solution. Satisfactory convergence was achieved with Newton's Method in combination with a simple bisection method if solution oscillation occurred. This same numerical solution technique is used in several components of the ISU hydrologic model, however DeBoer's SUBROUTINE HEAD did not use this technique. His approach resulted in a rough approximation of the hydraulic head, required much less iteration time, and was, therefore, cheaper to use.
Elemental watershed discharge hydrograph comparisons using the present SUBROUTINE HEAD and DeBoer's SUBROUTINE HEAD are shown in Figures 10 and 11. The present head calculation method yields larger peak discharges, but the flow decreases faster than by DeBoer's method. Also, by the present method the flow returns to zero as the depressions empty when there is no subsurface drainage; this did not occur when using DeBoer's method as indicated in Figure 10. DeBoer's SUBROUTINE HEAD caused some erratic elemental watershed outflows as shown in Figure 11. This problem was not present in the new hydraulic head calculation method. These erratic outflows were smoothed by the ditch routing routine; however, the resulting hydrograph was higher and flatter than expected in this portion (Figure 12). The elemental watershed outflows with surface inlets only on a smaller scale (Figure 10) resulted in discharge hydrographs which were very similar after ditch routing (Figure 13), except for the failure of the hydrograph by DeBoer's method to return to zero flow.

Conclusions

The hydraulic head calculation method developed in this research is more rigorously based on the hydraulics of flow than the method previously used in the ISU hydrologic model. Therefore, the results can be relied upon with more confidence.
Figure 10. Discharge hydrographs from an elemental watershed with 5 depressions, surface inlets and overland flow.
Figure 11. Discharge hydrographs from an elemental watershed with 24 depressions, surface inlets, subsurface drainage and overland flow.
Model with revised HEAD routine

--- DeBoer's model
Figure 12. Discharge hydrographs from a watershed made up of elemental watersheds with 24 depressions, surface inlets, subsurface drainage and overland flow.
Figure 13. Discharge hydrographs from a watershed made up of elemental watersheds with 5 depressions, surface inlets and overland flow
One of the disadvantages of this solution is that considerably more computer time is required; the ISU hydrologic model is consequently more expensive to use with the new method.

After weighing the advantages and disadvantages of the two hydraulic head calculation methods, the newly developed method was chosen to be used in the ISU hydrologic model for the remainder of the research to be conducted. The increased reliability of the results was considered to be worth the increased cost for research purposes as an attempt was made to better understand the physical system and how it operates. If the ISU hydrologic model were to be applied on a routine basis to field situations for simulation purposes as a design or planning tool it might not be practical to use such a rigorous approach since acceptable results could probably be obtained with a hydraulic head calculation method which would cost less to operate.
BRANCHED FLOW INVESTIGATION

The ISU hydrologic model is based on the assumption that the elemental watersheds can be represented by a series of depressions, each with its contributing watershed area as indicated previously (Figure 3). This assumption was investigated using a simplified system of three depressions to determine its validity for simulation purposes. It can be observed in nature that all depressions are not connected in series by overland flow paths although many are connected in this fashion. Therefore, a branched system was investigated in which water from two depressions flows directly to another depression, both by overland flow and through surface inlets as shown in Figure 14.

Mathematical Model

A simple, three-depression branched system was developed for the ISU hydrologic model and the outflow hydrograph was compared with that of a three-depression series system of the same watershed area.

Hydraulic head calculation

Adaptation of the ISU hydrologic model to permit simulation with a branched system of depressions involved only minor changes with the exception of SUBROUTINE HEAD discussed in the preceding chapter. Since the hydraulic head in the main tile
Figure 14. Simple branched elemental watershed
at a surface inlet is dependent in part upon the head at inlets upstream, the use of a branched system complicates the head calculation by adding another variable at each inlet. Due to the branching in the main tile the head calculation becomes more complicated as the number of depressions in the elemental watershed increases. This factor makes it impossible to write a generalized subroutine to solve for the hydraulic head at each inlet as was done for the series system.

Due to the complexity involved, only a three-depression branched system was investigated and a subroutine was written specifically for this system to calculate the hydraulic head in the main tile at each surface inlet. The elemental watershed discharge hydrograph from this three-depression branched system was then compared with that from a three-depression series system of the same area.

**Hydrograph comparison with series model**

The discharge hydrographs from the small branched and series model systems are very similar as can be observed in Figure 15. These hydrographs result from surface inlet flow alone since the input was not large enough to cause overland flow from the lower depressions. The only difference occurs at the peak as the branched system creates a slightly larger discharge which declines more rapidly as compared to the
Figure 15. Discharge hydrographs from an elemental watershed with 3 depressions, surface inlets and overland flow.
series system which produces a flat peak. This effect could logically be expected since the flow from both upper depressions reaches the lower depression at nearly the same time in the branched system while water from the uppermost depression in the series system has farther to travel to reach the outlet.

Field Observation

In order to learn more about the hydraulics of field tile systems the Boone-Story Joint Sub-drain No. 1 located southwest of Ames, Iowa was chosen for observation during the period of this research. This drain serves an area of about 1100 acres of typical depressional watershed topography. There are two main branches in the system which join at a surface inlet into a single main tile 28 inches in diameter. Each branch contains surface inlets, several of which are located in roadside ditches.

Staff gages were placed at the surface inlet in one depression on each of the two main branches as well as at the surface inlet at the junction of the two branches with the hope of being able to observe the characteristics of drainage of these depressions due to the hydraulics of the branched system. However, no storm large enough to pond water in these depressions occurred during the two years of observation. One storm resulted in both branches of the
system flowing full and water rising above the tile in the surface inlets; however, the main tile downstream from the junction did not flow completely full.

During this runoff event several velocity measurements were made in the two branches flowing full by use of the fluorescein dye color method (King and Brater, 1963). The water surface elevation was also measured at the surface inlets on the upstream and downstream ends of the tile reaches. This hydraulic head difference was used in Equation 9 to solve for Manning's n, Q being known as the product of the measured velocity and cross-sectional area of the tile. The roughness coefficient values obtained in this manner for the two branches were 0.013 and 0.025. Some difficulty was encountered in distinguishing the color change as the dye passed the downstream inlet. This may account for some of the difference between the two measurements. No further information of value in this research could be obtained from this field branched system since no storm of sufficient magnitude occurred.

Conclusions

Some branching systems of depressions and surface inlets undoubtedly occur in nature and in present drainage systems, respectively. The extent of these systems as compared to series systems is unknown. Unless the differences in outflow
hydrographs for the two types of systems are magnified in larger systems with a greater extent of branching it seems, from this investigation, that the series system representation of natural systems is a good approximation of the more complex branched system. Because of this, the fact that it was impractical to write a hydraulic head calculation subroutine for the branched system on a larger scale and the increased cost, the series system of depressions as originally developed was used in further development of the ISU hydrologic model.
SOIL MOISTURE COMPONENT DEVELOPMENT

One of the objectives of this research is to develop a continuous simulation of watershed discharge through the crop season with the ISU hydrologic model. Previous to this time the ISU hydrologic model was functional only on an individual storm basis. In order to permit continuous simulation a more extensive soil moisture component is needed which will continuously simulate the soil moisture content in zones as affected by infiltration, evapotranspiration, percolation to the water table, soil moisture redistribution, and water table depth. The soil moisture component is very important in simulating watershed discharge because the moisture content in various soil zones significantly affects the amount of infiltration, percolation, and subsurface drainage for a given storm event. This, in turn, will drastically affect the magnitude and shape of the watershed discharge hydrograph.

The work of Saxton (1972), reviewed earlier, was adapted to the hydrologic, soil, and topographic conditions for which the ISU hydrologic model is designed and fitted into the model as an additional major component to permit continuous simulation of the soil moisture status and watershed discharge. The soil-water-air-plant system to be modeled is shown in Figure 16.
Figure 16. Soil-water-air-plant system
Evapotranspiration Calculation

Simulation of the evapotranspiration processes within the soil-water-air-plant system requires the division of the input energy to the system among the many processes involved in evaporation and transpiration of water from the system. The major input to the model is the daily potential ET as a measure of the energy available to produce ET. In the ISU hydrologic model this potential is defined as pan evaporation reduced by a factor of 0.85. This factor probably should vary some with the season of the year, but this average value is well supported by Saxton's work.

Figure 17 is a schematic diagram of the energy division and reduction used to calculate the actual ET in the model. The bottom part of Figure 17 involves actual water movement and will be discussed in the next section.

The first possible use of potential ET is for evaporation of interception water from plant surfaces up to a maximum of 0.10 inch if rainfall has occurred.

The remaining energy is divided between that available for soil evaporation and plant transpiration. This division is based on the percent plant canopy for the time of year. Soil evaporation is assumed to occur only from the top 6 inches of the soil. It occurs at the potential rate for soil moisture greater than 40% and no evaporation occurs below 25% soil moisture according to an empirical relation developed
Figure 17. Schematic diagram of the evapotranspiration energy division and reduction
by Saxton (1972). Some of the evaporation potential not actually used for evaporation becomes available for plant transpiration due to convective turbulence within the plant canopy. The remainder of the unused energy goes into other energy sinks such as heating the soil.

The plant transpiration potential is the sum of the direct potential for transpiration plus part of the unused soil evaporation energy. This potential is first modified by the phenological state of the plant, or its ability to transpire. For example, a green growing crop transpires more than a mature plant with many dry leaves. This is measured as the percent of the crop canopy transpiring based on field observations of the state of the plants throughout the growing season.

Actual transpiration is determined to a large degree by the soil moisture available to the plant. Therefore, it is necessary to know where the plant is seeking water. This is mainly a function of the root distribution and, of course, varies with the time of year. Actual transpiration is also affected by the atmospheric demand level and available soil moisture due to physiological responses in the plant such as stomatal closure. To represent these reductions in the plant transpiration, plant moisture stress relationships developed by Shaw (1963) and modified by Saxton (1972) are used in the model. These relationships are applied to each soil layer
separately according to the extraction pattern as developed by Saxton (1972) to determine the actual plant transpiration.

The actual ET to be withdrawn from the soil moisture profile by layers on a daily basis is the sum of the actual soil evaporation and actual plant transpiration.

Soil Moisture Calculation and Redistribution

The soil moisture calculation and redistribution is based on the division of the crop root zone into 6-inch soil zones. After the actual ET is withdrawn from the soil zones according to the amount and distribution calculated, infiltration is added to the profile and moisture redistribution takes place for each time increment of the day as shown in Figure 17. The selection of these time increments will be discussed later.

Infiltration modification

Saxton's model assumed that infiltrated water was stored uniformly in the top 6-inch soil zone until that zone reached 0.9 of saturation, then additional amounts were cascaded to lower zones with the same restriction. This restriction was revised for use in the ISU hydrologic model.

Infiltration is allowed up to field capacity with unlimited conductivity in the top 6-inch zone and successively in each zone down to 4 feet. Additional amounts are allowed
up to 0.9 of saturation in the 5th foot and in the 5-9 foot zone, which will be discussed in the next section. If subsurface drainage tile is present any additional infiltration is considered to be input to the tile drainage component of the ISU hydrologic model. If subsurface drainage is not present the top 4 feet of the profile are filled to 0.9 of saturation from the bottom up if there is additional infiltration. If the profile is filled to the surface in this manner infiltration ceases and does not occur again until some moisture is used from the profile.

*Alteration to permit subsurface drainage*

Saxton's model was designed for the loess region of western Iowa where the water table is not near the crop root zone. Therefore, his model included the top 6 feet of the soil profile and assumed the soil below this level to be at a constant moisture content, allowing percolation to and from the 6-foot profile. To permit use in the recently glaciated regions of north-central Iowa for which the ISU hydrologic model is designed, this aspect of the soil moisture model has been modified to allow a high water table and the option of subsurface drainage as shown in Figure 16.

Subsurface drain tile, when present, are assumed to be located 4 feet below the soil surface. The 6-inch soil zones are terminated at the 5 foot depth and the next 4 feet of soil
are treated as a single soil zone from 5 to 9 feet. This allows the water table to fluctuate within the 5 to 9 foot zone or above if sufficient moisture is present. When this water table reaches the 4 foot level subsurface drainage begins as indicated in the previous section. Available field data indicate very few instances in which the water table falls below 9 feet during the crop season in this topographic region.

Redistribution method

Following the addition of infiltration, if any, to the soil profile, redistribution of the soil moisture is calculated by the tension-conductivity method as described in Equation 6 for each time period. The redistribution occurs because of changes in moisture content in the various soil zones due to ET and infiltration which result in moisture movement between zones. This movement can be described by moisture-tension and moisture-conductivity relationships for the soils of the region.

The above relationships describing the full range from the wilting point to soil saturation for the Clarion-Webster soil association in this recently glaciated region are very scarce. One reason is undoubtedly the variability of these soils as compared with the loess soils of western Iowa. Some data were found for Webster soils and the conductivity and
tension relationships used in the ISU hydrologic model are based on this data. Nielsen (1958) and Nielsen, Kirkham, and Perrier (1960) include a limited amount of tension and conductivity data for Webster soils, but it is all for moisture contents near field capacity and above.

Fritton (1968) and Fritton, Kirkham, and Shaw (1970) developed a moisture-tension curve and moisture-conductivity curve for Webster silty clay loam. These relationships as shown in Figures 18 and 19 respectively were used in the ISU hydrologic model.

The model also requires values of the wilting point, field capacity, and saturation for each soil zone. These values were determined from data gathered by DeBoer (1969) and data presented by Shaw, Nielsen, and Runkles (1959). The values used are shown in Table 1.
Figure 18. Soil tension-moisture relationship for Webster silty clay loam
VOLUMETRIC MOISTURE CONTENT, %

TENSION, cm. of water

10^5

10^4

10^3

10^2

10^1

10

20

30

40

50

60

10

20

30

40

50

60
Figure 19. Conductivity-moisture relationship for Webster silty clay loam
Table 1. Wilting point, field capacity, and saturation values used in the soil moisture component (% by volume)

<table>
<thead>
<tr>
<th>Soil Zone (Ft.)</th>
<th>Wilting Point (%)</th>
<th>Field Capacity (%)</th>
<th>Saturation (%)</th>
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SEASONAL HYDROLOGIC WATERSHED MODEL

The seasonally operating ISU hydrologic model uses the basic framework of the single storm model as developed by DeBoer (1969) to continuously simulate the watershed discharge. To achieve this simulation several changes and additions have been made to the ISU hydrologic model. The major changes made and components added have been discussed previously and will be only briefly mentioned here; however, several other modifications will be explained in detail in the following sections.

Interception

The infiltration subroutine of the model was modified to allow a maximum of 0.1 inch per day of interception on the plant surfaces before any precipitation strikes the ground surface for potential infiltration or surface runoff. This interception water is then available for evaporation as the first use of the potential evapotranspiration energy.

Evapotranspiration

This component of the model is greatly expanded over the previous version which allowed only a constant amount of ET from the upper soil zone. The approach used in the model was developed by Saxton (1972) and is partially based on concepts developed by Shaw (1963). The method of ET calculation is
discussed in detail elsewhere as part of the soil moisture component development.

**Soil Moisture**

A more extensive soil moisture component was required for seasonal operation of the ISU hydrologic model in order to predict the antecedent soil conditions at the beginning of each precipitation event throughout the crop season. This required monitoring the soil moisture content in each layer of the crop root zone continuously throughout the season. The ET withdrawn from the soil profile on a daily basis as determined by the model is a very important factor in accomplishing this.

Also important, and to an extent compensating for over- or under-withdrawal of ET, is the soil moisture redistribution process which is determined by the tension-conductivity method as described in the soil moisture component development. If too much moisture is withdrawn by ET the upper region of the soil profile will be dryer and will result in more moisture being moved upward from the water table and lower root zone by the moisture redistribution process. However, if this occurs consistently it will no doubt affect the total water yield from the watershed during the crop season.

Where subsurface drainage is present, any excess water infiltrated into the crop root zone above its storage capacity
becomes input into the drainage system component of the ISU hydrologic model.

Seepage from Depressions into Soil

In addition to infiltrated water throughout the watershed, the soil profile receives water which is ponded on the soil surface in the depressions for a period of time. This was not taken into account in earlier versions of the ISU hydrologic model due to the short period of simulation. The model was modified to allow seepage from the depressions into the soil until saturation is reached or at a rate which maintains saturated conditions until the ponded water is gone. The maximum rate of seepage was assumed to be equal to the minimum infiltration rate for these soils.

The various options in the model involving surface inlets and/or subsurface drainage greatly affect the volume of water entering the soil through seepage from the depressions due to differences in the amount of time that the water stands in the depressions and the rapidity with which the soil profile drains below saturation. With surface inlets very little water enters the profile by seepage because the water is not ponded in depressions very long. With subsurface drainage only, all of the water ponded in depressions enters the profile by seepage over a period of time unless
the depressions are completely filled so that some water moves to the watershed outlet overland as surface runoff. When no drainage or surface inlets are present, more water is ponded in the depressions for a long period of time because the soil profile remains saturated longer and delays seepage. Also, of course, more overland flow from the depressions to the watershed outlet occurs. As with subsurface drainage only, the water stored in the depressions must seep into the soil profile, but this occurs over a much longer period of time with no drainage or surface inlets.

Hydraulic Head in Tile

The method of calculation of the hydraulic head in the main tile at each depression is completely changed from that of the previous version of the ISU hydrologic model as described in an earlier chapter. The present method, while more costly to use, is more firmly based on hydraulic theory and provides better simulation results.

Time Increment Changes

The basic time increment for use in the ISU hydrologic model during a storm runoff event should be determined by the duration of the runoff-producing portion of the precipitation. DeBoer (1969) has suggested using a time increment
equal to about one-half the major runoff-producing portion of the storm during all precipitation and until the discharge has decreased to 80 percent of the peak discharge, twice this routing time interval from 80 to 50 percent of peak discharge, and 4 times the interval thereafter. However, this is not practical during periods of low flow and no precipitation because of the excess computation time required. Therefore, the ISU hydrologic model is now designed to change from the basic time increment or a multiple of it for a given storm to a 6 hour time increment after the major portion of the runoff has passed. This longer time increment is used for all routine calculations in the model until the next precipitation event occurs, at which time the model changes to an appropriate increment for that particular storm. All calculations within the model are performed for each time increment with the exception of the evapotranspiration which is calculated on a daily basis and withdrawn from the soil profile at the beginning of each day.

The longer 6 hour time increment appears to cause no problems of accuracy or instability in the routing sections of the model when used during low or fairly steady flows. However, a trial using a longer 12 hour time increment resulted in some convergence difficulty in the channel or ditch routing section of the model, especially at very low flows.
Data Input and Output

Some input data are automatically read in by the computer program without cards. This includes the cumulative number of days to the beginning of each month (KDA), the ratio of actual to potential soil evaporation vs. moisture content (AOPEVP), the unsaturated conductivity vs. moisture content (CONDUC), the soil tension vs. moisture content (TENS), and the average daily pan evaporation for each month (AVPAN). The remainder of the input data are read in on cards in the sequence shown in Figure 20. The Appendix contains a complete listing of the ISU hydrologic model computer program in FORTRAN IV language as used on the IBM System 360, Model 65 computer. All parameters are defined in comments at the beginning of the subroutines in which they appear.

Program Description

The ISU hydrologic model in its present state of development consists of a main program and 15 subroutines as listed in the Appendix which deterministically simulate the watershed hydrologic processes shown in Figure 5.

The major function of the main program is to provide a framework to direct the operation of the model. It provides the means for all data input and output with the exception of some intermediate output which is printed from a subroutine. The main program also includes the channel routing procedure
Starting date and time
MON, IDAY, TIME1, TIME2

General watershed parameters
NITYPE, NELWSD, NEWAD

Drainage ditch parameters
RN, DLNGTH, BWIDTH, DDEPTH, SVERT, SHOR, DSLOPE, COEFBW

Initial elemental watershed tile discharges
QT

Iteration tolerances and general model parameters
TESTIN, TESTDR, TESTRO, TESTAS, TFACT1, TFACT2

IPLOT, IPUNCH, IROUTE

Evapotranspiration and soil moisture parameters
NRTDS, ETRATE, POMTRN, WP, FCP, SAT

Elemental watershed hydraulic parameters
NUELUN, MNT, MNC, TOELEV, K, S, MDTEST, SLPSUB, WWCOEF,
TSLOPE, DCOEF, CD, WEIRK

Elemental watershed physical parameters
AU, L, TD, E, PCEL, Dl, QFULL, ELEVMN

Infiltration parameters
ASOIL, NSOIL, TOTSTR, FCINFL, DPSTOR, SMASM, GRAVPR

Initial soil moisture
SOILM

Drainage parameters
HYDRCR, DRNPOR, FFCTN, CFACTR, SPACNG

Figure 20. Sequence of model input data
Information cards concerning watershed identification, arrangement of elemental watersheds along the drainage ditch and simulation period - all cards after the first must have a zero in column one except the last card which must contain a one in column one

Ditch reach lengths

DELX

Initial ditch flows for the various reaches

Q1

Elemental watershed arrangement along the drainage ditch

ITYPE

Routing time increment for initial period of simulation

DELTMB

Watershed identification, date, crop canopy, pan evaporation and index parameter indicating precipitation

AMISAR

- one card for each day

- there must be a one in column 22 for each day with precipitation, otherwise a zero

- the last card must have a 99 in columns 21-22

Basic routing time increment for each storm

DELTMB

- a -1 in columns 4-5 stops the program

Figure 20 (Continued)
Precipitation input data groups and changes in two infiltration parameters

ATIME, BTIME, RAINS, DP, FC

- each data group must contain a termination card with -1 in columns 19-20
- each data group must contain no more than a maximum total of 100 time increments
- there must be no more than 24 hours between any two consecutive data sets
- the last data group for each storm must end with a termination card followed by a card with -1000 in columns 16-20
- the DP and FC parameters must be present on the termination card of a data group in question or the parameter will remain unchanged

 Definitions

Data set - a single time and depth of precipitation reading

Data group - contains one or more data sets

---

Figure 20 (Continued)
which routes elemental watershed outflows down the drainage ditch to the watershed outlet.

SUBROUTINE IHEAD calculates the initial water table elevation and submain tile discharge for elemental watersheds with subsurface drainage. The assumption is made that the tile lines are not initially flowing under pressure.

SUBROUTINE INFILT calculates the interception on plant surfaces, the amount of water in surface storage, the amount of infiltration into the soil profile, and the amount of surface runoff from precipitation for each time increment. Infiltration is calculated by Equation 4 which provides for infiltration recovery over time as a function of the amount of moisture in the top foot of the soil profile. This procedure is shown schematically in Figure 21. This subroutine provides the input to SUBROUTINE REDIST and SUBROUTINE ROUT.

SUBROUTINE ET calculates the evapotranspiration on a daily basis and adjusts the soil moisture in each zone for this evapotranspiration. This procedure was discussed earlier and is shown schematically in Figure 17.

SUBROUTINE REDIST allows infiltration into the soil profile in the amount calculated in SUBROUTINE INFILT and redistributes the soil moisture within the crop root zone according to the current tensions and conductivities, both functions of moisture content. Moisture movement in or out of the top foot of soil by this subroutine or SUBROUTINE ET
Figure 21. Infiltration calculation procedure
affects the infiltration recovery and, thus, the infiltration calculated during the next time increment by SUBROUTINE INFILT.

SUBROUTINE RATEIN is used in SUBROUTINE ET to interpolate between two curves in calculating the reduction in transpiration due to plant moisture stress as described earlier and shown in Figure 17. It takes the available soil moisture and the potential ET and interpolates on the curves to obtain a ratio of actual to potential ET rate.

SUBROUTINE INTRP is used in SUBROUTINE ET and SUBROUTINE REDIST to perform a simple linear interpolation and determine the value of y for a given value of x where \( y = f(x) \).

SUBROUTINE ROUT routes the water between depressions through surface inlets and overland flow channels. It solves Equation 1 between successive depressions in an elemental watershed with an iterative solution using Bailey's Method (McCalla, 1967). This method requires the first and second derivatives of the equation which is expressed as

\[
F(D21) = \frac{I1+I2}{2} - \frac{O1+O2}{2} - \frac{V2-V1}{DELT} = 0 \quad (10)
\]

FUNCTION OUTFLO computes the amount and type of flow from each depression for each time increment and the flow from and the effective head controlling the flow from the lateral tile systems. In doing this it uses the output from SUBROUTINE HEAD and SUBROUTINE DRNAGE. Flow from a depression in the model can occur in four combinations which are
1) overland channel flow and surface inlet flow
2) overland flow and subsurface drainage flow
3) overland flow, surface inlet flow, and subsurface drainage flow, and
4) overland flow only.

FUNCTION OUTFLO also calculates the amount of seepage into the soil profile and the subsurface drainage system from the water ponded in depressions. This seepage is controlled by either the minimum infiltration rate, FCINFL, or the moisture holding capacity under the depressions, SSMASM, as previously discussed. The depression discharges calculated here are used as inputs to SUBROUTINE ROUT.

SUBROUTINE HEAD calculates the piezometric head in the main tile line at each depression for surface inlet flow. This subroutine is discussed in detail elsewhere in the text and is extensively different from methods used by DeBoer (1969) and Haan (1967). The head calculated by this subroutine is used in FUNCTION OUTFLO to determine the depression outflow when surface inlets are used and by SUBROUTINE DRNAGE to determine the lateral drainage flow.

SUBROUTINE DRNAGE computes the lateral and submain tile discharges by use of Equation 5 and Equation 1. The lateral tile system layout is shown in Figure 6. The subroutine calculates flow in three separate parts. The first part calculates the flow from a lateral tile that is not affected by
the head in the main tile line. The second part calculates the flow from the lateral tile line adjacent to and parallel with the main tile line. These relationships are shown in Figure 22. The third part computes the submain tile discharge based on a linear lateral tile discharge-distance function between the lateral tile line adjacent to the main tile line and the first lateral not influenced by the main tile line head. The output from this subroutine is used in FUNCTION OUTFLO to determine the main tile discharge at each depression for each time increment when subsurface drained elemental watersheds are used.

FUNCTION VOLUME is a relationship developed by Haan (1967) to compute the volume of water stored in a depression for a given depth of water. This function is used in SUBROUTINE ROUT.

FUNCTION DFLOW is an interpolating equation used to calculate the relative depth of flow in a circular conduit for a given conduit discharge using a Lagrangian polynomial approach (Henrici, 1964). It is used in calculating the initial head in the main tile line.

FUNCTION AREA is used to compute the drainage ditch cross-sectional flow area for a given discharge in the ditch. This function is used in routing the elemental watershed outflows down the drainage ditch.
Figure 22. Submain tile flow calculation
FUNCTION DSCHRG is used by the ditch routing procedure to compute the drainage ditch discharge for the newly calculated flow area in the ditch at the next downstream reach.

FUNCTION ASOL is used by the drainage ditch routing procedure to compute the drainage ditch cross-sectional flow area at the downstream reach at the end of a time increment. This function uses Bailey's Method for the iterative solution.

Of the preceding ISU hydrologic model program sections discussed, several are in essentially the same form as that used by DeBoer (1969). These include IHEAD, VOLUME, DFLOW, AREA, DSCHRG, and ASOL. In addition, the basic computational framework of subroutines INFILT, ROUT, OUTFLO, and DRNAGE is unchanged, however, many modifications have been made to accommodate the seasonal model and improve the performance of the model. The main program also follows basically the same format although it has been extensively modified to achieve continuous seasonal simulation with the model. The remaining subroutines, ET, REDIST, RATEIN, INTRP, and HEAD, are completely new sections of the ISU hydrologic model program.
EAST FORK HARDIN CREEK WATERSHED SIMULATION

The ISU hydrologic model operating continuously throughout the crop season as developed and modified by this research was used to simulate watershed discharge and soil moisture status in the crop root zone in the East Fork Hardin Creek Watershed near Jefferson, Iowa. This watershed of 24 square miles is located in the recently glaciated region of Iowa as shown in Figure 23. The topography is relatively flat and is characterized by numerous shallow depressional storage areas as can be seen in Figure 1. The watershed has been gaged by the United States Geological Survey since 1952. It has extensive subsurface drainage systems as shown in Figure 25. A more detailed description of the East Fork Hardin Creek Watershed can be found in DeBoer (1969). The simulation of this watershed required the use of a number of physical soil and watershed characteristics as input to the model along with the climatic data.

Watershed Input Data

A deterministic watershed model such as the ISU hydrologic model requires values for a large number of soil characteristics to accurately simulate the hydrologic processes taking place in the watershed. The availability of many of these parameters is very limited, especially for
Figure 23. Location of recently glaciated region of Iowa containing many surface depressions.
the Clarion-Webster soil association of which East Fork Hardin Creek Watershed is a part, since these soils are of glacial origin and have a large degree of variability even in localized areas.

The values of the soil wilting point, field capacity, and saturation were chosen from data from several sources presented by DeBoer (1969) and additional data from Shaw, Nielsen and Runkles (1959). The values used for infiltration parameters, saturated conductivity, drainable porosity, and constants describing the subsurface drainage flow geometry were all chosen by reviewing data summarized by DeBoer (1969). A lateral drain spacing of about 100 feet is recommended for the soils in the Watershed by the Iowa Drainage Guide (1962). This value was used in the model. The values used in the ISU hydrologic model for all the above parameters are shown in Figure 24. The required unsaturated conductivity-moisture content relationship and soil tension-moisture content relationship were discussed earlier and are shown in Figures 19 and 18, respectively.

The physical watershed characteristics were simulated by the elemental watershed generation program developed by Haan (1967). A drainage coefficient of 0.25 inches per day was used with an average overland flow channel and tile main slope of 0.001 feet/foot in the watershed generation program. Most of the existing tile mains lie approximately on this
GENERAL WATERSHED CHARACTERISTICS

THE SIMULATED WATERSHED CONTAINS 3 DIFFERENT KINDS OF ELEMENTAL WATERSHEDS AND A TOTAL OF 100 ELEMENTAL WATERSHEDS. THERE ARE 34 ELEMENTAL WATERSHEDS ABOVE THE HEAD OF THE DITCH.

DRAINAGE DITCH PARAMETERS

TOTAL LENGTH = 27500.0 FEET
BOTTOM WIDTH = 10.0 FEET
DEPTH = 10.0 FEET
SIDE SLOPES = 1.0 VERTICAL TO 2.0 HORIZONTAL
SLOPE = 0.00100 FEET/FOOT
MANNINGS ROUGHNESS COEFFICIENT = 0.035

Figure 24. Watershed input data for model
ELEMENTAL WATERSHED: TYPE 2

THIS ELEMENTAL WATERSHED HAS SUBSURFACE DRAINAGE ONLY

THIS ELEMENTAL WATERSHED CONTAINS 12 DEPRESSIONAL AREAS

SOIL PARAMETERS

FOR SUBROUTINE INFILT

\[
\begin{align*}
\text{ASOIL} &= 7.00 \text{ IN/HR} \\
\text{NSOIL} &= 1.50 \\
\text{TOTAL SOIL MOISTURE STORAGE (TOTSTR)} &= 5.80 \text{ IN.} \\
\text{STEADY STATE INFILTRATION RATE (FCINFL)} &= 0.15 \text{ IN/HR} \\
\text{SURFACE STORAGE (DPSTOR)} &= 0.10 \text{ IN.} \\
\text{TOTAL STORAGE MINUS ANTECEDENT MOISTURE (SMASM)} &= 0.80 \text{ IN.} \\
\text{GRAVITATIONAL POROSITY (GRAVPR)} &= 0.70 \text{ IN.}
\end{align*}
\]

FOR SUBROUTINE DRAINAGE

\[
\begin{align*}
\text{DRAINABLE POROSITY (DRNPOR)} &= 0.050 \\
\text{HYDRAULIC CONDUCTIVITY (HYDRCD)} &= 3.5 \text{ FT/DAY}
\end{align*}
\]

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<th>WILTING SATURATION</th>
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Figure 24 (Continued)
PHYSICAL PARAMETERS OF ELEMENTAL WATERSHED: TYPE 2

MANNINGS OVERLAND FLOW CHANNEL ROUGHNESS COEF. (MNC) = 0.350
MANNINGS MAIN TILE ROUGHNESS COEFFICIENT (MNT) = 0.011
OVERLAND FLOW CHANNEL SLOPE (S) = 0.0010 FEET/FOOT
OVERLAND FLOW CHANNEL SHAPE PARAMETER (K) = 0.001000
MAIN TILE OUTLET ELEVATION (TCELEV) = 4.0 FEET
MAIN TILE SLOPE (TSLOPE) = 0.0010 FEET/FOOT
SUBMAIN TILE SLOPE (SLPSUB) = 0.0050 FEET/FOOT
LATERAL TILE SPACING (SPACING) = 100.0 FEET
DRAINAGE COEFFICIENT (DCOEFF) = 0.250 INCHES/DAY
-C- FACTOR (CFACTR) = 0.9
-F- FACTOR (FFCTN) = 2.70

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<th>CREST ELEV. (FEET)</th>
<th>BOTTOM ELEV. (FEET)</th>
<th>SHD. AREA (ACRE)</th>
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Figure 24 (Continued)
SEQUENTIAL ARRANGEMENT OF
ELEMENTAL WATERSHEDS FOR
THE SIMULATION OF
EAST FORK OF HARDIN CREEK WATERSHED NEAR JEFFERSON, IOWA

******************************************************************************

DISTANCE DOWN
ORRAINAGE DITCH
(FEET)          ELEMENTAL WATERSHED TYPE
                DISCHARGING
                INTO THE DITCH
--------------------------------- -----------------------------------

0 (HEAD)            3,1,3,2,2,3,1,3,2,2,3,1,
                      3,2,2,3,1,3,2,2,3,1,3,2,
                      2,3,1,3,2,2,3,1,3,2
                      2,3

3,500                1,3,2,2,3,1,3,2,2

4,600                1,3,2,2,3,1,3,2

8,100                2,3,1,3,2

11,100               2,3,1,3,2

11,600               3,1,3,2,2,3,1,3

15,200               2,2,3,1

16,000               3,2,2,3,1,3

19,000               2,2,3,1,3,2,2,3,1,3,2,2,3,1

20,800               3,2

23,300               2,3,1,3

26,000               2,2

27,500 (OUTLET)      2,3,1,3

*** FOR APRIL - MAY, 1964 RUNOFF EVENTS ***

Figure 24 (Continued)
slope and have a 0.25 inch/day drainage coefficient as is shown in Figure 25. Personal communication with farmers and extension specialists indicates that only about 10-20 percent of the depressions have surface inlets. Most of the surface inlets are along roadside ditches with relatively few in farmed depressions. Subsurface drainage systems are an important feature of the Watershed; however, it is not 100 percent drained. Drains tend to be randomly located in low, wet areas such as under and around depressions, but not on sloping land.

Figure 24 shows the distribution of elemental watersheds used to represent the Watershed. Three types of elemental watersheds were used. The Watershed was assumed to be made up of elemental watersheds with

a) overland channel flow, surface inlets and subsurface drainage (20 percent),

b) overland flow and subsurface drainage (40 percent), and

c) overland flow only (40 percent).

This resulted in 20 percent of the Watershed having surface inlets, 60 percent of the Watershed having subsurface drainage systems, and 40 percent of the Watershed having no drainage at all. The elemental watersheds were distributed along the drainage ditch to simulate the actual drainage systems shown in Figure 25 as nearly as possible while maintaining an even distribution of the three types of elemental watersheds.
Figure 25. Major subsurface drainage network of East Fork Hardin Creek Watershed
throughout the Watershed.

The approximate dimensions of the existing drainage ditch as given by Haan (1967) were used in the model. The ditch has a trapezoidal shape with parameters as given in Figure 24.

The climatological input data required by the ISU hydrologic model are time-depth precipitation records and daily pan evaporation amounts. Precipitation input data for 1964 were obtained from Iowa Natural Resources Council recording raingage records collected at a site within the Watershed. An observer was hired to maintain our recording raingage to obtain precipitation records at a site within the Watershed during the 1972 season. Iowa climatological data published by the United States Department of Commerce was used as a source of comparative daily precipitation and daily pan evaporation amounts. Pan evaporation at the Ames station is the closest available and was used in the model.

Initial soil moisture amounts were obtained from unpublished data collected by Shaw\(^2\) at a sampling location near the Watershed. The simulated soil moisture status was then compared with later field measurements made at the same sampling location. The United States Geological Survey stream gaging records were used as a source of actual Watershed

discharge to compare with the simulated seasonal Watershed discharge.

Input Parameter Effects

In the process of calibrating the model to produce a reasonable simulation of the East Fork Hardin Creek Watershed several input parameters of the ISU hydrologic model were changed to determine their effect on the discharge hydrograph from the Watershed. This study was not approached as a true sensitivity analysis, but as an attempt to better match the field discharge hydrograph. The parameters varied are those for which values are not well established for this Watershed and those expected to provide the needed change in the simulated hydrograph to fit the measured hydrograph better.

For this investigation and calibration process a single storm of 2.70 inches precipitation occurring April 12-13, 1964 was used. It must be kept in mind that the input parameter effects indicated in the following pages are for a single specific situation and the magnitude of the effects could be much different under different conditions, e.g. when the soil is very dry, or if the depressions were initially full of water.

The effect of the number of depressions in an elemental watershed is shown in Figures 26 and 27. Figure 26 shows the
Figure 26. Discharge hydrographs showing the effect of depression numbers with surface inlets and overland flow.
Figure 27. Discharge hydrographs showing the effect of depression numbers with surface inlets, subsurface drainage and overland flow
effect of a change from 24 to 12 depressions per watershed on the discharge hydrograph with surface inlets and overland channel flow only. A very similar effect is shown in Figure 27 when the Watershed has 50 percent surface inlets and 100 percent subsurface drainage. It appears that a smaller peak discharge can be expected from simulation with a larger number of depressions per elemental watershed and all other parameters constant. This must be considered in choosing the elemental watershed size along with the fact that computer costs are greater with larger numbers of depressions in an elemental watershed. A similar study was made by DeBoer (1969) with results supporting those found here.

A change in percentage of surface inlets in the Watershed from 50 percent to 25 percent with all other parameters unchanged resulted in the hydrographs shown in Figure 28. A reduction in surface inlets reduces the peak discharge but has no effect on the rest of the discharge hydrograph. A change in subsurface drainage from 100 percent to 50 percent with all other parameters unchanged results in the hydrographs shown in Figure 29. A reduction in the proportion of the Watershed having subsurface lateral tile systems results in a decrease in the magnitude of the whole hydrograph. The difference in the volume of water in the two hydrographs is due to the excess water stored in the undrained depressions and in the soil profile in undrained regions of the Watershed.
Figure 28. Discharge hydrographs showing the effect of surface inlet percentage.
Figure 29. Discharge hydrographs showing the effect of subsurface drainage percentage
when the subsurface drainage is reduced.

Another factor to be considered is the size distribution of the depressions within an elemental watershed. Haan's watershed generation program uses a random number selection to determine the size of succeeding depressions. These variable sized depressions can cause the overland flow wave movement discussed by DeBoer (1969) due to the differences in storage capacity among depressions; however, this problem was not encountered in the present study to the degree reported by DeBoer. A related factor is that the watershed generation program produces smaller depressions in the upper part of the elemental watershed with larger depressions near the outlet. Due to the larger storage volume in the lower depressions, overland channel flow occurs often between smaller depressions but the water is stored in the larger depressions and no overland flow occurs at the elemental watershed outlet. This does not appear to properly represent the actual watershed conditions. Therefore, the order of the depressions was reversed in the elemental watersheds with no other parameter changes made, resulting in smaller depressions near the outlet of the elemental watershed. It would seem reasonable that this type of distribution would be more likely to occur in nature if the processes involved in their formation by glacial action are considered. As the ice melted leaving the depressions exposed the water from the receding glacier flowed toward the
natural waterways. As the water flowed through depressions to the waterways it would tend to lose any sediment carried in the depressions, thus decreasing the storage capacity or size of the depressions. Following this reasoning the depressions nearest the drainage ditch should be, in general, smaller than the depressions in the upper part of the elemental watersheds near the Watershed boundary. The reversal of the depressions in the model resulted in a larger peak discharge due to increased overland flow from the elemental watersheds and a slight decrease in the rest of the hydrograph after overland flow ceased since more of the water was removed by overland flow rather than at a delayed rate by subsurface drainage as shown in Figure 30.

Several input parameters involving soil and soil moisture characteristics were varied to determine their effect on the discharge hydrograph. Three SUBROUTINE INFILT parameters were adjusted. These included SMASM, GRAVPR and FCINFL. SMASM is a measure of the available water storage capacity in the top foot of soil at a given time. It is equal to the total storage capacity minus the moisture present in the top foot of soil at the time; therefore it is a function of the soil moisture status in the top foot at the beginning of precipitation and controls the infiltration function. An increase in SMASM decreases the discharge hydrograph as shown in Figure 31. This should be expected since this indicates
Figure 30. Discharge hydrographs showing the effect of lower depression size
Figure 31. Discharge hydrographs showing the effect of infiltration parameters
drier initial soil conditions, more infiltration and greater capacity to store moisture in the soil profile. GRAVPR, the gravitational porosity of the top foot of soil, is a measure of the volume of water which will drain by gravity from the layer at the minimum infiltration rate. This factor is closely related to SMASM in that it indicates when infiltrated water will begin to move from the control layer and thus increase SMASM and allow more infiltration. Therefore, decreasing GRAVPR has the effect of delaying additional infiltration and increasing the peak discharge as indicated in Figure 31. The minimum rate of infiltration, FCINFL, affects the volume of infiltrated water significantly only as the top foot of the soil profile becomes very wet. Therefore, its greatest effect is on the peak discharge as can be seen in Figure 32. However, it also slightly affects the recession portion of the hydrograph which is predominately subsurface drainage since the movement of ponded water from the depressions into the soil profile and the lateral tile is a function of FCINFL.

Figure 33 shows the combined effect due to increasing FCINFL and lowering the water table level slightly by decreasing the moisture content in the 5 to 9 foot soil block. The main effect of increasing FCINFL can be seen in the greatly reduced peak discharge, while lowering the water table level results in a lower recession portion of the hydrograph due to more water storage in the soil profile and less subsurface
Figure 32. Discharge hydrographs showing the effect of an infiltration parameter
Figure 33. Discharge hydrographs showing the combined effect of FCINFL and water table level.
drainage flow.

The combined effect of increasing the portion of the Watershed that has subsurface drainage and raising the water table level slightly is shown in Figure 34. The response shown confirms that obtained in previous investigations reported in Figures 29 and 33. Both changes should cause the same type of response in the discharge hydrograph, that is, an increase in the discharge contributed by subsurface drainage.

The "K" parameter is a shape factor in the parabolic cross-section used to describe the overland flow channels between depressions. The overland flow portion of the discharge hydrograph seemed to result in too sharp of a peak discharge with a rapid recession until the flow became predominately subsurface drainage. Therefore, the "K" parameter was increased within the measured range of $0.60 \times 10^{-4}$ to $0.25 \times 10^{-2}$ for natural waterways reported by DeBoer (1969) with the result shown in Figure 35. The peak discharge was decreased and the rate of recession slowed as expected.

The effect of changing the lateral tile drain spacing was also investigated with all other parameters constant except the parameter FFCTN, which must automatically change with the tile spacing since it expresses the flow geometry of the drainage system and is a function of the tile spacing, tile radius, and depth to an impermeable layer. Figure 36 indicates the effect of changing the drain spacing from 100
Figure 34. Discharge hydrographs showing the combined effect of subsurface drainage percentage and water table level.

- 40% subsurface drainage
- 45% moisture @ 5-9 ft.
- 60% subsurface drainage
- 45.5% moisture @ 5-9 ft.
Figure 35. Discharge hydrographs showing the effect of the overland flow channel shape parameter.
Figure 36. Discharge hydrographs showing the effect of lateral tile spacing.
feet to 300 feet. The 300 foot spacing also results in the small constant discharge being maintained longer and exceeding that of the 100 foot spacing about 9 days after the runoff started so that the same volume of water eventually appears in the discharge hydrograph.

In addition to these input parameter effects a trial simulation was made assuming that all depressions in the Watershed had been surface drained so that no water could be stored in them except temporarily during the overland flow process. All other parameters in the model remained the same except that it was assumed that there would be no surface inlets since the depressions were drained with surface ditches. Subsurface drainage was assumed in the same proportion as without surface drainage. The resulting hydrographs for the two conditions for the storm of April 12-13, 1964 are shown in Figure 37. After overland flow ceases the subsurface drainage portion of the hydrographs are very similar. With surface drainage all depressions are empty by midnight April 13 while there is a lot of water still stored in depressions for the case without surface drainage, especially in the elemental watersheds without subsurface drainage. Some water remains stored in those depressions with subsurface drainage and no surface inlets also. The difference in the volume of water between the two hydrographs should be the volume of water stored in depressions for the case with no surface drainage.
Figure 37. Discharge hydrographs showing the effect of surface drainage
Seasonal Simulation Results and Discussion

The ISU hydrologic model was used to simulate the soil moisture status and watershed discharge for the East Fork Hardin Creek Watershed continuously during the 1964 crop season. The simulation began on April 7 since some data were available indicating the soil moisture status near the Watershed at that time and was continued until October 31. The resulting mean daily watershed discharge is shown in Figure 38 along with the reported USGS mean daily flow from the recording stream gage in the Watershed. This figure also shows the daily precipitation totals at the recording gage within the Watershed and at the nonrecording gage at Jefferson about 5 miles south of the Watershed. The recording gage data were used as input to the model for the simulation.

A comparison of the measured and simulated peak discharges indicates considerable error in the simulation for certain storms. In several cases the main reason for this is the large variability in the amount of precipitation over the Watershed as indicated in Figure 38 and Table 2. No other gages are located near enough to the Watershed to better determine the storm patterns. The nonrecording gage at Rockwell City is about 20 miles northwest of the Watershed.

The literature indicates that this type and magnitude of variability in precipitation is not uncommon. Changnon (1963)
Figure 38. Precipitation and mean daily discharge for East Fork Hardin Creek Watershed during the 1964 crop season.
Table 2. Total monthly precipitation for 1964 crop season in inches

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<td>2.89</td>
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<td>2.88</td>
<td>2.36</td>
<td>4.16</td>
<td>1.90</td>
<td>0.59</td>
<td>21.99</td>
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<td>6.42</td>
<td>4.53</td>
<td>5.97</td>
<td>3.73</td>
<td>3.01</td>
<td>0.43</td>
<td>31.62</td>
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</table>

found a spatial variation of more than 6 inches, or 12 percent, in average annual precipitation between two gages only 5 miles apart. Variations were greatest for large, short duration storms producing excessive rainfall amounts and occurring during the spring and summer seasons. Similar results are reported by Corbett (1965), Huff and Neill (1956), Hershfield (1965), Nicks (1965) and Nicks and Hartman (1965). Dawdy and Bergmann (1969) used a single rain gage to model a 9.7 sq. mi. watershed and found that they could predict peak discharge within about 20 percent. They concluded that errors in rainfall measurement would be the limiting factor in most rainfall-runoff simulation studies. The seasonal simulation results presented here would support such a conclusion. The simulated discharge is much more accurate for storms which have more evenly distributed precipitation between the Hardin Creek and Jefferson gages. The precipitation variability
also affects the amount of moisture stored in the soil profile which then affects the infiltration and subsurface drainage in later storms as is apparent for the runoff event of May 25-28, 1964 shown in Figure 38.

The instantaneous discharge hydrographs for the major runoff events of the 1964 season are shown in Figures 39, 40, 41, and 42. The precipitation was small enough at the recording gage for the May 7-8 runoff event that the model produced no peak discharge. With the exception of the precipitation input problems previously discussed, the model simulated the Watershed peak discharges reasonably well. However, a relatively consistent trend can be noted in the recession portion of most of the hydrographs. The simulated hydrographs tend to fall more rapidly than the measured hydrographs immediately after the peak discharge, then flatten out as subsurface drainage becomes predominant. The simulated hydrograph then declines much more slowly than the measured hydrograph for a period of time, however, several days after the precipitation event it falls below the measured hydrograph as shown in Figure 38 so that the total volume of water discharged remains nearly the same. The total water yield for the 1964 season was 2.31 inches according to the USGS records. The simulated discharge resulted in a total water yield of 2.5 inches, or within about 10 percent of the measured volume.

In a generalized deterministic watershed model such as the
Figure 39. Simulation results of April 12-15, 1964 hydrologic event
Figure 40. Simulation results of April 26-29, 1964 hydrologic event
Figure 41. Simulation results of May 25-28, 1964 hydrologic event
Simulation results of June 11-14, 1964 hydrologic event

Figure 42.
ISU hydrologic model it is very difficult if not impossible to account for all the factors which occur in nature and affect the shape of the discharge hydrograph. One example of this is the effect of road grades and culvert restrictions on the time distribution of the overland channel flow in the Watershed. From observations made immediately after storms it is apparent that culverts under roads in natural waterways in this flat topography restrict the flow of water causing temporary ponding of surface runoff water above road grades. The effect of this ponding would be to decrease the maximum discharge of overland flow and stretch out the discharge of water over a longer period of time with a kind of reservoir effect. This could significantly change the shape of the Watershed discharge hydrograph for storms large enough to produce considerable overland flow. If a restriction of this type were built into the overland flow simulation section of each elemental watershed it would likely result in a somewhat delayed peak that is less sharp and declines less rapidly. This would be a better fit to the typical measured field hydrograph from the Watershed. This also would likely permit reduction of the percentage of subsurface drainage or the saturated hydraulic conductivity to get a better fit on the late recession portion of the measured hydrograph in Figure 39 without reducing the early recession part of the hydrograph too much as occurred in Figure 34 using 40 percent subsurface
drainage.

The ISU hydrologic model also simulates the soil moisture status of the crop root zone as an integral part of the watershed simulation. The total soil moisture in the top 5 feet simulated in the Watershed for the 1964 season is shown in Figure 43. Field data from a sampling site about 5 miles from the Watershed were available for three dates marked with x's in Figure 43. The first measured value was used as the initial moisture for the model and the last two values were compared with simulation results. The simulated total moisture compared very well with the limited measured data available. The three curves in Figures 43, 44, and 45 correspond to the three types of elemental watersheds used in the simulation. The undrained elemental watershed was the wettest throughout the season as would be expected with no means provided to drain away excess water from the profile as in the other two types of elemental watersheds.

Figures 44 and 45 show the simulated and measured soil moisture by 1 foot increments. It should be kept in mind when comparing the measured values with the simulation that the measured values represent a single measurement in Clarion silt loam while the model attempts to simulate an average of several soil types and textures over a large area. Also, the spatial variation of precipitation discussed previously affects the soil moisture levels as well as the discharge
Figure 43. Total soil moisture in the top 5 feet in East Fork Hardin Creek Watershed during the 1964 crop season.

- --- no drainage
- --- subsurface drainage
- --- inlets & subsurface drainage
Figure 44. Soil moisture by 1 foot increments during the 1964 crop season.
Figure 45. Soil moisture by 1 foot increments during the 1964 crop season
hydrographs. The top foot indicates considerable variation in moisture levels over time as would be expected due to rainfall with evapotranspiration losses lowering the level between rains. The moisture level in the lower zones responds to both precipitation and evapotranspiration demands more slowly and steadily. Field capacity in each layer is indicated by the letters FC.

The larger differences between measured and simulated moisture levels in the lower 3 feet could be due to several factors. One possibility is the difference in characteristics of the "average" soil simulated in the model and the specific Clarion silt loam soil measured. Another possibility is that the simulated moisture redistribution method in the model allows too much or too little movement due to inaccurate tensions and conductivities which are extremely variable in these glacial till soils. Still another factor could be the moisture extraction process by evapotranspiration. The model may be simulating crop water withdrawal at too slow a rate from the third and fourth foot and too great a rate from the fifth foot. Whatever the cause, it appears to be a problem of proper location of the moisture within the soil profile since the total moisture in the top 5 feet agrees very well with the measured moisture as indicated in Figure 43.
RECOMMENDATIONS FOR FUTURE WORK

The ISU hydrologic model in its present form is not capable of simulation through the winter period and early spring snowmelt runoff. Addition of a snow accumulation and snowmelt component to the model would permit year around operation and simulation of watershed discharge due to snowmelt runoff which can be a significant amount depending upon winter snowfall amount. One possible approach would be an accumulated degree-days method to simulate the snowmelt process.

Field values for some input data required by the model are very scarce as indicated earlier. The soil characteristics in the recently glaciated regions need to be investigated more thoroughly to provide better values for simulation uses. Field studies are needed to better evaluate the infiltration parameters used in the model since infiltration is very important in determining the surface runoff volume. Most soil characteristics and infiltration parameters used in the model are now estimated from very limited amounts of field data.

Field measurements of tile main discharges are needed to verify the model simulation on an elemental watershed basis. Improved accuracy of simulation of both surface and sub-surface discharges from an elemental watershed will result in better simulation of the total watershed discharge.
A sensitivity analysis of the ISU hydrologic model would be very valuable to determine which variables have the most effect on the discharge hydrograph and soil moisture status. Variables which are judged to be very important in obtaining an accurate simulation should be analyzed individually within a reasonable range of values with all other parameters held constant. These variables include soil parameters such as infiltration rate, hydraulic conductivity and moisture holding characteristics, and physical watershed parameters such as channel and tile slopes, channel shape and roughness coefficients. This analysis would indicate which parameters for the model are most critical in obtaining acceptable simulation results.

The ISU hydrologic model would be a valuable tool to help determine the effects of watershed modifications on the discharge hydrograph. The effect of varying degrees of surface and subsurface drainage could be studied for different cover conditions on a watershed. This study would be valuable in determining the effects of man-made modifications on peak flows and water yield from a watershed.

Use of the ISU hydrologic model on another typical watershed with surface depressions and subsurface drainage systems to demonstrate its value in watershed planning and design would be very valuable. This would also permit verification of the model and evaluation of its transferability to other
watersheds with similar topography. The model should be examined to determine its usefulness for state and federal agencies in planning and design. Judgements need to be made regarding necessary compromises between computer costs and detail of simulation for different watershed sizes and topographic features. This would enhance the applicability of the model and point out further developments which may be needed for practical use of the model by individuals or agencies as a tool in planning and design.

Other research possibilities include an investigation of the use of the ISU hydrologic model as a transport model, adding further components to simulate nutrient movement, movement of chemicals or sediment movement through the watershed.
SUMMARY AND CONCLUSIONS

A deterministic hydrologic watershed model was developed for drainage watersheds with depressional storage which simulates the watershed discharge and soil moisture status continuously throughout the crop season. This model, referred to as the ISU hydrologic model, is based on a hydraulic model developed by Haan (1967) and a single storm hydrologic model developed by DeBoer (1969) for the type of depressional watersheds and flat topography typical of the recently glaciated region of north central Iowa. The ISU hydrologic model uses daily pan evaporation and time-depth precipitation records as input. It simulates the processes of interception, surface storage, infiltration, surface runoff, soil profile storage, percolation to the water table, subsurface tile drainage, soil moisture redistribution, evapotranspiration, and depression, tile main and drainage ditch routing. The resulting outputs are daily evapotranspiration, soil moisture status in the crop root zone and watershed discharge. Other intermediate outputs such as water table height, and infiltration amounts are available if desired.

The hydraulic head calculation method was revised significantly from previously developed techniques to provide better simulation of surface inlet flow from depressions into the tile main.
A simple branched flow system was investigated and compared with the series approximation previously used in the ISU hydrologic model. The branched system proved to be much more complex to simulate due to the hydraulic head interactions between branches of the system.

Several watershed input parameters were investigated to determine their effects on the watershed discharge hydrograph. The effects of different numbers of depressions per elemental watershed were studied as well as the effects of changing the percent of the watershed having surface inlets or subsurface drainage.

The ISU hydrologic model was calibrated for the East Fork Hardin Creek Watershed using the storm of April 12-13, 1964 then the complete 1964 crop season was simulated making no further changes in the model input parameters. The results indicated a reasonable agreement with field measurements. The more obvious discrepancies are largely due to spatial variations in precipitation over the watershed which were not accounted for by the model input data.

The ISU hydrologic model appears to provide satisfactory simulation results for depressional watersheds; improved input parameters and more representative precipitation data are necessary for improvement in the simulation accuracy. The major conclusions are summarized as follows:
1) The ISU hydrologic model satisfactorily simulated the watershed discharge and soil moisture status within the limits of available input data accuracy.

2) The newly developed hydraulic head calculation method, although more costly, provides improved simulation results.

3) The series system representation of natural systems of depressions is a good approximation of the more complex branched system.

4) Reducing the number of depressions per elemental watershed increases the simulated peak discharge and decreases the computer costs.

5) The location of large depressions near the elemental watershed outlet has a significant effect on the overland channel flow into the drainage ditch.

6) The peak discharge is very sensitive to the number of surface inlets in the watershed.

7) The proportion of subsurface drainage in the watershed affects the peak discharge as well as the recession portion of the hydrograph.

8) An increase in lateral tile spacing results in a lower watershed discharge for the first few days, but maintains flow for a longer period, eventually discharging the same volume of water.

9) The infiltration routine parameters are very important in determining the watershed peak discharge from a given storm.

10) Complete surface drainage of depressions resulted in a greatly increased peak discharge, but no water was left ponded in depressions after 24 hours.
REFERENCES


Heins, E. 1965. Link farm drainage stress to flooding. Des Moines (Iowa) Register, May 9, Section L:1.


Iowa Drainage Guide. 1962. Iowa Agricultural and Home Economics Experiment Station Special Report No. 13 (Revised).


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Last, but not least, a note of gratitude to my parents whose encouragement to this end began many years ago and is most recently demonstrated by my mother's typing of this manuscript.
A MATHEMATICAL WATERSHED MODEL FOR THE SIMULATION OF DISCHARGE HYDROGRAPHS FROM WATERSHEDS CHARACTERIZED BY DEPRESSIONAL STORAGE AND SUBSURFACE DRAINAGE FACILITIES - KENNETH L CAMPBELL - DEC., 1972

PARAMETER IDENTIFICATION

A1 : DRAINAGE DITCH FLOW CROSS-SECTIONAL AREA AT START OF TIME INTERVAL (SQUARE FEET)

A2 : DRAINAGE DITCH FLOW CROSS-SECTIONAL AREA AT END OF TIME INTERVAL (SQUARE FEET)

AB : DEPRESSIONAL AREA OUTFLOW AT START OF TIME INTERVAL (CFS)

AMISAR : ET AND SOIL MOISTURE STORAGE ARRAY CONTAINING DAILY VALUES OF THE FOLLOWING PARAMETERS, IN COLUMN:

1) CROP
2) MONTH
3) DAY
4) YEAR
5) CROP CANOPY (%)
6) PAN EVAPORATION (INCHES)
7) PRECIPITATION CODE
   EQUALS 1 , DAY OF RAIN
   EQUALS 99 , AFTER LAST DAY OF SEASON
   EQUALS 0 , OTHERWISE
8-17) SIMULATED SOIL MOISTURE BY 6 INCH ZONES (INCHES)
18) SIMULATED SOIL MOISTURE IN 5-9 FOOT BLOCK (INCHES)

AREAF1 : TOTAL INUNDATED AREA IN ELEMENTAL WATERSHED (ACRES)

ASOIL : SOIL PARAMETER WHICH DESCRIBES INFILTRATION RELATIONSHIP

ATIME : HOUR TIME FOR PRECIPITATION INPUT DATA (HOUR)

ATOT : TOTAL AREA WITHIN AN ELEMENTAL WATERSHED (ACRES)

AU : AREA OF DEPRESSIONAL AREA WATERSHED (ACRES)

BTIME : MINUTE TIME FROM PRECIPITATION INPUT DATA (MINUTES)
BWIDTH: DRAINAGE DITCH BOTTOM WIDTH (FEET)
CARD: IDENTIFICATION DATA
CD: SURFACE INLET ORIFICE COEFFICIENT
CFACTR: RATIO OF AVERAGE WATER TABLE HEIGHT TO MAXIMUM HEIGHT BETWEEN DRAINS
CONST1: PARAMETER USED TO COMPUTE FULL TILE MAIN FLOW
CONST3: PARAMETER USED TO CONVERT RUNOFF FROM IN/HR TO CFS
COEFBW: PARAMETER USED TO DESCRIBE DITCH DISCHARGE RELATIONSHIP
D1: WATER DEPTH IN DEPRESSION AT START OF TIME INCREMENT (FEET)
D2: WATER DEPTH IN DEPRESSION AT END OF TIME INCREMENT (FEET)
DCOEF: DRAINAGE COEFFICIENT (IN/DAY)
DDEPTH: DRAINAGE DITCH DEPTH (FEET)
DELT: TIME INCREMENT OR INTERVAL (SECONDS)
DELTFS: VOLUME OF WATER SEEPING INTO THE SOIL FROM A DEPRESSION (INCHES)
DELTM: TIME INTERVAL (MINUTES)
DELTMB: BASE TIME INCREMENT (MINUTES)
DELTM6: TIME INTERVAL (HOURS)
DELTQ: SURFACE RUNOFF FOR A GIVEN TIME INTERVAL (INCHES)
DFMAIN: TILE MAIN FLOW DEPTH (FEET)
DPQ: TOTAL WATERSHED DISCHARGE (CFS)
DLNGTH: TOTAL LENGTH OF DRAINAGE DITCH (FEET)
DP: NEW VALUE FOR DPSTOR
DPSTOR: AMOUNT OF SURFACE STORAGE BEFORE SURFACE RUNOFF OCCURS (INCHES)
DRNPOR: DRAINABLE POROSITY OF SOIL PROFILE (% BY VOLUME)
DS: SURFACE INLET DIAMETER (FEET)
DSLOPE: DRAINAGE DITCH SLOPE (FEET/FOOT)
E: BOTTOM ELEVATION OF DEPRESSIONAL AREA (FEET)
ELEVMN: ELEVATION OF TILE MAIN ABOVE MAIN OUTLET AT CENTER OF DEPRESSIONAL AREA (FEET)
ETRATE: PLANT MOISTURE STRESS CURVES - SEE SUBROUTINE ET
EVAPTR: EVAPOTRANSPIRATION FROM TOP FOOT OF SOIL (INCHES)
F1: ACCUMULATED INFILTRATION AT START OF TIME INCREMENT (INCHES)
FC : NEW VALUE FOR FCINFL
FCINFL : FINAL OR STEADY STATE INFILTRATION RATE (INCHES/HOUR)
FCP : SOIL FIELD CAPACITY (PERCENT BY VOLUME)
FFCTN : A FACTOR WHICH DEPENDS ON TILE DRAINAGE SYSTEM GEOMETRY
FLOW : TOTAL ELEMENTAL WATERSHED DISCHARGE (CFS)
GRAVPR : AMOUNT OF GRAVITY DRAINED PORE STORAGE IN TOP FOOT (INCHES)
H : TOTAL HEAD AT A DEPRESSION (FEET)
HMAIN : TOTAL HEAD IN TILE MAIN (FEET)
HRS1, HRS2 : TIME FROM PRECIPITATION INPUT DATA (HOURS)
HYDBCD : HYDRAULIC CONDUCTIVITY OF ELEMENTAL WATERSHED SOIL (FEET/DAY)
10 : SURFACE RUNOFF RATE (INCHES/HOUR)
11 : DEPRESSION INFLOW AT START OF TIME INTERVAL (CPS)
12 : DEPRESSION INFLOW AT END OF TIME INTERVAL (CPS)
IAY : CUMULATIVE DAYS FROM BEGINNING OF MONTH SIMULATION STARTS
IBKD : TOTAL NUMBER OF DAYS FROM BEGINNING OF YEAR TO START OF SIMULATION
IC : NUMBER OF TIME INCREMENT
ICHNGE : INDEX PARAMETER INDICATING CHANGE IN DP AND FC
IDAY : IAY SIMULATION STARTS AND LATER SAME AS IAY
IJ : CUMULATIVE DAYS FROM BEGINNING OF YEAR
INDEX1 : PARAMETER FROM FUNCTION OUTFLO - INDICATES TYPE OF SURFACE INLET
INDEX2 : PARAMETER FROM FUNCTION OUTFLO - INDICATES WHEN OVERLAND CHANNEL OCCURS
IPLOT : EQUALS 1, PLOT RESULTS
       EQUALS 2, DO NOT PLOT RESULTS
IPUNCH : EQUALS 1, DO NOT PUNCH RESULTS
       EQUALS 2, PUNCH RESULTS
IROUTE : EQUALS 1, ROUTE FLOW DOWN DRAINAGE DITCH
       EQUALS 2, DO NOT ROUTE FLOW DOWN DRAINAGE DITCH
ITYPE : DATA SET THAT SPECIFIES ARRANGEMENT OF ELEMENTAL WATERSHEDS
       ALONG THE DRAINAGE DITCH
ITYPEN, NZZ, MZZ : PARAMETERS USED IN READING ITYPE FROM CARDS
IVALU1 : INDEX PARAMETER CONTROLLING INITIALIZING OF VARIABLES IN
         SUBROUTINE INFILT
IVALU2 : INDEX PARAMETER CONTROLLING INITIALIZING OF VARIABLES IN SUBROUTINE ET
IVALU3 : INDEX PARAMETER CONTROLLING INITIALIZING OF VARIABLES IN SUBROUTINE REDIST
JDRAIN : INDEX PARAMETER ELIMINATING SUBROUTINE DRAINAGE DURING INITIALIZATION
JJ : CUMULATIVE DAYS FROM BEGINNING OF YEAR
JKJ : ELEMENTAL WATERSHED TYPE NUMBER
K : SHAPE FACTOR FOR OVERLAND FLOW CHANNELS - SEE SUBROUTINE OUTFLO
KETA : INDEX PARAMETER INDICATING END OF IDENTIFICATION DATA
L : LENGTH OF TILE MAIN BETWEEN DEPRESSIONS (FEET)
MDTEST : PARAMETER TO SPECIFY TYPE OF ELEMENTAL WATERSHED DRAINAGE
MDTEST = 1, OVERLAND FLOW AND SURFACE INLETS
MDTEST = 2, OVERLAND FLOW ONLY
MDTEST = 3, OVERLAND FLOW, SURFACE INLETS AND SUBSURFACE DRAINAGE
MDTEST = 4, OVERLAND FLOW AND SUBSURFACE DRAINAGE
MNC : MANNINGS ROUGHNESS COEFFICIENT FOR OVERLAND FLOW CHANNELS
MNT : MANNINGS ROUGHNESS COEFFICIENT FOR MAIN TILE LINES
MON : MONTH SIMULATION STARTS
NDISK : PARAMETER CONTROLLING TEMPORARY STORAGE OF DATA ON DISKS
NELWSD : TOTAL NUMBER OF ELEMENTAL WATERSHEDS USED FOR A SIMULATION RUN
NEWAD : NUMBER OF ELEMENTAL WATERSHEDS ABOVE THE DITCH HEAD
NTYPE : NUMBER OF ELEMENTAL WATERSHED TYPES
NORCH : NUMBER OF REACHES USED FOR DRAINAGE DITCH ROUTINE
NORCHO, NZY, MZY : PARAMETERS USED IN READING Q1 FROM CARDS
NORCHX, NZX, MZX : PARAMETERS USED IN READING DELX FROM CARDS
NRMTDS : ROOT DISTRIBUTION IN SOIL PROFILE - SEE SUBROUTINE ET
NRSOIL : SOIL PARAMETER WHICH DESCRIBES INFILTRATION RELATIONSHIP
NTIM : NUMBER OF TIME INCREMENTS IN DATA GROUP
NTIM1 : DAY OF YEAR SIMULATION STOPS
NUELUN : NUMBER OF DEPRESSIONS IN ELEMENTAL WATERSHED
NSOIL : INITIAL SOIL PARAMETER
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C 01 :</td>
<td>TIL: MAIN DISCHARGE FROM ELEMENTAL WATERSHED (CFS)</td>
</tr>
<tr>
<td>C 02 :</td>
<td>OVERLAND FLOW CHANNEL DISCHARGE FROM ELEMENTAL WATERSHED (CFS)</td>
</tr>
<tr>
<td>C PCEL :</td>
<td>DEPRESSION CREST ELEVATION (FEET)</td>
</tr>
<tr>
<td>C PERCOL :</td>
<td>MOISTURE REDISTRIBUTION IN OR OUT OF TOP FOOT (INCHES)</td>
</tr>
<tr>
<td>C POMTRN :</td>
<td>PHENOLOGICAL STATE CURVE FOR CROP - SEE SUBROUTINE ET</td>
</tr>
<tr>
<td>C PRECIP :</td>
<td>PRECIPITATION INPUT DATA ARRAY (INCHES)</td>
</tr>
<tr>
<td>C Q1 :</td>
<td>DRAINAGE DITCH REACH DISCHARGE AT START OF TIME INTERVAL (CFS)</td>
</tr>
<tr>
<td>C Q2 :</td>
<td>DRAINAGE DITCH REACH DISCHARGE AT END OF TIME INTERVAL (CFS)</td>
</tr>
<tr>
<td>C QFULL :</td>
<td>FULL FLOW TILE MAIN DISCHARGE (CFS)</td>
</tr>
<tr>
<td>C QMAIND :</td>
<td>MAIN TILE DISCHARGE (CFS)</td>
</tr>
<tr>
<td>C QSUBMN :</td>
<td>SUBMAIN TILE DISCHARGE (CUBIC FEET/DAY)</td>
</tr>
<tr>
<td>C QT :</td>
<td>INITIAL ELEMENTAL WATERSHED TILE MAIN DISCHARGE (CFS)</td>
</tr>
<tr>
<td>C QU :</td>
<td>TOTAL ELEMENTAL WATERSHED DISCHARGE (CFS)</td>
</tr>
<tr>
<td>C QUOTD :</td>
<td>RATIO OF MAIN TILE DISCHARGE TO FULL MAIN TILE DISCHARGE</td>
</tr>
<tr>
<td>C RAIN2 :</td>
<td>ACCUMULATED PRECIPITATION DATA ASSOCIATED WITH AND USED AS INPUT TO THE MODEL ROUTINES (INCHES)</td>
</tr>
<tr>
<td>C RAINS :</td>
<td>ACCUMULATED PRECIPITATION INPUT DATA (INCHES)</td>
</tr>
<tr>
<td>C RESAT :</td>
<td>0.9 OF SOIL SATURATION (INCHES)</td>
</tr>
<tr>
<td>C RN :</td>
<td>MANNINGS ROUGHNESS COEFFICIENT FOR DRAINAGE DITCH</td>
</tr>
<tr>
<td>C S :</td>
<td>OVERLAND FLOW CHANNEL SLOPE (FEET/FOOT)</td>
</tr>
<tr>
<td>C SAT :</td>
<td>SOIL SATURATION (PERCENT BY VOLUME)</td>
</tr>
<tr>
<td>C SDELT :</td>
<td>CUMULATIVE TIME DURING THE DAY (HOURS)</td>
</tr>
<tr>
<td>C SHOR :</td>
<td>HORIZONTAL LEG OF DRAINAGE DITCH SIDE SLOPE</td>
</tr>
<tr>
<td>C SLPSUB :</td>
<td>SUERMAIN TILE SLOPE (FEET/FOOT)</td>
</tr>
<tr>
<td>C SMASM :</td>
<td>TOTAL STORAGE CAPACITY MINUS PRESENT SOIL MOISTURE IN TOP FOOT (INCHES)</td>
</tr>
<tr>
<td>C SOILM :</td>
<td>INITIAL SOIL MOISTURE AT BEGINNING OF SIMULATION (% BY VOLUME)</td>
</tr>
<tr>
<td>C SPACNG :</td>
<td>LATGER TILE LINE SPACING (FEET)</td>
</tr>
<tr>
<td>C SQ2 :</td>
<td>INFLOW TO DITCH FROM AN ELEMENTAL WATERSHED (CFS)</td>
</tr>
<tr>
<td>C SSSMASM :</td>
<td>SAME AS SMASM EXCEPT UNDER DEPRESSIONS STORING WATER (INCHES)</td>
</tr>
<tr>
<td>C SVERT :</td>
<td>VERTICAL LEG OF DRAINAGE DITCH SIDE SLOPE</td>
</tr>
<tr>
<td>C TD :</td>
<td>MAIN TILE DIAMETER (INCHES OR FEET)</td>
</tr>
</tbody>
</table>
C TESTAS : TOLERANCE FACTOR USED TO TERMINATE ITERATIVE PROCEDURE IN
C SUBROUTINE ASOL
C TESTDR : TOLERANCE FACTOR USED TO TERMINATE ITERATIVE PROCEDURE IN
C SUBROUTINE DRNAGE
C TESTIN : TOLERANCE FACTOR USED TO TERMINATE ITERATIVE PROCEDURE IN
C SUBROUTINE INFILT
C TESTRO : TOLERANCE FACTOR USED TO TERMINATE ITERATIVE PROCEDURE IN
C SUBROUTINE ROUT
C TFACT1,TFACT2 : FACTORS USED TO CHANGE THE ROUTING TIME INCREMENT OR
C TIME INTERVAL
C TILEFL : TILE MAIN DISCHARGE FROM ELEMENTAL WATERSHED (CFS)
C TIME : ACCUMULATED TIME VALUES DERIVED FROM ROUTING TIME INCREMENT
C (HOURS)
C TIMEI1 : HOUR SIMULATION STARTS
C TIMEI2 : MINUTE SIMULATION STARTS
C TIMEPT : TIME INPUT DATA ARRAY (HOURS)
C TOLELV : MAIN TILE OUTLET ELEVATION (FEET)
C TOTSTR : TOTAL STORAGE CAPACITY IN TCP FOOT (INCHES)
C TSLOPE : MAIN TILE SLOPE (FEET/FOOT)
C WEIRK : SURFACE INLET WEIR COEFFICIENT
C WP : SOIL WILTING POINT (PERCENT BY VOLUME)
C WWCOEF : OVERLAND FLOW CHANNEL DISCHARGE PARAMETER - SEE FUNCTION
C QOUTFLO
C ZFD : ZERO FLOW DEPTH FOR SURFACE INLET (FEET)
C ZFW : ZERO FLOW DEPTH FOR OVERLAND FLOW CHANNEL (FEET)
C
C*****************************************************************************
C
C COMMON QTILE1,QTILE2
C COMMON D1,D2,PCEL,E,TD,H,TOLELV,MNT,MNC,NUELUN,AU,L,CONST1,
C 1K,QU,S,O1,O2,OF, I1,I2,ZFD, MDTEST,INDEX1,INDEX2, Y
C COMMON HMAIN,ELEVMN,QPULL, HYDRCD,DRNPOF,PPCTN,
C 1CFACTR,SPACNG,HT1,HWT1,QIN1,HWT2, DELTM,SDELM,JKJ,QTILE9,WEIR
C COMMON QLEFT,JDRAIN,QSUBMN,QB,QTILES,INDEX3,DPMAIN,HT2, QIN2
C COMMON WEIRK, CD,SLEPSUB,OS, D21,WWCOEF,DELTPS,FCINFL,SSMASM

1440 1450
1460 1470
1480 1490
1500 1510
1520 1530
1540 1550
1560
1570 1580
1590 1600
1620 1630
1650 1660
1670 1680
1690 1700
1710 1720
1740 1750
1760 1770
1780 1790
1800
732 FORMAT(' ',I2,F7.2,F5.2,F7.2,6(F7.2,F5.2,F5.1))
215 FORMAT(8F10.4)
301 FORMAT (15X,3F5.0,12F4.0)
100 FORMAT (3I5)
750 FORMAT (F5.0,F10.0,7F5.0)
75 FORMAT (6F5.0,3I5)
13 FORMAT (I5,3F5.0,F10.0,F5.0,I5,6F5.0)
1 FORMAT (8F10.0)
7 FORMAT (4012)
READ (5,854) MCN,IDAY,TIMEI1,TIMEI2
854 FORMAT(2I3,2F4.0)
READ(5,100) NITYPE,NELWSD,NEWAD
READ(5,750) RN,DLNGTH,BWIDTH,DDEPTH,SVERT,SHOR,DSLOPE,COEFBW
READ(5,3 ) (QT (I),I=1,NITYPE)
READ(5,75) TESTIN,TESTDR,TESTRO,TESTAS,TFACT1,TFACT2,IPLOT,
1 IPUCH,ROUTE
C THIS SECTION INPUTS EVAPOTRANSPIRATION AND SOIL MOISTURE INFORMATION
DO 850 I=1,11
850 READ(5,851) (NRTDS(I,J),J=1,10)
851 FORMAT(10(I3,1X))
DO 852 I=1,6
852 READ(5,853) (ETRATE(I,J),J=1,21)
853 FORMAT(21F3.2)
READ(5,855) (PCMTRN(I),I=1,50)
855 FORMAT(8(F4.0,F4.2))
DO 856 I=1,11
856 RESAT(I)=0.9*(SAT(I)/100.)*6.
857 FORMAT(3F5.0)
RESAT(11)=RESAT(11)*8.
C OUTPUT DRAINAGE DITCH PARAMETERS
WRITE (6,700) NITYPE, NELWSD, NEWAD, DLENGTH, BWIDTH, DDEPTH, SVERT, SHOR,
1DSLOPE, RN
700 FORMAT ('1',///,T20,'GENERAL WATERSHED CHARACTERISTICS',///,
1T2,'THE SIMULATED WATERSHED CONTAINS',I2,T36,' DIFFERENT KINDS OF
2ELEMENTAL',//,T2,'WATERSHEDS AND A TOTAL OF',I4,T32,'ELEMENTAL WAT
3ERSHEDS. THERE ARE ',//,I3,T5,'ELEMENTAL WATERSHEDS ABOVE THE HE
4AD OF THE DITCH.'///,T10,'****************************************
5***********,,///,T20,'DRAINAGE DITCH PARAMETERS',///,T12,'TOTAL
6 LENGTH = ',F7.1,T36,'FEET',//,T12,'BOTTOM WIDTH = *,F4.1,T34,'
7FEET',//,T12,'DEPTH = ',F4.1,T27,'FEET', //,T12,'SIDE SLOPES =
8 ',F4.1,T32,'VERTICAL TO ',F4.1,T49,' HORIZONTAL', //,T12,'SLOPE =
9 ',F7.5,T30,'FEET/FOOT', //,T12,'MANNINGS ROUGHNESS COEFFICIENT
1 = ',F5.3)

START OF MAJOR DO LOOP NUMBER 1
2000 DC 1000 JKJ = 1,NITYPE
READ (5,13) NUELDN, MNT, MNC, TOELEV, K, S, MDTEST, SLPSUB, WWCOEP, TSLOPE,
1 DC01:F,CD, WEIRK
READ (5,1) (A0(I),L(I), TD(I), E(I), PCEL (I), D1(I), QFULL(I), ELEVMN(I),
1=1, NUELUN)
READ (5,3) ASOIL, NSOIL, TOTSTR, FCINFL , DPSTOR, SMASM, GRAVPR
READ (5,3) (SOILM(I),I=1,11)
READ (5,1) HYDRCD, DRNPOR, FFCTN, CFACTR, SPACNG

OUTPUT SOIL PARAMETERS FOR EACH ELEMENTAL WATERSHED
WRITE (6,702) JKJ
702 FORMAT ('1',T20,'ELEMENTAL WATERSHED : TYPE ',I2)
GO TO (703,705,707,709), MDTEST
703 WRITE (6,704)
704 FORMAT ( ///,T5,'THIS ELEMENTAL WATERSHED HAS SURFACE INLETS')
GO TO 711
705 WRITE (6,706)
706 FORMAT ( ///,T5,'THIS ELEMENTAL WATERSHED IS NOT DRAINED')
GO TO 711
707 WRITE (6,708)
708 FORMAT ( //,T5,'THIS ELEMENTAL WATERSHED HAS SURFACE INLETS AND S
1UBSURFACE DRAINAGE*)
GO TO 711
709 WRITE (6,710)
710 FORMAT ( //,T5,'THIS ELEMENTAL WATERSHED HAS SUBSURFACE DRAINAGE
ONLY')
711 WRITE (6,712) NUELUN, ASOIL, NSOIL, TCTSTR, FcinFL, DpSTOR, SMASM,
1GRAVPR, DRNPOR, HYDRCD
712 FORMAT (//,T5,'THIS ELEMENTAL WATERSHED CONTAINS ',T2,T42,' DEPRESSI
ONAL AREAS ',//,T10,'*********** ************ *********************
2****:,:** •,//,T26,* SOIL PARAMETERS ' ,/,T2,' FOR SUBROUTINE INFILT
3' ,/,T2,'----------- ' ,/,T2,'ASOIL = ',F4.2,T16,'IN/HR
4 NSOIL = ',F4.2,//,T2,' TOTAL SOIL MOISTURE STORAGE (TOTST
5R) = ',F4.2,T47,'IN. ',//,T2,' STEADY STATE INFILTRATION RATE (FCIN
6FL) = ',F4.2,T50,'IN/HR',//,T2,' SURFACE STORAGE (DPSTOR) = ',F4.
72,T35,'IN. ',//,T2,' TOTAL STORAGE MINUS ANTECEDENT MOISTURE (SMASM)
8 = ',F4.2,T58,'IN. ',//,T2,' ' 9 'GRAVITATIONAL POROSITY (GRAVPR) = ',F4.2
T42,'IN. ',//,T2,' FOR SUBROUTINE DRAIN ',//,T2,' '-----------
1---' ,/,T2,' DRAINABLE POROSITY (DRNPOR) = ',F5.3
2//,T2,' HYDRAULIC CONDUCTIVITY (HYDRCD) = ',F4.1,T42,'FT/DAY',///)
WRITE (6,713) (I, WP(I), FCP(I), SAT(I), SOILM(I), I = 1,11)
713 FORMAT (' '1',T8, 'PHYSICAL PARAMETERS OF ELEMENTAL WATERSHED
11ER POINT CAP. (PER CENT) MOIST',11('T2',I4,2F8.1,2F10.1))
WRITE (6,714) JKJ
WRITE (6,716) MNC, MNT, S, K, TOELEV, TSLOPE, SLPSUB, SPACNG,
1DCOF, TCFACTR, PFCFN, (I,TD(I),L(I),QFULL(I),FCEL(I),E(I),AU(I),D1(I),I=1,2
2NELUN)
714 FORMAT ('1',T8, 'PHYSICAL PARAMETERS OF ELEMENTAL WATERSHED : TYPE ' 1
1',I2)
716 FORMAT (//,T2, '************ ************ ************ ************
1************ ',//,T2,'MANNINGS OVERLAND FLOW CHANNEL ROUGHNE
2SS COEF. (MNC) = ',F5.3,//,T2,'MANNINGS MAIN TILE ROUGHNESS
3COEFFICIENT (MNT) = 'F5.3//T2, 'OVERLAND FLOW CHANNEL SLOPE (S)
4 = 'F6.4,T43, 'FEET/FOOT'//T2, 'OVERLAND FLOW CHANNEL SHAPE PARA
5METER (K) = 'F9.6//T2, 'MAIN TILE OUTLET ELEVATION (TOELEV) = 'F5.1,T46, 'FEET',
6'T =F6.4,T36, 'FEE
7T/FOOT'//T2, 'MAIN TILE SLOPE (TSLOPE) = 'F6.4,T39, 'FEET/FOOT
8',//T2, 'LATERAL TILE SPACING (SPACING) = 'F5.1,T40, 'FEET',
9',//T2, 'DRAINAGE COEFFICIENT (DCOEF) = 'F5.3,T39,
11'INCHES/DAY',//T2, '-C- FACTOR (CFACTR) = 'F3.1, //T2, '-F- FACT
20R (FFCTN) = ',F5.2,//','
21************************************************************
22,TILE BAIN',T41,'DEPRESSION',//T7
23,'DEPR. ',T22,'FULL
24 CREST BOTTOM WSHD. INITIAL 
25',//T3, ',NO.',T9, ',DIA. LENGTH
26 FLOW ELEV. ELEV. AREA WATER DEP. 
27',//T7, ', (INCH) (FEE
28 T) (CFS) (FEET) (FEET) (ACRE) (FEET) 
29 25(/,2X,I2,3X,F4.1,
30 2X,F6.1,2X,F4.2,4X,F4.1,5X,F4.1))
31
32THE FOLLOWING SECTION INITIALIZES THE PROGRAM
33
34SSLASM=SSLASM
35DO 40 I=1,NUELUN
36INDEX1(I) = 4
37O1(I)=0.
38DO 859 J=1,370
39DO 859 J=1,18
859AMISAR(I,J)=0.
859DO 4 I=1,NUELUN
TD(I) = TD(I)/12.

SPECIFIES MAXIMUM SURFACE INLET DIAMETER OF 1 FOOT

DS(I) = 1.
IF (TD(I) - 1.) < 0.5, DS(I) = TD(I)

ATOT = ATOT + AU(I)

CONST1(I) = 1.49 * 3.142 * (TD(I)**3.2) / HNT / 4 / SQRT(L(I)) / (4**.667)

4 CONST3(I) = 43560. * AU(I) / 3600. / 12.

E(NUELUN + 1) = DDEPTH

H(NUELUN+1) = TOELEV

CALL IHEAD(ATOT, SPACNG, QT, JKJ, HYDRCD, PFCTN, HWT1, Q TILE8, NUMEUL, QSUBMN, AU, WATERT, ELEVNN, TOELEV, TD, HT1, Q TILE1)

QMAIN = 0.

CALL I HEAD (ATOT, SPACNG, QT, JKJ, HYDRCD, PFCTN, HWT1, Q TILE8,
NUELUN, QSUBMN, AU, WATERT, ELEVNN, TOELEV, TD, HT1, Q TILE1)

QMAIN = QMAIN + QSUBMN(I) / 3600. / 24.

QUOTD = QMAIN / QFULL(I)

DFMAIN(I) = DFLOW(QUOTD) * TD(I)

HMAIN(I) = ELEVNN(I) + TOELEV + DFMAIN(I)

83 H(I) = HMAIN(I)

HMAIN(NUELUN+1) = TOELEV

GO TO 261

262 DO 263 I = 1, NUELUN

263 H(I) = TOELEV + ELEVNN(I)

QIN1 = 0.

CALCULATE INITIAL DEPRESSION AND ELEMENTAL WATERSHED OUTFLOW
C
DO 14 I=1,NUELUN
JDBAIN = 1
AB(I) = OUTFLO(D1,I)
14 QU(I) =01(I) +02(I)
C
CALCULATE INITIAL INUNDATED AREA FOR AND INFLOW TO DEPRESSIONS
C
IC = 0.
AREAFL(1,JKJ) = 0.
DO 5 I=1,NUELUN
IF (E1(I).EQ.0.) GO TO 5
AREAFL(1,JKJ) = AREAFL(1,JKJ) + 1.33*D1(I)**1.67
5 I1(I)=CONST3(I)*I0
C
FLOW(1,JKJ) = QT(JKJ)
TILEFL(1,JKJ) = QT(JKJ)
IBKD=KDA(HON)+IDAY
SDELT(JKJ) = TIMEI1 + TIMEI2/60.
IC= 1
IVALU1 =1
IVALU2 =1
IVALU3 =1
RAIN2:(1) = 0.
CALL INFILT(ASOIL,NSOIL,TOTSTR,FCINFL,DPSTOR,SMASM, GR:VPR,
1DELTF,RAIN2,IC,IVALU1,DELTF,DELTQ,SDELT,JKJ,
2F1,VOLDP,PEXCES,QEEXES,INTRCP,TESTIN,SDELT)
CALL ET(AMISAR,IBKD,INTRCP,AOPEVP,POMTRN,NRTDS,WP,FCP,ETRATE,
1ATRANS,AVAPR, JJ, HRET, AVPAN,IVALU2,SOILM,AAET,APET,APAN,AAEVAP,
2AATRAN,AAINT)
CALL HEDIST(AMISAR,ATRANS,QLEFT,RESAT,DELTM6,DELT,JJ,TENS,CONDC,
1HRET,PERCOL,WP,IVALU3,FCP,ZTRAN,ZINF,ZOUTF,ATPERC,MDTEST,SMASM,
2SMASM)
C
STOR: THE FOLLOWING INFORMATION ON DISK FOR FUTURE USE
C
WRIT: (8) NUELUN,MNT,MNC,TOELEV,K,S,MDTEST,SLPSUB,ASOIL,NSOIL,
00E7 L + HDHCN = LN
06ZT Z + (aVUSN-aSMiaK) *3 = HDaON 6Z1
08ZT 3
0LZT HDHia am,
onoiva
iNawao^id aansaaivM ivinawaia
092Tj aHi QNY asavHDSia HDvaa
368x455 IVIIINI 'HI
9N31 HDvaa HDHia asvNivaa jndNi
361x455 D
0S0Tj 3
0D0
060 *7 HDHia 39¥NIVaa DPOTV SGaHSUaiVM 3
090 *7 "iviNawaia ao iNawaoNvaav qnv Noiivoiaiiwaai aaHsaaivn iiidino d
0S0Tj 3
0*70*7 L aaawnfi dooi oao anaw ao ana 3
0E0*7 3
020*7 aNN:ciN03 oooL
010 *7 (NmaDN'L=L'H' (w) Lo ' (H) H ' (H) LxaaNi'(w) sa)'jnaas'aao;)WM'
697x157 z
000 *7 (t+NmanN) NiYHH' ( L + NmanN) a ' (NDianN '
1J=6 ' (w) NIVWH' (H) E1SN03' (W) LISN03' (W) NWAaiai
366E 'I
270x121 (w) nnaO'(w) LQ'(w)'ia3d ' (u) a'(K) ai'(w) 1'(w) nq) (e) :îiiaM
iLb£ oaadiv' (01 'I =w' (w)ainoz' (H)aNiz' (w)Nvaiz) 'iNivv'Nvaivv'dVAavv'Nvdvt?
315x98 i=H
205x98 'ladv'laW
289x98 (81
315x98 i=H
351x98 (w
351x98 'rr) avsiwv) ' (NmanN'
520x86 i=w' (w)
555x86 eaTiiO'
633x86 (w) limh)e
156
156
NORCHX = NORCH/16 + 1
NZX = 1
DO 801 I=1,NORCHX
MZX = NZX + 15
READ(5,3)(DELX(J),J=NZX,MZX)
801 NZX = NZX + 16
NORCHQ = N1/16 + 1
NZY = 1
DO 803 I=1,NORCHQ
MZY = NZY + 15
READ(5,3)(Q1(J),J=NZY,MZY)
803 NZY = NZY + 16
ITYPEN = NELWD/40 + 1
NZZ = 1
DO 805 I=1,ITYPEN
MZZ = NZZ + 39
READ(5,7)(ITYPE(J),J=NZZ,MZZ)
805 NZZ = NZZ + 40

DICTFQ(1)=Q1(N1)
NDISK=1
REWIND 8
TIME(1)=TIME1+TIME2/60.

THE FOLLOWING SECTION INPUTS EVAPORATION DATA AND INDICATES PRECIP. DATES

IJ=INKD+1
11 READ(5,6) DELTMB
6 FORMTAT(F5.0)
IF(IDELTMB.EQ.-1.) GO TO 404
19 READ(5,858)(AMISAR(IJ,J),J=1,7)
858 FORMTAT(A2,3F3.0,F4.0,F4.2,F3.0)
IF(AMISAR(IJ,7)-99.) 9,12,12
12 NTIM=IJ-1
GO TO 15
9 IJ=IJ+1
GO TO 19
15 IJ=IBKD
16 DO 34 J=1,NTIM1
   IJ=IJ+1
   IF (AMISAR(IJ,7)-1.) 34,23,36
23 NTIM= (J-1) *1440./DELTMB+1
   GO TO 25
34 CONTINUE
36 NTIM= (NTIM1-JJ )*1440./DELTMB+1
25 NTIM=NTIM+(24.-SDELT(1))/DELTMB*60.+1
   DO 37 J=1,NTIH
      RAIN2(J)=0.
37 CONTINUE
   DELTM=DELTMB
   ICHNGE=1
   GO TO 20

C
C
C    THE FOLLOWING SECTION READS IN TIME-PRECIPITATION DATA AND
C    CONVERTS IT TO PRECIPITATION INPUT AT DELTM(MINUTES) TIME
C    INCREMENTS
C    -THE FIRST DATA GROUP MUST CONTAIN PRECIPITATION (THE SECOND INPUT
C       CARD MUST HAVE A GREATER PRECIPITATION VALUE THAN THE FIRST)
C    -EACH TIME-PRECIPITATION DATA GROUP MUST HAVE A TERMINATION CARD
C       WHICH CONTAINS A NEGATIVE NUMBER IN THE SPACE ALLOCATED TO VARIABLE
C       ATIML
C    -THE :CINFL AND DPSTOR PARAMETER VALUES CAN BE CHANGED DURING A
C       COMPUTER RUN BY INCLUDING THE NEW VALUES ON THE DATA GROUP
C       TERMINATION CARD FOR WHICH THE VALUES ARE TO INITIALLY APPLY
C
C
398 READ (5,3) DELTM
IF (DELTMBEQ.-1.) GO TO 404
PMOIST = 0.
RAIN1 = 0.
QTEST = Q1(N1)
LRAIN = 1
I = 0

INPUTS PRECIPITATION DATA AND CHECKS FOR END OF JOB, END OF TIME-PRECIPITATION DATA GROUP AND FOR WATERSHED SOIL PARAMETER CHANGES

399 NCHECK = 1
ICHNGE = 1
400 READ (5,301) ATIME,BTIME,RAINS,(DP(M ),FC(M ),M =1,NITYPE)
401 IF (ATIME+1000.) 403,405,403
405 DELTMB=360.
IVALC1=1
IJ=J
IF (IJ .LT.NTIB1) GO TO 16
GO TO 11
403 NCARD1 = I
IF(DP(1)) 811,811,812
811 ICHNGE = 1
GO TO 416
812 ICHNGE = 2
GO TO 416

GO TO (380,382),LRAIN
380 PRECIP(1) = RAINS
TIMEPT(1) = HRS2
TIME(1)= HRS2
DO 221 JKJ = 1, NITYPE
SDELT (JKJ) = HRS2
221 CONTINUE
HRS1 = HRS2
WRITE (6, 730) (J, J = 1, NITYPE)
730 FORMAT (' ', T6, 'TIME ACCUM WSHD TOTAL DISCHARGE (CFS)
1, TILE DISCHARGE (CFS) AND INUNDATED AREA (ACRES)
2, (HRS) (IN) (CFS) ', 3X, T26, '-----', I2, T34, '-----
4T51, '----- ----', I2, T68, '----- ----', I2, T85, '-----
5----- ----', I2, T102, '----- ----', I2, T119, '-----',/)
WRITE (6, 732) IAY, TIME (1), RAIN2 (1), DITCHQ (NTIM), (FLOW (NTIM, N3),
1TILEFL (NTIM, N3), AREAFL (NTIM, N3), N3 = 1, NITYPE)
GO TO (219, 220), IPUNCH
220 WRITE (7, 215) TIME (1), (FLOW (NTIM, N3), N3 = 1, NITYPE)
219 LRAIN = 2
NTIM = 1
GO TO 400
C CALCULATES ACCUMULATED TIME-PRECIPITATION DATA SETS
C 382 IF (HRS2 - HRS1) 303, 304, 303
303 TIMEPT (I) = TIMEPT (I-1) + (24. - HRS1) + HRS2
GO TO 305
C EACH DAY MUST END WITH 2400 HOURS
C 304 TIMEPT (I) = TIMEPT (I-1) + HRS2 - HRS1
305 PRECIP (I) = RAINS
C IF (PRECIP (2) - PRECIP (1)) 409, 410, 415
409 WRITE (6, 411)
411 FORMAT (' ', T5, 'ERROR IN PRECIPITATION INPUT DATA ')
GO TO 404
C TEST FOR INCREASE IN ROUTING TIME INCREMENT
C
410 GO TO (420, 306), NCHECK
420 NCHECK = 2
   DO 430 II = 2, NTIM
      IF (DITCHQ(II) - QTEST) 421, 426, 426
421 QRATIO = DITCHQ(II)/QTEST
   IF (CRATIO - TFACT1) 422, 422, 430
422 IF (CRATIO - TFACT2) 424, 424, 423
423 DELTM = 2.*DELTMB
   GO TO 430
424 DELTM = 4.*DELTMB
   GO TO 430
426 QTEST = DITCHQ(II)
   DELTM = DELTM
430 CONTINUE
   GO TO 306
415 NCHECK = 1
   DELTM = DELTM
306 HRS1 = HRS2
   GO TO 400
416 RAIN:(1) = PRECIP(1)
   DELTM6 = DELTM/60.
   AOTIME = (TIMEPT(NCARD1) - TIMEPT(1))/DELTM6
   NOTIME = AOTIME + 0.1
   DTIM1 = TIMEPT(1)
   NTIM = NOTIME + 1
SUBDIVIDES A GIVEN ACCUMULATED TIME-PRECIPITATION DATA SET INTO
'DELTM' TIME INCREMENTS AND CORRESPONDING ACCUMULATED
PRECIPITATION FOR WATERSHED SIMULATION RUNS
DO 315 M=2, NTIM
   DTIM1 = DTIM1 + DELTM6
   DO 307 J=2, NCARD1
      IF (ITIME - TIMEPT(J)) 308, 309, 307
307 CONTINUE
362 READ (9) NULLE. MNR. MNC. TOLEST. K'S. MPEST. SISPUB. ANDI. NSOIL.
TOTSTR, FCINFL, DPSTOR, SMASM, EVAPTR, GRAVPR, SSMASM, HYRCD, DRNPOH,

FCNFL, CFACFR, SPACNG, JJ, F1, VOLDPP, PEXCES, QEXCES, INTRCP, QIN1,

HWT1, QTILE8, M = 1, NUELON, (AMISAR, JJ, M, M = 1, 18), AAET, APET,

APAN, NAEVAP, AATRAN, AAMNT, (ZTRAN, M, ZINF, M, ZOUTF, M, M = 1, 10), ATPERC

READ (9) (AU, L, T, M, E, PCEL, D1, QFULL, M, ZTRN, M, ZINF, M, ZOUTF, M, M = 1, 10), ATPERC

EVLON, HMAIN, M = 1, NUELON)

GO TO (815, 816), ICHNGE

FCINF:: = FC (JKJ)

DPSTOR = DP (JKJ)

START OF MAJOR DO LOOP NUMBER 3

DO 10 IC = 2, NTIM

SDELT(JKJ) = SDELT(JKJ) + DELTM6

CALL INFILT(AOSI, NOSI, TOTSTR, FCINFL, DPSTOR, SMASM, GRAVPR,

1 DELTM, RAIN2, IC, IVALU1, DELTF, DELTQ, SDELT, JKJ,

2 F1, VOLDPP, PEXCES, QEXCES, INTRCP, TESTIN, SDELT)

IF(D1(NUELON).LE.0.10) SSMASM = SSMASM - DELTF

IF (SDELT(JKJ) < 2U.) 18, 26, 26

IDAY = IDAY + 1

SDELT(JKJ) = SDELT(JKJ) - 24.

CALL ET(AMISAR, IBKD, INTRCP, AOPEVP, POMTRN, NRTDS, WP, FCP, ETRATE,

1 ATRANS, EVAPTR, JJ, HRETR, AVPAN, IVALU2, SOILM, AAET, APET, AAMNT,

2 AATRAN, AAMNT)

SMASM = SSMASM + EVAPTR

SMASM = SSMASM + EVAPTR

SMASM = SSMASM + EVAPTR

18 CALL REDIST(AMISAR, ATRANS, QLEFT, RESAT, DELTM6, DELTF, JJ, TENS, CONDUC,

1 HRETR, PERCOL, WP, IVALU3, FCP, ZTRAN, ZINF, ZOUTF, ATPERC, MDTEST, SMASM,

2 SSMASM)

SMASM = SSMASM + PERCOL

SMASM = SSMASM + PERCOL

F1 = TOTSTR - SMASM

IO = DELTQ/DELTM6

DO 229 I = 1, NUELON

229 D2(I) = D1(I) + 0.10
CALL ROUT

UPDATE PARAMETERS FOR ANOTHER TIME INCREMENT

GO TO (24,24,21,21), MDTEST

QIN1 = QIN2
DO 22 I = 1, NUELUN
QTILE8(I) = QTILE9(I)
HWT1(I) = HWT2(I)
QTILE1(I) = QTILE2(I)
WATER1(I) = WATER(I) + HT2(I) - HT1(I)
22 HT1(I) = HT2(I)
DO 21 QIN1 = QIN2

DO 21 I = 1, NUELUN
QTILE8(I) = QTILE9(I)
HWT1(I) = HWT2(I)
QTILE1(I) = QTILE2(I)
WATER1(I) = WATER(I) + HT2(I) - HT1(I)

GO TO (24,24,21,21), MDTEST

21 QIN1 = QIN2
DO 22 I = 1, NUELUN
QTILE8(I) = QTILE9(I)
HWT1(I) = HWT2(I)
QTILE1(I) = QTILE2(I)
WATER1(I) = WATER(I) + HT2(I) - HT1(I)
22 HT1(I) = HT2(I)
DO 21 QIN1 = QIN2

IF(D2(I).EQ.0.) GO TO 130
DO 8 I = 1, NUELUN
IF(D2(I).EQ.0.) GO TO 130

AREAPL(IC,JKJ) = 0.
DO 8 I = 1, NUELUN
IF(D2(I).EQ.0.) GO TO 130

AREAPL(IC,JKJ) = AREAPL(IC,JKJ) + 1.33*D2(I)**1.67

D1(I) = D2(I)
I1(I) = I2(I)
8 QU(I) = QU(I) + QU2(I)

END OF MAJOR DO LOOP NUMBER 3

STORE THE FOLLOWING INFORMATION ON DISK FOR FUTURE USE

GO TO (366, 368), NDISK

WRITE (9) NUELUN, MNT, MNC, TOELEV, K, S, MDTEST, SLPSUB, ASOIL, NSOIL,
1 TOTSTR, FCINFL, DPSTOR, SSMAS, EVAPTR, GRAVPR, SSMAS, HYRCD, DRNPR,
2 FCCT4, CFCTR, SPACNG, JJ, P1, VOLDR, PECS, PECS, INTRCP, QIN1,
3 (HWT1(M), QTILE8(M), M = 1, NUELUN), (AMISAR(JJ,M), M = 1, 18), AATR, APET,
4 ATRAN, AAEVAP, AAPRTN, AAINR, (ZTRAN(M), ZINF(M), ZOUTF(M), M = 1, 10), ATPERC
WRITE (9) (AU(M), L(M), TD(M), E(M), PCEL(M), D1(M), QFULL(M),

164
END OF MAJOR DC LOOP NUMBER 2

THIS SECTION ROUTES ELEMENTAL WATERSHED OUTFLOW DOWN THE DRAINAGE DITCH

GO TO (217, 218), IPUNCH

DO 216 I = 2, NTIM
   TIME(I) = TIME(I - 1) + DELTM6
216 WRITE(7, 215) TIME(I), (FLOW(I, J), J = 1, NTYPE)
NELWSD MUST BE GREATER THAN NEWAD

217 GO TC (31, 30), IROUTE
30 WRITE(6,97)
97 FORMAT('112X'TOTAL WATERSHED OUTFLOW'/14X'DAY TIME OUTFLOW'
1//)
   DO 116 KJ=2,NTIM
    TIME(KJ) = TIME(KJ-1) + DELTM6
   IF(TIME(KJ)-24.) 32,33,33
33 TIME(KJ) = TIME(KJ) - 24.
   IAY=IAY+1
32 DITCHQ(KJ) = FLOW(KJ,1)
116 WRITE(6,98) IAY,TIME(KJ),DITCHQ(KJ)
98 FORMAT(14X,I2,F9.2,F10.5)
GO TO 99
31 ITIMI=1
30 DO 105 I=1,N1
105 A1(I) = AREA(Q1(I),RN,COEFBW)
   DO 106 I=1,NORCH,2
106 SQ2(:) = 0.
   N2=NEWAD+1
   DO 108 I=N2,NELWSD
108 N3=ITYPE(I)
   N4 = 2.*(I-NEWAD)
109 SQ2(N4) = FLOW(KJ,N3)
   Q2(1) = 0.
   DO 110 I=1,NEWAD
110 Q2(1) = Q2(1) + FLOW(KJ,N3)
A2(1) = AREA(Q2(1), RN, COEFBW)
IF (Q2(1).EQ.0.) GO TO 111
DELT = DELTM*60.
DO 114 I=1,NORCH
LAMBDA=DELT/DELX(I)
BETA=LAMBDA*Q2(I)-A2(I)/2.+DELT*SQ2(I)/DELX(I)
ADUM=A2(I)
A2(I+1) = ASOL (LAMBDA, ALPHA, BETA, ADUM, RN, COEFBW, TESTAS)
POWER=1./.73
114 Q2(I+1) = DSCHRG (A2(I+1), RN, POWER, COEFBW)
GO TO 112
111 DO 113 I=1,NORCH
Q2(I+1)=0.
113 A2(I+1)=0.
112 DITCHQ(KJ)=Q2(N1)
DO 115 I=1,N1
Q1(I)=Q2(I)
115 A1(I)=A2(I)
TIME(KJ) = TIME(KJ-1) + DELTM6
IF (TIME(KJ)-24.) 2,35,35
35 TIME(KJ)=TIME(KJ)-24.
IAY=IAY+1
2 WRIT:(6,732) IAY,TIME(KJ),RAIN2(KJ),DITCHQ(KJ), (FLOW(KJ,N3),
1 TILEPL(KJ,N3), AREAPL(KJ,N3), N3=1, NTYPE)
C C END OF MAJOR DC LOOP NUMBER 4
C 99 TIME(1) = TIME(NTIM)
GO TO (120,121),IPLT
C C NO PLOTTING ROUTINE INCLUDED IN THE PROGRAM
C 120 CONTINUE
121 I= 1
IF (RAIN2(NTIM).NE.0.) GO TO 399
IF (AREISAR(IJ,7).EQ.1.) GO TO 398
SUBROUTINE IHEAD (ATOT, SPACNG, QT, JKJ, HYDRCD, FFCTN, HWT1, QTILE8,  
1 NUELUN, QSUBMN, AU, WATERT, ELEVMN, TOELEV, TD, HT1, QTILE1)

*********************************************************************
C
C THIS SUBROUTINE CALCULATES THE INITIAL WATERTABLE ELEVATION AND SUBMAIN T
C DISCHARGE
C
C BASIC ASSUMPTION - TILE MAINS ARE NOT INITIALLY FLOWING UNDER PRESSURE
C - INFLUENCES CALCULATION OF INITIAL WATERTABLE ELEVATION
C
C PARAMETER IDENTIFICATION
C
C ATOT : TOTAL AREA OF ELEMENTAL WATERSHED (ACRE)
C AU : SIZE OF DEPRESSIONAL AREA (ACRE)
C ELEVMN : ELEVATION OF MAIN TILE AT CENTER OF DEPRESSIONAL AREA ABOVE MAIN
C OUTLT (FEET)
C FFCTN : A PARAMETER WHICH DEPENDS ON THE DRAINAGE SYSTEM GEOMETRY
C HT, H1, HWT1 : HEIGHT OF WATER TABLE ABOVE LATERAL TILE (FEET)
C HYDRCD : HYDRAULIC CONDUCTIVITY OF ELEMENTAL WATERSHED SOIL (FEET/DAY)
C NUELUN : NUMBER OF DEPRESSIONAL AREAS IN AN ELEMENTAL WATERSHED
C QSUBMN : SUBMAIN TILE DISCHARGE FROM A DEPRESSIONAL AREA (CUBIC FEET/DAY)
C QT : INITIAL TILE DISCHARGE FROM ELEMENTAL WATERSHED (CUBIC FEET/SECOND)
C QTILE, QTILE1, QTILE6 : TILE DISCHARGE PER UNIT AREA OF ELEMENTAL WATERSHED (FEET/DAY)
C SPACNG : LATERAL TILE LINE SPACING (FEET)
C TD : MAIN TILE DIAMETER (FEET)
C TPTILE : TOTAL LENGTH OF LATERAL TILE IN ELEMENTAL WATERSHED (FEET)
C TOELEV : ELEVATION OF MAIN TILE OUTLET INTO DRAINAGE DITCH (FEET) 8150
C WATERT : ELEVATION OF WATER TABLE (FEET) 8160
C 8170
C *************************************************** 8180
C 8190
C DIMENSION QT(25),HT1(25),QTILE1(25),QSUBMN(25),AU(25),WATERT(25), 8200
C 1ELEVMN(26),TD(25),HWT1(25),QTILE8(25) 8210
C 8220
C 8230
C 8240
C TFTILE = ATOT*43560./SPACNG 8250
C QTILE = (QT(JKJ)/TFTILE)*3600.*24./SPACNG 8260
C HT = (SPACNG *QTILE/HYDRCD) * 1./(1.-QTILE/HYDRCD) * FFCTN 8270
C DO 10 I=1,NUELUN 8280
C HWT1(I) = HT 8290
C QTILE8(I) = QTILE 8291
C HT1(I) = HT 8292
C QTILE1(I) = QTILE 8300
C QSUBMN(I) = (QT(JKJ) * AU(I)/ATOT) * 24. * 3600. 8310
C 10 WATERT(I) = ELEVMN(I) + TOELEV + TD(I) + HT1(I) 8320
C RETURN 8330
C END 8340
C
C SUBROUTINE INFILT (ASOIL,NSOIL,TOTSTR,FCINFL,DPSTOR,SMASM, 8350
C GRAVFR,DELM,RAIN2,IC,IVALU1,DELTQ,SDELT,JKJ, 8360
C 2F1,VOLDPR,PEXCES,QEXCES,INTRCP,TESTIN,SDELT) 8370
C
Cѐ xt subroutine derives the surface runoff 'DELTQ' (inches) and 8380
C the amount of infiltration 'DELTF' (inches) from precipitation for 8390
C each time increment 'DELTM' (minutes) 8400
C
C USES BAILEY'S ITERATIVE PROCEDURE 8410
PARAMETER IDENTIFICATION

ASOIL : SOIL PARAMETER WHICH DESCRIBES INFILTRATION RELATIONSHIP
DELT : TIME INCREMENT (HOURS)
DELTAP : AMOUNT OF INFILTRATED WATER FOR TIME INCREMENT (INCHES)
DELM : TIME INCREMENT (MINUTES)
DELTIP : RAINFALL AMOUNT FOR TIME INCREMENT (INCHES)
DELTPE : AMOUNT OF EXCESS SURFACE WATER FOR TIME INCREMENT (INCHES)
DELTQ : AMOUNT OF SURFACE RUNOFF FOR TIME INCREMENT (INCHES)
DPSTOR : AMOUNT OF SURFACE STORAGE BEFORE SURFACE RUNOFF OCCURS (INCHES)
F1 : ACCUMULATED INFILTRATION AT START OF TIME INCREMENT (INCHES)
F2 : ACCUMULATED INFILTRATION AT END OF TIME INCREMENT (INCHES)
F2FCTN : INFILTRATION EQUATION FUNCTION (SHOULD APPROACH ZERO)
FAVG : AVERAGE INFILTRATION RATE FOR A TIME INCREMENT (INCHES/HOUR)
FCINFL : FINAL OR STEADY STATE INFILTRATION RATE (INCHES/HOUR)
FDRAIN : AMOUNT OF WATER REMOVED FROM SOIL LAYER BY DRAINAGE DURING TIME INCREMENT (INCHES)
FPFCTN : FIRST DERIVATIVE OF INFILTRATION EQUATION
FSFCTN : SECOND DERIVATIVE OF INFILTRATION EQUATION
GRAVPR : AMOUNT OF GRAVITY DRAINED PORE STORAGE (INCHES)
INTRCP : VOLUME OF WATER STORED ON PLANT SURFACES (INCHES)
IVALU1 : AN INDEX PARAMETER CONTROLLING INITIALIZING OF VARIABLES
NSOIL : SOIL PARAMETER WHICH DESCRIBES INFILTRATION RELATIONSHIP
PEXCES : ACCUMULATED EXCESS WATER WHICH HAS NOT INFILTRATED (INCHES)
QEXCES : ACCUMULATED SURFACE RUNOFF (INCHES)
RAIN2 : DEPTH OF PRECIPITATION (INCHES)
SEDELT : CUMULATIVE TIME DURING THE DAY (HOURS)
SDELTAP : ACCUMULATED INFILTRATION WATER (INCHES)
SHASM : TOTAL STORAGE CAPACITY MINUS PRESENT SOIL MOISTURE IN TOP FOOT (INCHES)
STRMGP : TOTAL STORAGE MINUS GRAVITATIONAL WATER (INCHES)
TESTIN : TOLERANCE FACTOR USED TO TERMINATE ITERATIVE PROCEDURE
TOTSTR : TOTAL STORAGE CAPACITY IN TOP FOOT (INCHES)
VOLDPR : AMOUNT OF EXCESS WATER HELD IN SURFACE STORAGE (INCHES)
**DIMENSION RAIN2(100), SDELT(6)**

**REAL NSOIL, INTRCP**

**2200 GO TO (60, 61), IVALU1**

**60 PEXCES = 0.**
**DELTP = 0.**
**INTRCP = 0.**
**DELTF = 0.**
**SDELTFF = 0.**
**FAVG = 0.**
**DELTE = 0.**
**VOLDPR = 0.**
**QEXCES = 0.**
**FDRAIN = 0.**

**STRMGP = TOTSTR - GRAVPR**
**F1 = TOTSTR - SMAXM**
**IVALU1 = 2**

**RETURN**

**61 DELT = DELT/60.**
**DELTP = RAIN2(IC) - RAIN2(IC-1)**

**CALCULATES INTERCEPTION**

**IF(INTRCP.GE.0.10) GO TO 51**
**IF(DLTP.GT.0.10 - INTRCP) GO TO 50**

**IF(INTRCP = INTRCP + DELTP**
**DELTP = 0.**
**GO TO 51**

**50 DELTP = DELTP - 0.10 + INTRCP**

**51 F2 = F1**
IF (DELT) 16, 16, 15
16 IF (VOLDPR) 20, 20, 15

CALCULATES A ZERO ROOT FOR F2FCTN

15 N = 0
5 IF (TOTSTR - F2) 88, 88, 9
88 F2 = TOTSTR - 0.001
GO TO 20
9 F2FCTN = F2 / DELT - ASOIL * (((TOTSTR - F2) / TOTSTR) ** NSOIL) / 2. - FCINF
1 - ASOIL * (((TOTSTR - F1) / TOTSTR) ** NSOIL) / 2. - F1 / DELT
IF (ABS (F2FCTN) - TESTIN) 20, 20, 10
10 FPFC1N = 1. / DELT + NSOIL * ASOIL * (((TOTSTR - F2) / TOTSTR) ** (NSOIL - 1.)) / 2.
1 / TOTSTR
FPFCTN = - (NSOIL - 1.) * NSOIL * ASOIL * (((TOTSTR - F2) / TOTSTR) ** (NSOIL - 2.)) / 2.

F2FCTN = F2FCTN / (FPFCTN - F2FCTN * F2FC1N / 2. / FPFCTN)
N = N + 1
IF (N - 7) 41, 41, 35
35 WRITE (6, 100) N, SDEL (JKJ), JKJ
100 FORMAT (' ', T30, I2, T53, F6.2, T1, ' NO. OF ITERATIONS EXCEEDS', T34, '
1 TIME EQUAL TO', T3, ' FOR ELEMENTAL WATERSHED', T15, T35, ' INFILT
2 ROUTINE')
GO TO 20
41 GO TO 5

CALCULATES THE INCREMENT OF INFILTRATED WATER, THE INITIAL AND
AVERAGE INFILTRATION RATE, THE INCREMENT OF EXCESS SURFACE WATER
AND THE AMOUNT OF EXCESS WATER IN SURFACE STORAGE FOR EACH TIME
INCREMENT

F3 = F2 - F1
F4 = DELTP + VOLDPR
IF (F3 - F4) 44, 27, 29
44 DELTPE = F2 - F1
DELTPE = DELTP - DELTF
GO TO 30
27 DELTF = F2 - F1
DELTPR = 0.
GO TO 30
29 DELTF = DELTP + VOLDPR
DELTPR = DELTP - DELTF
30 PEXCES = PEXCES + DELTPE
F5 = 'VOLDPR + DELTPE
IF (F5 - DPSTOR) 46, 46, 36
46 VOLDPR = F5
DELTP = 0.
GO TO 47
36 VOLDPR = DPSTOR
DELTP = F5 - DPSTOR
QEXCES = QEXCES + DELTQ
47 F15 = F1+ DELTF
IF (F15 - STRMGP) 14, 14, 11
11 F7 = FCINFL*DELT
F20 = F15 - 17
IF (F20 - STRMGP) 12, 12, 13
13 FDRAIN = F7
GO TO 7
12 FDRAIN = F15 - STRMGP
GO TO 7
14 FDRAIN = 0.
7 SMASM = SMASM - DELTF + FDRAIN
SDELTF = SDELTF + DELTF
RETURN
END

SUBROUTINE ET (AMISAR, IBKD, INTPCP, AOPEVP, POMTRN, WRTDS, WP, FC, ETRATE, 0010
1ATRANS, EVAPTR, J, HRETR, AVPAN, IVALU2, SOILM, AAET, APET, APAN, AAEVAP, 0020
2AATRAN, AAINT)
0021
C ******************************************
C THIS SUBROUTINE CALCULATES EVAPOTRANSPIRATION ON A DAILY BASIS AND 0040
ADJUSTS SOIL MOISTURE IN EACH ZONE FOR THIS EVAPOTRANSPARATION

PARAMETER IDENTIFICATION

AAET : ACCUMULATED ACTUAL EVAPOTRANSPARATION (INCHES)
AAREVAP: ACCUMULATED ACTUAL SOIL EVAPORATION (INCHES)
AAINT : ACCUMULATED INTERCEPTION EVAPORATION (INCHES)
AAATRAN : ACCUMULATED ACTUAL TRANSPARATION (INCHES)
AET : ACTUAL DAILY EVAPOTRANSPARATION (INCHES)
AAREVP : ACTUAL DAILY SOIL EVAPORATION (INCHES)
AAINT : DAILY INTERCEPTION EVAPORATION (INCHES)
AMISAR : ET AND SOIL MOISTURE STORAGE ARRAY CONTAINING DAILY VALUES OF
PARAMETERS LISTED IN MAIN PROGRAM
AOPEVP : RATIO OF ACTUAL TO POTENTIAL SOIL EVAPORATION VS. MOISTURE CONTENT
APAN : ACCUMULATED PAN EVAPORATION (INCHES)
APET : ACCUMULATED POTENTIAL EVAPOTRANSPARATION (INCHES)
APEVAP : RATIO OF ACTUAL TO POTENTIAL SOIL EVAPORATION FOR A GIVEN SOIL
MOISTURE
ATRANS : ACTUAL DAILY TRANSPARATION FROM EACH 6 INCH ZONE (INCHES)
AVPAN : AVERAGE DAILY PAN EVAPORATION FOR EACH MONTH OF YEAR (INCHES)
AVSM : RATIO OF AVAILABLE SOIL MOISTURE IN 6 INCH ZONE TO THAT AVAILABLE
AT FIELD CAPACITY
CSMP : SOIL MOISTURE IN TOP 6 INCHES (% BY VOLUME)
ETRATE : PLANT MOISTURE STRESS CURVES
EVAPTR : ACTUAL DAILY EVAPOTRANSPARATION FROM TOP FOOT OF SOIL (INCHES)
FC : SOIL FIELD CAPACITY (% BY VOLUME)
IBKD : TOTAL NUMBER OF DAYS FROM BEGINNING OF YEAR TO START OF SIMULATION
ID : TYPE OF CROP ON WATERSHED
IM : MONTH
INTRCP : VOLUME OF WATER STORED ON PLANT SURFACES (INCHES)
IVALU2 : INDEX PARAMETER CONTROLLING INITIALIZING OF VARIABLES
IY : YEAR
J : DAY OF YEAR
KD : DAY
NRTDS : ROOT DISTRIBUTION IN SOIL PROFILE
C PCT : FUNCTION DETERMINING TRANSFER OF UPEVAP TO PLANT CANOPY FOR
C TRANSPIRATION
C PET : DAILY POTENTIAL EVAPOTRANSPIRATION (INCHES)
C PETC : REMAINING PET AFTER INTERCEPTION EVAPORATION (INCHES)
C PEVAP : ENERGY AVAILABLE FOR SOIL EVAPORATION (INCHES)
C PMPTRN : PERCENT OF PLANT CANOPY TRANSPIRING ON A GIVEN DAY
C POMTRN : PHENOLOGICAL STATE OF CROP VS. TIME OF YEAR (% TRANSPIRING)
C PPTRAN : POTENTIAL TRANSPIRATION REDUCED BY SEASON OF YEAR (INCHES)
C PTRANS : TOTAL POTENTIAL ENERGY AVAILABLE FOR PLANT TRANSPIRATION (INCHES)
C RETBAT, HFETB : REDUCTION IN TRANSPIRATION DUE TO PLANT MOISTURE STRESS
C (%/100)
C SOILM : INITIAL SOIL MOISTURE AT BEGINNING OF SIMULATION (% BY VOLUME)
C SUMTRN : TOTAL ACTUAL DAILY TRANSPIRATION FROM CROP ROOT ZONE (INCHES)
C TRANSP : ENERGY AVAILABLE FOR PLANT TRANSPIRATION (INCHES)
C UPEVAP : UNUSED ENERGY AVAILABLE FOR SOIL EVAPORATION (INCHES)
C WP : SOIL WILTING POINT (* BY VOLUME)
C
C DIMENSION AMISAR(370,18),NRTDS(11,10),ETRATE(6,21),AOPEVP(50),
1 WP(11),FC(11),FOMTRN(50),ATRANS(10),HRETR(10),AVPAN(12),SOILM(11)
0100
REAL INTRCP
0110
35 FORMAT(A3,2X,I2,'-',I2,'-',I2,'/)
0120
34 FORMAT(10X,6F8.2)
0130
71 FORMAT(10X,8F8.2)
0140
C
C GO TO (49,33), IV4LU2
0150
49 AET=0.
0170
APET=0.
0180
APAN=0.
0190
AAEVAP=0.
0200
AATRAN=0.
0210
AAINT=0.
0220
DO 43 IJ=8,17
0230
43 AMISAR(IBKD ,IJ)=(SOILM(IJ-7)/100.)*6.
0240
AMISAR(IBKD ,18)=(SOILM(11)/100.)*48.
0270
J=IBKD
0280
IVALU2 = 2
RETURN

J = J + 1
ID = AMISAR(J, 1)
IM = AMISAR(J, 2)
KD = AMISAR(J, 3)
IY = AMISAR(J, 4)
WRITE(6, 34) ID, IM, KD, IY
I = J - 1
PET = AMISAR(J, 6) * 0.85

SUBTRACTING INTERCEPTION FROM PET

IF (PET.GT.INTRCP) GO TO 51
PETC = 0.
INTRCP = INTRCP - PET
GO TO 52

51 PETC = PET - INTRCP
INTRCP = 0.

DIVIDING TRANS AND EVAP

52 TRANSP = PETC * (AMISAR(J, 5) / 100.)
PEVAP = PETC - TRANSP

CALCULATE EVAP AND UNUSED EVAP TO TRANS

CSMP = AMISAR(I, 8) / 0.06
CALL INTRP(AOEVP, CSMP, APEVAP)
AEPVAP = (APEVAP / 100.) * PEVAP
UPEVAP = PEVAP - AEPVAP
IF (AMISAR(J, 5) .LE. 0.) GO TO 13
IF (AMISAR(J, 5) .GE. 60.) GO TO 14
PCT = (10. / 6.) * AMISAR(J, 5)
GO TO 18

13 PCT = 0.
PCT=100.

CONTINUE

UPEVAP = UPEVAP * (PCT / 100.)

PTRANS = TRANSP + UPEVAP

REDUCING TRANS BY SEASON

AJ = J

CALL INTRP (POMTRN, AJ, PMPTRN)

PPTBA = PMPTRN * PTRANS

FINDING ROOT DISTRIBUTION

IF (J.GT.NRTDS (1,10)) GO TO 19

GO TO 17

19 II=1

GO TO 16

17 DO 15 II=1,10

IF (NRTDS (1,II) - J) 15, 16, 16

CONTINUE

16 NCOL = II

IJ=1

SUMTRN = 0.

APPLYING ROOT DIST. AND SOIL MOISTURE REDUCTION TO CALCULATED TRANS FROM EACH SOIL ZONE

DO 20 JJ=8,17

AVSM = ((AMISAR (I, JJ) / 0.06) - WP (JJ-7)) / (PC (JJ-7) - WP (JJ-7))

IF (AVSM .GE. 1.) AVSM = 1.

IF (AVSM .LE. 0.) AVSM = 0.0001

CALL RATEIN (ETRATE, AVSM, PET, RETRAT)

HRETR (JJ-7) = RETRAT

ATRANS (IJ) = RETRAT * PPTBA * (NRTDS (IJ+1, NCOL) / 100.)

SUMTRN = SUMTRN + ATRANS (IJ)

20 IJ=IJ+1
\[ \text{AINT} = \text{PET} - \text{PETC} \]
\[ \text{AET} = \text{AEVAP} + \text{SUMTRN} + \text{AINT} \]
\[ \text{AAET} = \text{AAET} + \text{AET} \]
\[ \text{APET} = \text{APET} + \text{PET} \]
\[ \text{AAEVA} = \text{AAEVA} + \text{AEVAP} \]
\[ \text{AAATRAU} = \text{AAATRAU} + \text{SUMTRN} \]
\[ \text{AAINT} = \text{AAINT} + \text{AINT} \]
\[ \text{IF} (\text{AHISAR} (J,6) \cdot \text{GT.} 0.) \text{ GO TO 91} \]
\[ \text{AMISAR} (J,6) = \text{AVPAN} (\text{IM}) \]

91  \[ \text{APAN} = \text{APAN} + \text{AMISAR} (J,6) \]
\[ \text{ATRANS} (1) = \text{AEVAP} + \text{ATRANS} (1) \]
\[ \text{EVAPTR} = \text{ATRANS} (1) + \text{ATRANS} (2) \]
\[ \text{IJ} = 1 \]
\[ \text{WRITE} (6,71) \text{ AMISAR} (J,6), \text{PET}, \text{AET}, \text{AEVAP}, \text{SUMTRN}, \text{AINT}, \text{INTRCP}, \text{EVAPTR} \]
\[ \text{WRITE} (6,35) \text{ APAN}, \text{APET}, \text{AAET}, \text{AAEVA}, \text{AAATRAU}, \text{AAINT} \]

ADJUSTING SOIL MOISTURES FOR EVAPOTRANSPIRATION

DO 21 JI=8,17
\[ \text{AMISAR} (J,JI) = \text{AMISAR} (I,JI) - \text{ATRANS} (IJ) \]
\[ \text{IJ} = \text{IJ} + 1 \]
\[ \text{AMISAR} (J,18) = \text{AMISAR} (I,18) \]
RETURN

END

SUBROUTINE REDIST(AMISAR, ATRANS, QLEFT, RESAT, DELTM6, DELTF, J, TENS, 1
ICONDUC, HRER, PERCOL, WP, IVALU3, FC, ZTRAN, ZINF, ZOUTF, ATPERC, MDTEST, 2
SMASM, SSMASM)

*******************************************************************************

THIS SUBROUTINE ALLOWS INFILTRATION INTO SOIL PROFILE AND
REDISTRIBUTES SOIL MOISTURE ACCORDING TO CURRENT TENSIONS AND
CONDUCTIVITIES—BOTH FUNCTIONS OF SOIL MOISTURE CONTENT

*******************************************************************************
PARAMETER IDENTIFICATION

AINFIL: INFILTRATION MOVEMENT INTO EACH 6 INCH SOIL ZONE DURING A TIME INCREMENT (INCHES)
AMISAR: ET AND SOIL MOISTURE STORAGE ARRAY CONTAINING DAILY VALUES OF PARAMETERS LISTED IN MAIN PROGRAM
AOUTF: ACCUMULATED MOISTURE MOVEMENT OUT OF EACH 6 INCH SOIL ZONE (INCHES)
ATPERC: ACCUMULATED EXCESS WATER ABOVE STORAGE CAPACITY OF SOIL PROFILE (INCHES)
ATRANS: ACTUAL DAILY TRANSPIRATION FROM EACH 6 INCH ZONE (INCHES)
AVGSM: AVERAGE SOIL MOISTURE IN TWO ADJACENT SOIL ZONES (% BY VOLUME)
CON: UNSATURATED HYDRAULIC CONDUCTIVITY FOR A GIVEN MOISTURE CONTENT (INCHES/HOUR, LN(K))
COND: MOISTURE MOVEMENT OUT OF EACH 6 INCH SOIL ZONE DURING A TIME INCREMENT (INCHES)
CONDUC: UNSATURATED HYDRAULIC CONDUCTIVITY VS. SOIL MOISTURE (INCHES/HOUR, LN(K)+100)
CSMP: SOIL MOISTURE IN A GIVEN SOIL ZONE (% BY VOLUME)
DELTF: INFILTRATION MOVEMENT INTO TOP 6 INCH SOIL ZONE DURING A TIME INCREMENT (INCHES)
DELM6: TIME INTERVAL (HOURS)
FC: SOIL FIELD CAPACITY (% BY VOLUME)
GRAD: HYDRAULIC GRADIENT CAUSING MOISTURE MOVEMENT BETWEEN SOIL ZONES
IVALU3: INDEX PARAMETER CONTROLLING INITIALIZING OF VARIABLES
MDTEST: PARAMETER INDICATING DRAINAGE FACILITIES USED IN ELEMENTAL WATERSHED - SEE MAIN
OUTFLW: MOISTURE MOVEMENT OUT OF EACH 6 INCH SOIL ZONE DURING A TIME INCREMENT (INCHES)
PERCO: EXCESS INFILTRATION AVAILABLE FOR INPUT TO LATERAL DRAIN TILE DURING A TIME INCREMENT (INCHES)
PERCOL: MOISTURE REDISTRIBUTION IN OR OUT OF TOP FOOT (INCHES)
QLEFT: EXCESS MOISTURE USED AS INPUT TO LATERAL DRAIN TILE (INCHES)
RESAT: 0.9 OF SOIL SATURATION (INCHES)
SMASM: TOTAL STORAGE CAPACITY MINUS PRESENT SOIL MOISTURE IN TOP FOOT (INCHES)
SSMASM: SAME AS SMASM EXCEPT UNDER DEPRESSIONS STORING WATER (INCHES)
TASM: TOTAL AVAILABLE SOIL MOISTURE IN TOP 5 FEET (INCHES)
C TENS : SOIL TENSION VS. MOISTURE CONTENT (CM. OF WATER)
C TENS, TENZ : SOIL TENSION FOR A GIVEN MOISTURE CONTENT (CM. OF WATER)
C TSM : TOTAL SOIL MOISTURE IN TOP 5 FEET (INCHES)
C WP : SOIL WILTING POINT (% BY VOLUME)
C ZINF : ACCUMULATED INFILTRATION INTO EACH 6 INCH SOIL ZONE (INCHES)
C ZPERC : EXCESS REDISTRIBUTED WATER PERCOLATING INTO A LOWER 6 INCH
C SOIL ZONE DURING A TIME INCREMENT (INCHES)
C ZTRAN : ACCUMULATED TRANSPARATION FROM EACH 6 INCH SOIL ZONE (INCHES)
C
************:

C DIMENSION AMISAR(370,18),ATRANS(10),OUTFLW(10),CONDUC(50),WP(11),
1 AINFIL(12),RESAT(11),COND(10),ZTRAN(10),ZINF(10),ZOUTF(10),
2 HRETR(10),TENS(50),TENZ(12),FC(11)
C
36 FORMAT (/,8X,13F8.4)
37 FORMAT(8X,10F8.4,1X,F5.2)
38 FORMAT(/)
70 FORMAT(9X,11F10.2)
95 FORMAT(8X,12F8.4)
C
GO TO (42,1), IVALU3
42 DO 47 I=1,10
ZTRAN(I)=0.
ZINF(I)=0.
ZOUTF(I)=0.
ATRANS(I)=0.
47 OUTFLW(I)=0.
DO 48 I=1,12
TENZ(I)=0.
48 AINFIL(I)=0.
ATPERC=0.
IVALU3=2
RETURN
C
1 DO 150 KZZ=1,11
AINFIL(KZZ+1)=0.
CONTINUE

AINFIL(1) = DELTF

ALLOWING INFILTRATION WITH UNLIMITED CONDUCTIVITY, STORAGE LIMITED TO FIELD CAPACITY ABOVE 4 FEET AND 0.9*SATURATION FROM 4 TO 9 FEET

JI = 8
PERCO = 0.

AMISAR(J, JI) = AMISAR(J, JI) + AINFIL(JI-7)

IF (AMISAR(J, JI) GT FC(JI-7) / 100. * 6.) GO TO 22
GO TO 23

AINFIL(JI-6) = AMISAR(J, JI) - FC(JI-7) / 100. * 6.
AMISAR(J, JI) = FC(JI-7) / 100. * 6.
JI = JI + 1
IF (JI GT 15) GO TO 50
GO TO 25

AMISAR(J, JI) = AMISAR(J, JI) + AINFIL(JI-7)

IF (AMISAR(J, JI) GT RESAT(JI-7)) GO TO 51
GO TO 23

AINFIL(JI-6) = AMISAR(J, JI) - RESAT(JI-7)
AMISAR(J, JI) = RESAT(JI-7)
JI = JI + 1
IF (JI GT 18) GO TO 24
GO TO 50

PERCO = AINFIL(12)
GO TO (2, 2, 23, 23), MDTEST

JI = JI - 1
AMISAR(J, JI) = AMISAR(J, JI) + PERCO
IF (AMISAR(J, JI) GT RESAT(JI-7)) GO TO 3
PERCO = 0.
GO TO 23

PERCO = AMISAR(J, JI) - RESAT(JI-7)
AMISAR(J, JI) = RESAT(JI-7)
IF (JI GT 1) GO TO 2
SNASH = 0.
SSMASM = 0.
REDISTRIBUTION OF SOIL MOISTURE ACCORDING TO CURRENT TENSIONS AND
CONDUCTIVITIES—BOTH FUNCTIONS OF SOIL MOISTURE CONTENT

23 JI=8
ZPERC=0.
PERC=0.
DO 85 KZZ=1,10
85 OUTFLW(KZZ)=0.
26 IF(JI.EQ.8) GO TO 59
   IF(JI.EQ.17) GO TO 60
   GO TO 61
59 CSMP=AMISAR(J,JI)/0.06
   CALL INTRP(TENS,CSMP,TENSS)
   TENZ(JI-7)=TENSS
61 CSMP=AMISAR(J,JI+1)/0.06
   CALL INTRP(TENS,CSMP,TENSS)
   TENZ(JI-6)=TENSS
   JI=JI+1
   GO TO 26
60 CSMP=AMISAR(J,JI+1)/0.48
   CALL INTRP(TENS,CSMP,TENSS)
   TENZ(11)=TENSS
   DO 65 JI=8,17
   IF(JI.NE.17) GO TO 62
   AVGSM=((AMISAR(J,JI)/0.06)+AMISAR(J,JI+1)/0.48)/2.
   GO TO 63
62 AVGSM=(AMISAR(J,JI)+AMISAR(J,JI+1))/0.12
63 GRAD=(TENZ(JI-6)-TENZ(JI-7)+(6.*2.54))/(6.*2.54)
   CALL INTRP(CONDOC,AVGSM,CON)
   CON=CON-100.
   JI=JI+1
   OUTFLW(JI-8)=OUTFLW(JI-8)+COND(JI-8)
   if (AMISAR(J,JI+1).GT.RESAT(JI-6)) GO TO 28
   JI=JI+1
   AMISAR(J,JI)=AMISAR(J,JI)-COND(JI-7)
   AMISAR(J,JI+1)=AMISAR(J,JI+1)+COND(JI-7)
   IF(AMISAR(J,JI+1).GT.RESAT(JI-6)) GO TO 28
   JI=JI+1
   OUTFLW(JI-8)=OUTFLW(JI-8)+COND(JI-8)
IF(JI.EQ.18) GC TO 27
GO TO 64

28 ZPERC=AMISAR(J,JI+1)-RESAT(JI-6)
AMISAR(J,JI+1)=RESAT(JI-6)
IF(JI.EQ.17) GO TO 29
AMISAR(J,JI+2)=AMISAR(J,JI+2)+ZPERC
GO TO 30

29 AMISAR(J,JI+1)=AMISAR(J,JI+1)+ZPERC

30 OUTFLW(JI-7)=OUTFLW(JI-7)+COND(JI-7)
IF(JI.EQ.17) GO TO 27
AINFIL(JI-5)=AINFIL(JI-5)+ZPERC
JI=JI+1
ZPERC=0.
GO TO 64

27 CONTINUE
JI=8
PERCO=COND(2)
QLEFT=PERC+PERCO
ATPERC=ATPERC+QLEFT
TSM=0.
TASM=0.
DO 94 LL=8,17
TSM=TSM+AMISAR(J,LL)
94 TASM=TASM+AMISAR(J,LL)-WP(LL-7)*0.06
DO 120 LN=1,10
ZTRAN(LN)=ZTRAN(LN)+ATRANS(LN)
ZINF(LN)=ZINF(LN)+AINFIL(LN)
120 ZOUTF(LN)=ZOUTF(LN)+OUTFLW(LN)
WRITE(6,36) (AMISAR(J,LL),LL=8,18),TSM,TASM
WRITE(6,95) (AINFIL(LL),LL=1,11),PERCO
WRITE(6,95) (OUTFLW(LL),LL=1,10),QLEFT
RETURN
END
SUBROUTINE RATEIN(ETRATE, PASM, PEVAP, VETRAT)

*** THIS SUBROUTINE IS USED TO INTERPOLATE BETWEEN TWO DIFFERENT CURVES. IT TAKES THE AVAILABLE SOIL MOISTURE AND THE POTENTIAL ET AND INTERPOLATES ON THE CURVES TO OBTAIN A RATIO OF RELATIVE ET RATE. IN THE CALL STATEMENT THE VARIABLES ARE:

* ETRATE....THE ARRAY CONTAINING THE ET RATE CURVES
* PASM......THE X-VALUE (AVAILABLE SOIL MOISTURE)
* PEVAP.....THE POTENTIAL ET VALUE NEEDED TO FIND THE RELATIVE ET RATE
* VETRAT....THE RELATIVE ET RATE RATIO

DIMENSION ETRATE(6,21)
DO 1 J=2,21
IF(ETRATE(1,J) - PASM) 1,2,2
1 CONTINUE
2 JJ=J-1
IF(PEVAP-ETRATE(4,1)) 3,3,4
3 IF(PEVAP.LT.ETRATE(3,1)) GO TO 5
I=3
IJ=4
GO TO 6
5 I=2
IJ=3
IF(PEVAP.LE.0.05) GO TO 10
GO TO 6
4 IF(PEVAP.GT.ETRATE(5,1)) GO TO 7
I=5
IJ=4
GO TO 6
7 IF(PEVAP.GE.0.70) GO TO 11
I=6
IJ=5
6 IL=0
8 AA=(ETRATE(IJ,J) - ETRATE(IJ,JJ))/(ETRATE(1,J) - ETRATE(1,JJ))
Y = ETRATE(IJ, JJ) + AA*(PAS - ETRATE(1, JJ))

IL = IL + 1
IF (IL.EQ.2) GO TO 9

II = IJ
IJ = I
YVAL = Y
GO TO 8

AAEVAI' = (YVAL - Y) / (ETRATE(II, 1) - ETRATE(IJ, 1))
YETRAT = YVAL + AAEVAI' * (PEVAP - ETRATE(II, 1))
GO TO 12

YETRAT = 1.
GO TO 12

YETRAT = 0.
GO TO 13

IF (YETRAT.GT.1.) GO TO 14

IF (YETRAT.LT.0.) YETRAT = 0.
GO TO 14

YETRAT = 1.
RETURN
END

SUBROUTINE INTRP(DAPA, X, Y)

*******************************************************************************
* * THIS IS A 'TABLE LOOK-UP AND INTERPOLATION' SUBROUTINE. IT TAKES * *
* A GIVEN VALUE OF X, SEARCHES 'DAPA' FOR THE INTERVAL OF X AND * *
* INTERPOLATES THE Y VALUES TO OBTAIN A VALUE OF Y FOR THE GIVEN X * *
* * DAPA IS A SINGLE DIMENSIONED ARRAY OF X,Y VALUES THAT ARE * *
* LOCATED IN THE FOLLOWING MANNER: * *
* X1,Y1, X2,Y2, X3,Y3, ......, XN,YN * *
* * DIMENSION DAPA (50) *
J = 1
N = 1
11 XDAPA = DAPA(N)
   IF (X - XDAPA) 14, 13, 12
12 IF (XDAPA .LE. 0.) GO TO 16
17 J = 2
   N = N + 2
   GO TO 11
13 Y = DAPA(N + 1)
   RETURN
16 IF (J < 1) 17, 17, 15
14 IF (J .LE. 1) GO TO 15
   AA = (DAPA(N + 1) - DAPA(N - 1))/ (DAPA(N) - DAPA(N - 2))
   Y = DAPA(N - 1) + AA * (X - DAPA(N - 2))
   RETURN
15 WRITE (6, 1)
   1 FORMAT (' NOTE: X VALUE FOR INTRP OUT OF RANGE ')
   Y = DAPA(2) + 0.001
   RETURN
   END

SUBROUTINE ROUT
   
C *********************************************************************
C THIS SUBROUTINE ROUTES THE WATER BETWEEN DEPRESSIONS THROUGH SURFACE
C INLETS AND OVERLAND FLOW CHANNELS
C USES BAILEY'S ITERATIVE PROCEDURE
C
C PARAMETER IDENTIFICATION
C
C AB : DISCHARGE FROM DEPRESSION AT START OF TIME INCREMENT (CFS)
AC : VOLUME OF WATER IN DEPRESSION CORRESPONDING TO DEPTH D1 (CUBIC FEET) 0430
BC : DISCHARGE FROM DEPRESSION CORRESPONDING TO DEPTH D2 OR D21 (CFS) 0440
CCO, CC, CCP, CCQ : COEFFICIENTS USED TO CALCULATE OVERLAND FLOW FUNCTION DERIVATIVES
CD : ORIFICE COEFFICIENT FOR SURFACE INLET 0460
CO1, CO2, COEF : COEFFICIENTS USED TO CALCULATE SHORT TUBE FLOW DERIVATIVES
CONST3 : PARAMETER USED TO CONVERT RUNOFF FROM IN/HR TO CFS
CSEEP : COEFFICIENT USED TO CALCULATE SEEPAGE FUNCTION DERIVATIVE
CV1, CV2, CV0 : COEFFICIENTS USED TO CALCULATE DEPRESSION VOLUME DERIVATIVES
CW1, CW2, CW0 : COEFFICIENTS USED TO CALCULATE WEIR FLOW DERIVATIVES
D1 : WATER DEPTH IN DEPRESSION AT START OF TIME INCREMENT (FEET) 0470
D2 OR D21 : WATER DEPTH IN DEPRESSION AT END OF TIME INCREMENT (FEET) 0480
D2A, D2B, D2C, D2D : CONSECUTIVE ITERATION WATER DEPTHS (FEET)
DELT : TIME INCREMENT (SECONDS) 0490
DELTFS : VOLUME OF WATER SEEPING INTO THE SOIL FROM A DEPRESSION (INCHES)
DELM : TIME INCREMENT (MINUTES)
DISCH1, DISCH2 : 1ST AND 2ND DERIVATIVES OF DISCHARGES FROM DEPRESSION
DS : SURFACE INLET DIAMETER (FEET) 0500
DSEEP1, DSEEP2 : 1ST AND 2ND DERIVATIVES OF SEEPAGE FUNCTION
Datile1, Datile2 : 1ST AND 2ND DERIVATIVES OF SURFACE INLET FLOW FUNCTION
DVOLM1, DVOLM2 : 1ST AND 2ND DERIVATIVES OF DEPRESSION VOLUME FUNCTION
DWAY1, DWAY2 : 1ST AND 2ND DERIVATIVES OF OVERLAND CHANNEL FLOW FUNCTION
E : BOTTOM ELEVATION OF DEPRESSIONAL AREA (FEET)
FD21 : THIS FUNCTION EQUALS ZERO WHEN A ROOT OF THE EQUATION IS DETERMINED
FDX, FDY, FDZ : CONSECUTIVE ITERATION DEPTH FUNCTION DEVIATIONS FROM ZERO
FPRI1 : FIRST DERIVATIVE OF FUNCTION FD21
FPRI2 : SECOND DERIVATIVE OF FUNCTION FD21
H : TOTAL HEAD AT A DEPRESSION (FEET)
I : DEPRESSION NUMBER
I0 : SURFACE RUNOFF RATE (INCHES/HOUR)
I1 : INFLOW TO DEPRESSION AT START OF TIME INCREMENT (CUBIC FEET/SECOND) 0540
I2 : INFLOW TO DEPRESSION AT END OF TIME INCREMENT (CUBIC FEET/SECOND)
IJK : INDEX PARAMETER CONTROLLING EXTENDED ITERATION
INDEX1 : PARAMETER FROM FUNCTION OUTFLO - INDICATES TYPE OF SURFACE INLET
INDEX2 : PARAMETER FROM FUNCTION OUTFLO - INDICATES WHEN OVERLAND CHANNEL
FLOW OCCURS

INDEX3 : PARAMETER FROM FUNCTION OUTFLO - INDICATES WHEN SEEPAGE FROM DEPRESSION INTO SOIL OCCURS

IOVER, IMIKE, ITRUTH : INDEX PARAMETERS USED WITH BISECTION METHOD

K : PARAMETER USED TO DESCRIBE SIZE OF PARABOLIC OVERLAND FLOW CHANNELS

KCONST : PARAMETER USED FOR ERROR ANALYSIS OUTPUT WHEN SUBROUTINE FINDS TROUBLE

KTEST1, KTEST2, KTEST3 : INDEX PARAMETERS USED IN TEST FOR SOLUTION OSCILLATION

M : NUMBER OF ITERATIONS IN SOLVING FOR WATER DEPTH IN DEPRESSION

MNC : MANNINGS ROUGHNESS COEFFICIENT FOR OVERLAND FLOW CHANNELS

O2 : OVERLAND FLOW FROM DEPRESSION (CFS)

S : SLOPE OF OVERLAND FLOW CHANNELS (FEET/FEET)

SSMASM : SAME AS SMAASM EXCEPT UNDER DEPRESSIONS STORING WATER (INCHES)

TESTRO, TEST : TOLERANCE FACTOR USED TO TERMINATE ITERATIVE PROCEDURE

WEIRK : SURFACE INLET WEIR COEFFICIENT

WWCOEF : OVERLAND FLOW CHANNEL DISCHARGE PARAMETER - SEE FUNCTION OUTFLO

Y : DEPTH OF FLOW IN OVERLAND FLOW CHANNEL (FEET)

ZFD : ZERO FLOW DEPTH FOR SURFACE INLET (FEET)

*********************************************************************

COMMON QTILE1, QTILE2
COMMON D1, D2, PCEL, E, TD, H, TOELEV, MNT, MNC, NUELUN, AU, L, CONST1, 1K, QU, S, O1, O2, OF, I1, I2, ZFD, MDTEST, INDEX1, INDEX2, Y
COMMON HMAIN, ELEVN, QFULL, HYDRCD, DRNPOR, FPCTN, 1CFACTR, SPACNG, HT1, HWT1, QIN1, HWT2, DELTM, SDELT, JKJ, QTILE9, WATERT
COMMON QLEFT, JRAIN, QSUBMN, AB, QTILE8, INDEX3, DPMAIN, HT2, QIN2
COMMON WEIRK, CD, SLPSUB, OS, D21, WWCOEF, DELTFS, FCINFL, SMAASM
COMMON TESTDR, TESTRO, ZFW, DS, MM, IO, CONST3
REAL K, MNT, MNC, I0, I1 (25), I2 (25), L (25)
4HT2(25), D21(25), DS(25), OS(25), HT1(25), CONST3(25), HWT1(25)

DIMENSION CW1(25), CO1(25), CO2(25), CW2(25), HWT2(25)

C

2400 DELT = DELTM*60.

CC0 = 1.49*SQR(S)*1.333*((1./K)**0.667)*((1./K)**0.5)/MNC/2.

CV1 = 2.424*43560.*0.496/DELT

CV2 = 1.424*CV1

DO 10 I=1, NUELUN

CW1(I) = WEIRK*DS(I)*1.5/2.

CO1(I) = CD * 3.14 * DS(I)*DS(I)*0.5*64.4/4./2.

CW2(I) = CW1(I)*0.5

CO2(I) = CO1(I)*(-0.5)*64.4

10 D21(I) = D2(I)

KCONST = 1

DO 20 I=1, NUELUN

IJK = 1

IOVER = 1

IMIKE = 1

IRUTH = 1

KTEST3 = 0

KTEST2 = 0

D2A = 0.

D2B = 0.

D2C = 0.

I2(I) = CONST3(I)*IO

FDY = 0.

FDZ = 0.

IF(I-2) 12, 15, 15

15 I2(I) = I2(I) + O2(I-1)

C

CALCULATE THE ROOT(ZERO) OF FD21

C

12 MM = 1

N = 0

TEST = TESTRO

AC = VOLUME(D1(I))
59 IF (D21(I)) 72, 58, 58
72 D21(I) = (D2B+D2C)/2.
58 BC = OUTFLO(D21,I)
FD21 = (I1(I)+I2(I))/2. -(AB(I)+BC)/2. +
1(AC-VOLUME(D21(I)))/DELT
IF(ABS(FD21)-D21(I)*TEST ) 71, 40, 40
C
C TESTS FOR SOLUTION OSCILLATION
C
40 D2D=D2A
D2A = D2B
D2B = D2C
D2C = D21(I)
FDX = FDY
FDY = FDZ
FDZ = FD21
GO TO (41,260),IOVER
41 IF (FD21)50, 50, 51
50 KTEST1 = 1
GO TO 56
51 KTEST1 = 2
56 IF (KTEST2 - KTEST1) 52, 53, 52
52 IF (KTEST1 - KTEST3) 53, 54, 53
53 IOVER = 1
KTEST3 = KTEST2
KTEST2 = KTEST1
GO TO 200
54 IOVER = 2
GO TO 260
C
C CALCULATES THE FIRST AND SECOND DERIVATIVES OF FD21
C
200 CV0= D21(I)**1.424
DVOLM1 = CV1*CV0
DVOLM2 = CV2*CV0/D21(I)
IZIND= INDEX1(I)
GO TO (60,61,62,90),IZIND

DTILE1 = 0.1560
DTILE2 = 0.
GO TO 63
CWO = D21(I) - ZFD
SQCW0 = SQRT(CWO)
DTILE1 = CWO(I) * SQCW0
DTILE2 = CWO2(I) / SQCW0
GO TO 63
COEF = 54.4 * ABS(E(I) + D21(I) - H(I))
SQCOEF = SQRT(COEF)
CTILE1 = CWO1(I) / SQCOEF
DTILE2 = CWO2(I) / SQCOEF / COEF * (E(I) + D21(I) - H(I)) / ABS(E(I) + D21(I) - H(I))
CONTINUE
GO TO 64, 65), INDEX2
DWAY1 = 0.1790
DWAY2 = 0.1800
GO TO 66
CC = 1.5 / K / Y + 1.
CCP = CC**0.333
CCQ = SQRT(Y)
DWAY1 = WWCOEF * 0.667 * CC0 * (1.5 * CCP / CC / CC / CCQ / K + 2.25 * CCQ * CCP / CC)
DWAY2 = WWCOEF * WWCOEF * 0.667 * CC0 * (2.5 * 1.5 * CCQ * CCP / K / Y / Y / CC / CC / CC + 1.5 * CCQ * CCP / K / Y / Y / CC / CC + 9. * CCP / 8. / CCQ / CC)
GO TO 67, 68, INDEX3
CSEEP = DELTFS / 12. * 1.33 * 43560. / DELTM / 60.
CSEEP1 = CSEEP * 1.67 * D21(I) ** 0.67
CSEEP2 = CSEEP1 * 0.67 / D21(I)
FPR1 = - DISCH1 - DVOLM1
FPR2 = - DISCH2 - DVOLM2
IF (IFPRIM) 75, 85, 81
D21(:, :) = D21(I) + 2.
KCON2 = 2
GO TO 76
85 D21(I)=D21(I)+1.
   KCONST=3
   GO TO 76
75 KCONST =1
   IF (ABS(FPRIM2).LT.40000.) GO TO 259
   IF (ABS(FD21).LT.1.0 ) GO TO 259
   IF (FD21.GT.0.) GO TO 44
   D21(I)=D21(I)-0.05
   GO TO 45
44 D21(I)=D21(I)+0.02
45 GO TO (46,76), IJK
46 MM=1
   IJK=2
   GO TO 76
   
   CALCULATES A NEW TRIAL DEPTH AS AN ESTIMATE OF THE ZERO OF FD21
   259 D21(I) =D21(I) -(FD21/(FPRIM1 -(FPRIM2*FD21)/2./FPRIM1))
   260 GO TO ( 76,264),IOVER
   
   USE THE BISECTION METHOD TO FIND NEW ROOT APPROXIMATION IF THE
   RESULTS OF BAILEY'S METHOD OSCILLATE
   264 IF( FDX) 265,265,270
   265 IF(FDZ) 266,266,275
   266 IF (FDY) 280,280,281
   280 GO TO (282,283),IRUTH
   282 IMIKE=2
   IRUTH=2
   283 GO TO (284,285),IMIKE
   285 D2DD=D2D
   IMIKE=1
   284 D21(I)=(D2DD+D2C)/2.
   GO TO 76
281 IF (ABS(FDX)-ABS(FDZ)) 267,267,269
267 D21(I)=(D2A+D2B)/2.
GO TO 76
269 D21(I) = (D2B + D2C)/2.
    GO TO 76
274 D21(I) = (D2A + D2C)/2.
    GO TO 76
270 IF (FDY) 268, 268, 286
286 IF (FDY) 281, 281, 280
268 IF (FDY) 272, 272, 273
273 IF (ABS(FDX) - ABS(FDY)) 274, 274, 269
272 IF (ABS(FDY) - ABS(FDZ)) 267, 267, 274
275 IF (FDY) 273, 273, 272

C

76 MM = MM + 1
380 IF (MM - 5) 59, 59, 301
301 N = N + 1
    IF (N - 3) 300, 80, 80
300 TEST = TEST * 3.
    WRITE (6, 302) TEST
302 FORMAT (' I AM INCREASING TESTRO TO 'F6.2)
    MM = 1
    GO TO 59
80 GO TO (69, 77, 78) , KCONST
69 WRITE (6, 70) I, JKJ , SDELT (JKJ) , FD21
70 FORMAT (' ', T10, 'ITERATIONS EXCEEDED 15 FOR POTHOLE NUMBER 'I4, 1 T70, 'ELEMENTAL WATERSHED ', I5 , ', ', T10, ' FOR TIME EQUAL ', F7.2, T35, 2 ' AND FD21 EQUAL ', F10.5)
    GO TO 71
77 WRITE (6, 79) I
79 FORMAT (' ', T10, 'ITERATIONS EXCEEDED 15 FOR POTHOLE NUMBER 'I4, 1 T10, 'DERIVATIVE OF FUNCTION - FD21- IS POSITIVE')
    GO TO 71
78 WRITE (6, 48) I
48 FORMAT (' ', T10, 'ITERATIONS EXCEEDED 15 FOR POTHOLE NUMBER 'I4, 1 T10, 'DERIVATIVE OF FUNCTION - FD21- IS ZERO')
71 IF (D21(I)) 32, 34, 34
32 D2(I) = 0.
BC=OUTFLO(D2, I)
GO TO 36
34 D2( I) = D21( I)
36 AB( I) = BC
20 CONTINUE
   IF(SSMASM.LT.DELTFS) GO TO 21
   IF(D2(NUELUN).GT.0.10) SSMASM=SSMASM-DELTFS
21 RETURN
END

FUNCTION OUTFLO(DEPTH, I)
C *********************************************************************
C THIS SUBROUTINE COMPUTES THE AMOUNT AND TYPE OF FLOW FROM THE
C DEPRESSIONS AND THE FLOW FROM THE EFFECTIVE HEAD CONTROLLING
C THE FLOW FROM THE LATERAL TILE SYSTEMS
C
C MDTEST = 1 - OVERLAND FLOW AND SURFACE INLETS
C MDTEST = 2 - OVERLAND FLOW ONLY
C MDTEST = 3 - OVERLAND FLOW, SURFACE INLETS AND SUBSURFACE DRAINAGE
C MDTEST = 4 - OVERLAND FLOW AND SUBSURFACE DRAINAGE

PARAMETER IDENTIFICATION
AREASP : WATER SURFACE AREA IN DEPRESSION (ACRES)
AU : DEPRESSION CONTRIBUTING AREA (ACRES)
CCO, CC20, CC21 : COEFFICIENTS USED TO CALCULATE OVERLAND CHANNEL FLOW
CQ : OVERLAND FLOW CHANNEL DISCHARGE (CUBIC FEET/SECOND)
D21 : WATER DEPTH IN DEPRESSION AT END OF TIME INCREMENT (FEET)
DELTFS : VOLUME OF WATER SEEPING INTO THE SOIL FROM A DEPRESSION (INCHES)
DELTM : TIME INCREMENT (MINUTES)
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DELTS</td>
<td>Depression seepage converted to complete depression contributing area (inches)</td>
<td></td>
</tr>
<tr>
<td>DEPTH</td>
<td>Depth of water in depression (feet)</td>
<td>2670</td>
</tr>
<tr>
<td>DFMN</td>
<td>Depth of flow in tile main (feet)</td>
<td>2680</td>
</tr>
<tr>
<td>E</td>
<td>Elevation of depression bottom (feet)</td>
<td>2710</td>
</tr>
<tr>
<td>ELEMVN</td>
<td>Elevation of tile main above tile outlet (feet)</td>
<td>2720</td>
</tr>
<tr>
<td>FCINFL</td>
<td>Steady state rate of water movement through soil surface (in/hr)</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Total head at a depression (feet)</td>
<td>2730</td>
</tr>
<tr>
<td>MMAIN</td>
<td>Total head on tile main (feet)</td>
<td>2750</td>
</tr>
<tr>
<td>I</td>
<td>Depression number</td>
<td></td>
</tr>
<tr>
<td>INDEX1</td>
<td>Parameter which indicates type of surface inlet flow</td>
<td>2760</td>
</tr>
<tr>
<td>INDEX2</td>
<td>Parameter which indicates when overland channel flow occurs</td>
<td>2770</td>
</tr>
<tr>
<td>INDEX3</td>
<td>Parameter which indicates when seepage from depression occurs</td>
<td></td>
</tr>
<tr>
<td>JDRAIN</td>
<td>Index parameter eliminating subroutine drainage during initialization</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Parameter used to describe size of parabolic overland flow channels</td>
<td>2790</td>
</tr>
<tr>
<td>MDT</td>
<td>Parameter which indicates type of drainage</td>
<td>2800</td>
</tr>
<tr>
<td>MDTEST</td>
<td>Parameter which indicates type of drainage</td>
<td>2810</td>
</tr>
<tr>
<td>MNC</td>
<td>Manning's roughness coefficient for overland flow channels</td>
<td></td>
</tr>
<tr>
<td>OF</td>
<td>Surface inlet discharge from a depression (cubic feet/second)</td>
<td>2820</td>
</tr>
<tr>
<td>OS</td>
<td>Depression discharge through seepage into soil (cfs)</td>
<td></td>
</tr>
<tr>
<td>OUTFLO</td>
<td>Total depression outflow (cfs)</td>
<td></td>
</tr>
<tr>
<td>PCEIL</td>
<td>Crest elevation of a depression (feet)</td>
<td></td>
</tr>
<tr>
<td>QFULL</td>
<td>Full tile main discharge (cubic feet/second)</td>
<td>2860</td>
</tr>
<tr>
<td>QLEFTS</td>
<td>Total water entering lateral tile drainage system (inches)</td>
<td>2870</td>
</tr>
<tr>
<td>QSMN</td>
<td>Subsurface drainage discharge into tile main (cubic feet/day)</td>
<td></td>
</tr>
<tr>
<td>QUOTD</td>
<td>Ratio of main tile discharge to full main tile discharge</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>Slope of overland flow channels (feet/foot)</td>
<td></td>
</tr>
<tr>
<td>SEEPG</td>
<td>Maximum possible volume of water seeping from a depression during a time increment (inches)</td>
<td></td>
</tr>
<tr>
<td>SSASM</td>
<td>Same as SSASM except under depressions storing water (inches)</td>
<td>2890</td>
</tr>
<tr>
<td>TD</td>
<td>Tile main diameter (feet)</td>
<td></td>
</tr>
<tr>
<td>TOELEV</td>
<td>Tile outlet elevation (feet)</td>
<td>2900</td>
</tr>
<tr>
<td>TQ</td>
<td>Tile main discharge between two depressions (cubic feet/second)</td>
<td>2910</td>
</tr>
<tr>
<td>WWCOEF</td>
<td>Overland flow channel discharge parameter - can use a value equal to 1.0</td>
<td>2940</td>
</tr>
<tr>
<td>Y</td>
<td>Depth of flow in overland flow channel (cubic feet/second)</td>
<td>2950</td>
</tr>
</tbody>
</table>
ZFW : ZERO FLOW DEPTH IN OVERLAND FLOW CHANNEL (FEET)

**ồng QTILE1, QTILE2
**ồng D1, D2, PCEL, E, TD, H, TOELEV, MNT, MNC, NUELUN, AU, L, CONST1,
1K, QU, S, TQ, CQ, OF, I1, I2, ZFD, MDTEST, INDEX1, INDEX2, Y
**ồng HMAIN, ELEVMN, QFULL, HYRCD, DRNPOF, FFCTN,
1CFACr, SPACNG, HT1, HWT1, QIN1, HWT2, DELTM, SDELT, JKJ, QTILE9, WATERT
**ồng QLEPT, JDRAIN, QSUBMN, AB, QTILE8, INDEX3, DFMAIN, HT2, QIN2
**ồng WEIRK, CD, SLPSUB, OS, D21, WWCOEF, DELTFS, FCINF, SSMASM
**ồng TESTDR, IESTRO, ZFW, DS,
REAL K, MNT, MNC, IO, I(25), I2(25), L(25)
DIMENSIONS QTILE1(25), QTILE2(25), D1(25), D2(25), PCEL(25),
1E(26), TD(25), H(26), AU(25), CONST1(25), QU(25), CQ(25), TQ(25), OF(25),
2INDEX1(25), HMAIN(26), ELEVMN(26), QFULL(25), QTILE8(25),
3QTILE9(25), SDELT(6), WATERT(25), QSUBMN(25), AB(25), DFMAIN(25),
4HT2(25), D21(25), DS(25), OS(25), HT1(25), CONST3(25), HWT1(25)
DIMENSION DEPTH(25), HWT2(25)

2500  
CCO = 1.49 * SQRT(S) * 1.33 * ((1./K) ** 0.667) * ((1./K) ** 0.5) / MNC
IF (DEPTH(I) .NE. 0.) GO TO 20
SEEPG = 0.
AREASP = 0.
GO TO 22
20  SEEPG = FCINF *** DELTM / 60.
AREASP = 1.33 * DEPTH(I) ** 1.67
22  GO TO (90, 27, 91, 65), MDTEST

27  TQ(I) = 0.
OF(I) = 0.
INDEX1(I) = 4
GO TO 9
91 MDT = MDTEST - 1
DELTS = SEEPG
DELTS = SEEPG * AREASP / AU(i)
IF (DEPTH(i) .LE. 0.10) DELTS = 0.
QLEFTS = QLEFT + DELTS
GO TO 26

90 MDT = MDTEST
26 CALL HEAD(DEPTH, I)
GO TO (93, 40), MDT
40 GO TO (93, 38), JDRAIN
38 CALL DRNAGE( DRRNPR, CFACTR, SPACNG, FFCTN, HYDRCD, DELT, QLEFT)
   1, QTILE8, QTILE9, QIN1, QIN2, HWT1, SDLT, JKJ, I, HT1, WATRT, HMAIN, ELEVMN,
   2TD, QTILE1, QTILE2, HWT2, QSUBMN, AU, TOELEV, SLPSUB, HWT2, TESTDR)
93 IF (OF(i).NE.0.) GO TO 30
INDEX1(i) = 4
INDEX2 = 1
IF (I.EQ.1) GO TO 31
IF (TQ(I-1).LE.0.) GO TO 31
GO TO 30
31 IF (QSUBMN(i).LT.0.) QSUBMN(i) = 0.
30 GO TO (21, 39), MDT

CALCULATES MAIN TILE DISCHARGE AND HEAD IN THE MAIN TILE LINE
AFTER THE SUBMAIN DISCHARGE HAS BEEN CALCULATED - FOR MDTEST = 3

39 IF (I-1) 41, 41, 45
41 TQ(I) = + OF(i) + QSUBMN(I)/24./3600.
GO TO 46
45 TQ(I) = + OF(i) + TQ(I-1) + QSUBMN(I)/24./3600.
46 IF (TQ(I).EQ.0.) H(I) = TOELEV + ELEVMN(I)
   HMAIN(I) = H(I)
   GO TO 9

21 IF (I-1) 7, 7, 8
7 TQ(I) = OF(i)
GO TO 9
8 TQ(I) = OF(I) + TQ(I-1)
GO TO 9
C
C CALCULATES THE HEAD IN THE DEPRESSIONAL AREA, MAIN TILE DISCHARGE
C AND HEAD IN MAIN TILE LINE AFTER THE SUBMAIN DISCHARGE HAS BEEN
C CALCULATED - FOR MDTEST = 4
C
65 OF(I) = 0.
DELTs = SEEPG
DELTs = SEEPG * AREASP/AU(I)
IF (DEPTH(I) .LE. 0.10) DELTs = 0.
QLEFTs = QLEFT + DELT
INDEX1(I) = 4
GO TO (67, 66), JDRAIN
66 CALL DRNAGE (DRNPOE, CFAC, SPACNG, FPCTN, HYRCD, DLT, QLEFTs, MDTEST = 4)
1, Q TILE8, QTILE9, QIN1, QIN2, HWT1, SDELT, JKJ, I, HT1, WATERT, HMAIN, ELEVMN,
2, TD, QTILE1, QTILE2, HT2, QSUBMN, AU, TOELEV, SLPSUB, HWT2, TESTDR)
67 IF (I - 1) 71, 71, 73
TQ(I) = QSUBMN(I)/24./3600.
GC TO 75
71 TQ(I) = QSUBMN(I)/24./3600. + TQ(I-1)
73 IF ('(Q(I) - QFULL(I))' 77, 77, 79
75 IF ('(Q(I) - QFULL(I))' 77, 77, 79
77 QUOT) = TQ(I)/QFULL(I)
DMAIN(I) = DFLOW(QUOTD) * TD(I)
HMAIN(I) = ELEVMN(I) + TOELEV + DMAIN(I)
GO TO 9
79 HMAIN(I) = HMAIN(I+1) + ((TQ(I)*TQ(I))/CONST1(I) * CONST1(I)) * 
1 Q(T(I))/ABS(TQ(I))
IF (HMAIN(I) - E(I) - D21(I)) = 81, 81, 82
81 82 WRIT3 (6, 85) I, SDELT(JKJ)
85 FORMAT(' ', 'T46', 'I4', 'T70', 'F6.2', 'T2', 'MAIN TILE HEAD EXCEEDS WATER SURFACE
1 AT DEPR.'53', ' TIME EQUAL TO')
HMAIN(I) = E(I) + D21(I)
GO TO 9
C
C CALCULATES OVERLAND CHANNEL FLOW AND TOTAL OUTFLOW FROM A
DEPRESSIONAL AREA

9 IF(E(I) + DEPTH(I) - PCEL(I) - ZFW) 10, 10, 11
10 CQ(I) = 0.
   INDEX2 = 1
   GO TO 12
11 Y = W * COEF * (E(I) + DEPTH(I) - PCEL(I))
   CC20 = Y ** 1.5
   CC21 = (1.5/K/Y + 1.) ** 0.667
   CQ(I) = CC0 * CC20 / CC21
   INDEX2 = 2
12 IF(DEPTH(I) .EQ. 0.) GO TO 17
   GO TO (16, 16, 19, 19), MDTEST
13 IF (DEPTH(I) .GT. 0.10) GO TO 15
14 IF (SSMASM - SEEPEG) 13, 14, 14
15 DELTPS = SSMASM
   GO TO 15
16 DELTPS = SEEPEG
17 OS(I) = DELTPS / 12. * AREASP * 43560. / DELTM / 60.
   INDEX3 = 2
   GO TO 18
18 OUTFLO = OF(I) + CQ(I) + OS(I)
   JDRAIN = 2
100 RETURN

END

SUBROUTINE HEAD(DEP, I)

SUBROUTINE HEAD(DEP, I)
SIMULATION OF SURFACE INLET SERIES TILE FLOW BY KENNETH L. CAMPBELL

THIS SUBROUTINE COMPUTES THE MAIN TILE HEAD FOR EACH DEPRESSIONAL AREA

PARAMETER IDENTIFICATION

CD : SURFACE INLET ORIFICE COEFFICIENT
CONST1 : PARAMETER USED TO COMPUTE FULL TILE MAIN FLOW - SEE MAIN
DEP : DEPTH OF WATER IN DEPRESSION (FEET)
DS : SURFACE INLET DIAMETER (FEET)
E : BOTTOM OF DEPRESSIONAL AREA ELEVATION (FEET)
ELEVMN : ELEVATION OF TILE MAIN ABOVE MAIN OUTLET AT CENTER OF DEPRESSIONAL AREA (FEET)
FH2 : THIS FUNCTION EQUALS ZERO WHEN A ROOT OF THE EQUATION IS DETERMINED
FHX, FHY, FHZ : CONSECUTIVE ITERATION HEAD FUNCTION DEVIATIONS FROM ZERO
FPH2 : FIRST DERIVATIVE OF FUNCTION FH2
H : HEAD IN MAIN TILE LINE (FEET)
H1, H2, H3 : HYDRAULIC HEAD IN MAIN TILE AT CONSECUTIVE DEPRESSIONS (FEET)
H2A, H2B, H2C, H2C : CONSECUTIVE ITERATION HYDRAULIC HEAD VALUES (FEET)
HH : NEW APPROXIMATION OF HEAD IN MAIN TILE LINE (FEET)
IE : DEPRESSION NUMBER
INDEX1 : INDEX PARAMETER WHICH INDICATES THE TYPE OF SURFACE INLET
FLOW - SOURCE = FUNCTION OUTFLO
IOVER, IKEN, ICINDY : INDEX PARAMETERS USED WITH BISECTION METHOD
JK, KK : ITERATION PARAMETERS
KLC : PARAMETER FOR ERROR ANALYSIS OUTPUT WHEN SUBROUTINE FINDS TROUBLE
KTEST3, KTEST2, KTEST1 : INDEX PARAMETERS USED IN TEST FOR SOLUTION OSCILLATION
NUELUN : NUMBER OF DEPRESSIONS IN ELEMENTAL WATERSHED
OF : SURFACE INLET DISCHARGE (CFS)
PQ1, PQ3, PQ2 : FIRST DERIVATIVE OF MAIN TILE FLOWS AND SURFACE INLET FLOW
Q1, Q3 : MAIN TILE FLOW ABOVE AND BELOW A SURFACE INLET (CFS)
Q2 : ACTUAL SURFACE INLET FLOW (CFS)
COMMON QTILE1,QTILE2
COMMON D1,D2,PCEL,TD,H,TOELEV,MNT,MNC,NUELUN,AU,L,CONST1,1K,QU,S,O1,O2,OF,I1,I2,ZFD,MDTEST,INDEX1,INDEX2,Y
COMMON HMAIN,ELEVMN,QFULL,HYRDCD,DNRPOR,PPCTN,1CFACTR,SPACNG,HT1,HWT1,QIN1,HWT2,DELM1,SDELT,JKJ,QTILE9,WATERT
COMMON QLEFT,JDRAIN,QSUBMN,AB,QTILE8,INDEX3,DFMAIN,HT2, QIN2
COMMON WEIRK,CD,SLPSUB,OS,D21,WWCOEF,DELTFS,FCINFL,SSSMAS
COMMON TESTDR,TESTRO,ZFW,DS,MM,lO,CONST3
DIMENSION DEP(25),HWT2(25)
DIMENSION HH(25)

2700 JK=0
HH(NUELUN+1)=H(NUELUN+1)
GO TO 23
22 JK=JK+1
IF (JK-10) 32,33,33
33 WRITE (6,80) HH(IE),H(IE),IE,SDELT(JKJ)
80 FORMAT (2X,'ITERATIONS EXCEEDED 10 FOR HH=',F6.2,',H=',F6.2,' AT DE
1PRESSION','I2','TIME',F6.2)
GO TO 41
32 DO 30 IE=I,NUELUN
H(IE)=HH(IE)
30 CONTINUE
   GO TO 24
23  II=NUELUN-I+1
24  DO 3 J=1,II
   iOVer=1
   IKFN=1
   ICINDY=1
   KTEST3=0
   KTEST2=0
   H2A=0.
   H2B=0.
   H2C=0.
   FHZ=0.
   FHY=0.
   KK=1
   IE=NUELUN+1-J
   IF (DEP(IE)-ZFD) 1,2,2
1    QW2=0.
   GO TO 8
2    QW2=WEIRK*DS(IE)*(DEP(IE)-ZFD)**1.5
8    H2=H(IE)
    H3=HH(IE+1)
   IF (IE.EQ.1) GO TO 4
   H1=H(IE-1)
   GO TO 5
4    Q1=0.
    PQ1=0.
5    IF (IE.EQ.1) GO TO 6
   IF (1.EQ.H2) GO TO 42
   Q1=CONST1(IE-1)*SQRT(ABS(H1-H2))*H1-H2)/ABS(H1-H2)
   P01=-CONST1(IE-1)/2./SQRT(ABS(H1-H2))
   GO TO 6
42   Q1=0.
    PQ1=0.
6    IF (1.EQ.H3) GO TO 43
   Q3=CONST1(IE)*SQRT(ABS(H2-H3))*H2-H3)/ABS(H2-H3)
   PQ3=CONST1(IE)/2./SQRT(ABS(H2-H3))
GO TO 18
43 Q3=0.
PQ3=0.
18 IF (E(IE)+DEP(IE).EQ.H2) GO TO 19
   Q02=CD*3.1416*DS(IE)**2/4.*SQRT(64.4*ABS(E(IE)+DEP(IE)-H2)) *(E(IE)
1+DEP(IE)-H2)/ABS(E(IE)+DEP(IE)-H2)
   GO TO 17
19 Q02=0.
17 IF (E(IE)+DEP(IE).LT.H2) GO TO 14
   IF (DEP(IE).GE.DS(IE)) GO TO 14
   IF (Q02.LT.QW2) GO TO 14
   Q2=QW2
   INDEX1(I)=1
   PQ2=0.
   GO TO 10
14 Q2=Q02
   IF (E(IE)+DEP(IE).EQ.H2) GO TO 16
   PQ2=-64.4*CD/2.*3.1416*DS(IE)**2/4./SQRT(64.4*ABS(E(IE)+DEP(IE)-H2
1))
   GO TO 15
16 PQ2=0.
15 INDEX1(I)=2
10 FH2=Q1+Q2-Q3+QSUBMN(IE)/24./3600.
   IF (ABS(FH2)-0.010)7,7,9
C C TESTS FOR SOLUTION OSCILLATION
C
9 H2D=H2A
   H2A=H2B
   H2B=H2C
   H2C=H2
   FHX=FHY
   FHY=FHZ
   FHZ=FHZ
   GO TO (55,260),IOVER
55 IF (FH2)50,50,51
50 KTEST1=1
GO TO 56
51 KTEST1=2
56 IF (KTEST2-KTEST1) 52, 53, 52
52 IF (KTEST1-KTEST3) 53, 54, 53
53 IOVER=1
   KTEST3=KTEST2
   KTEST2=KTEST1
   GO TO 200
54 IOVER=2
   GO TO 260
C
200 FPH2=PQ1+PQ2-PQ3
   IF (FPH2) 75, 85, 81
   81 H2=H2+2.
      KLC=2
      GO TO 12
   85 H2=H2+1.
      KLC=3
      GO TO 12
   75 KLC=1
      H2=H2-FH2/FPH2
   GO TO (12, 264), IOVER
C
C USE THE BISECTION METHOD TO FIND NEW ROOT APPROXIMATION IF THE
C RESULTS OF NEWTON'S METHOD OSCILLATE
C
260 IF (FHX) 265, 265, 270
265 IF (FHZ) 266, 266, 275
266 IF (FHY) 280, 280, 281
280 GO TO (282, 283), ICINDY
282 IKEN=2
   ICINDY=2
283 GO TO (284, 285), IKEN
284 H2DD=H2D
   IKEN=1
285 H2=(H2DD+H2)/2.
   GO TO 271
281 IF (ABS(FHX)-ABS(FHZ)) 267, 267, 269
267 H2=(H2A+H2B)/2.
    GO TO 271
269 H2=(H2B+H2C)/2.
    GO TO 271
274 H2=(H2A+H2C)/2.
    GO TO 271
270 IF (FHZ) 268, 268, 286
286 IF (FHY) 281, 281, 280
268 IF (FHY) 272, 272, 273
273 IF (ABS(FHX)-ABS(FHY)) 274, 274, 269
272 IF (ABS(FHY)-ABS(FHZ)) 267, 267, 274
275 IF (FHY) 273, 273, 272
271 CONTINUE

C
12 KK=KK+1
380 IF (KK-10) 5, 5, 11
11 GO TO (69, 77, 78), KLC
69 WRITE(6,60) IE,JKJ,SDELT(JKJ),FH2
60 FORMAT (1X,T10,'ITERATIONS EXCEEDED 10 FOR DEPRESSION NO. ',I4,
     1'T70,'ELEMENTAL WATERSHED',I5,'/','T10,'FOR TIME','F7.2','T30,'AND FH2= '
     2,F10.5)
    GO TO 7
77 WRITE(6,79) IE
79 FORMAT (1X,T10,'ITERATIONS EXCEEDED 10 FOR DEPRESSION NO.',I4,/, 
     1'T10,'DERIVATIVE OF FUNCTION FH2 IS POSITIVE')
    GO TO 7
78 WRITE(6,82) IE
82 FORMAT (1X,T10,'ITERATIONS EXCEEDED 10 FOR DEPRESSION NO.',I4,/, 
     1'T10,'DERIVATIVE OF FUNCTION FH2 IS ZERO')
    7 IF (H2.LT.TOELEV+ELEVMN(IE)) H2=TOELEV+ELEVMN(IE)
     HH(IE)=H2
    3 CONTINUE
     DO 21 IE=I,NUELON
         IF (ABS(HH(IE)-H(IE))-0.03) 21, 21, 22
21 CONTINUE
41 H(I)=HH(I)
PARAMETER IDENTIFICATION

THIS SUBROUTINE COMPUTES THE LATERAL AND SUBMAIN TILE DISCHARGES

END

100 RETURN

OP(I)=OZ
C
HWT2 : HEIGHT OF WATER TABLE ABOVE LATERAL TILE AT END OF TIME INTERVAL (FEET) 4830
C
FEET)
C
HYDRCRD : HYDRAULIC CONDUCTIVITY OF ELEMENTAL WATERSHED SOIL (FEET/DAY) 4860
C
I : DEPRESSION NUMBER 4850
C
NTILE : NUMBER LATERAL TILE LINES AFFECTED BY ENERGY HEAD IN MAIN TILE NTILES, BNTILE : NUMBER OF LATERAL TILE LINES IN DEPRESSIONAL AREA 4880
C
QIN1 : RATE OF INFLOW TO WATER TABLE AT START OF TIME INTERVAL (CUBIC FEET/DAY) 4900
C
QIN2 : RATE OF INFLOW TO WATER TABLE AT END OF TIME INTERVAL (CUBIC FEET/DAY) 4920
C
QLEFT : AMOUNT OF WATER WHICH PERCOTLATED THROUGH SOIL PROFILE (INCHES) 4940
C
QSUB : DISCHARGE FROM SUBMAIN TILE (CPS) 4950
C
QSUBMN : DISCHARGE FROM SUBMAIN TILE (CUBIC FEET/DAY) 4960
C
QTILE1 : WATER TABLE WATER FLUX AT START OF TIME INTERVAL (FEET/DAY) 4970
C
QTILE2 : WATER TABLE WATER FLUX AT END OF TIME INTERVAL (FEET/DAY) 4980
C
QTILE8 : WATER TABLE WATER FLUX AT START OF TIME INTERVAL (FEET/DAY) 4990
C
QTILE9 ; WATER TABLE WATER FLUX AT END OF TIME INTERVAL (FEET/DAY) 4990
C
SLPSUB : SUBMAIN TILE SLOPE (FEET/FOOT) 5000
C
SPACNG : LATERAL TILE LINE SPACNG (FEET) 5010
C
TD : MAIN TILE DIAMETER (FEET) 5020
C
TESTDR : TOLERANCE FACTOR USED TO TERMINATE ITERATIVE PROCEDURE 5030
C
TOELEV : ELEVATION OF MAIN TILE OUTLET INTO DRAINAGE DITCH (FEET) 5040
C
WATERT : ELEVATION OF WATER TABLE (FEET) 5050
C
******************************************************************************
C
DIMENSION SDELT(6), HT1(25), WATERT(25), HMAIN(26), ELEVMN(26), TD(25) 5060
1, Q TILE1(25), Q TILE2(25), HT2(25), QSUBMN(25), AU(25), Q TILE8(25), 5070
2Q TILE9(25), HWT1(25), HWT2(25)
C
2600 DELTD = DELTM/1440.
C
QIN2 = (QLEFT/12.)* SPACNG/DELT D
C
CONVER = SQRT (AU(I)*43560.)
C
UFACTR = DRNPO R*CPACTR*SPACNG*SPACNG*PFCTN/HYDRCRD/DELT D
C
CALCULATES THE DISCHARGE FROM A LATERAL TILE LINE THAT IS NOT
AFFECTED BY THE HEAD IN THE MAIN TILE LINE

\[ \text{QTIILE}9(I) = \text{QTIILE}8(I) \]

\[ \text{N} = 0 \]

\[ \text{IF} (\text{QTIILE}9(I) - \text{HYRCD}) < 0.5 \]

\[ \text{FQ1} = (\text{QIN1} + \text{QIN2}) / 2. - \text{SPACNG} * (\text{QTIILE}8(I) + \text{QTIILE}9(I)) / 2. - \]

\[ \text{UFACTR} * \text{QTIILE}9(I) / (1. - \text{QTIILE}9(I) / \text{HYRCD}) + \text{DRNPOR} * \text{CFACTR} * \text{SPACNG} * \]

\[ \text{2 HWT1(I) / DELTD} \]

\[ \text{IF} (\text{ABS} (\text{FQ1}) - \text{TESTDR}) > 35, 35, 34 \]

\[ \text{IF} (\text{N} = \text{N} + 1) \]

\[ \text{QFACT} = 1. - \text{QTIILE}9(I) / \text{HYRCD} \]

\[ \text{FPQ1} = -0.5 - \text{UFACTR} * \]

\[ (1. / \text{QFACT} + \text{QTIILE}9(I) / \text{HYRCD} / \text{QFACT} / \text{QFACT}) \]

\[ \text{FDPO1} = - \text{UFACTR} * (2. / \text{HYRCD} / \text{QFACT} / \text{QFACT}) \]

\[ \text{QTIILE9(I)} = \text{QTIILE9(I)} - \text{FQ1} / (\text{FPQ1} - \text{FQ1} * \text{FDPO1} / 2. / \text{FPQ1}) \]

\[ \text{IF} (\text{M} = 8) 32, 32, 24 \]

\[ \text{WRITE}(6,102) \text{N, SDELT(JKJ), HWT2(I), I, JKJ, FQ1) \]

\[ \text{102 FORMAT(' T30, T53, F6.2, T86, T116, I3, T2,' NO. OF ITERATION} \]

\[ 1 \text{S EXCEEDS' T34, ' TIME EQUAL TO' T61, ' WATER TABLE (FT) EQUAL TO' T98, ' PHOLE NUMBER' / T3, 'ELEMENTAL WATERSHED', I5, T35, 'DRNAGE} \]

\[ \text{2 ROUTINE PART 1 AND FQ1= ' F10. 5) \]

\[ \text{35 HWT2(I)} = \text{SPACNG} * \text{FFCTN} * \text{QTIILE9(I)} / \text{HYRCD} / (1. - \text{QTIILE9(I)} / \text{HYRCD}) \]

\[ \text{IF} (\text{HWT2(I)} - 5.) 16, 16, 61 \]

\[ \text{WRITE}(6,99) I, SDELT(JKJ), JKJ, HWT2(I) \]

\[ \text{99 FORMAT(' T64, I4, T85, F6.2, T2, ' WATER TABLE ELEV. GREATER THAN T} \]

\[ \text{THE SOIL SURFACE FOR PHOLE' T68, ' TIME EQUAL TO' / T3, 'ELEMENTAL} \]

\[ \text{2 WATERSHED', I5, T35, 'DRNAGE ROUTINE PART 1, HWT= ' F4. 1) \]

CALCULATES THE DISCHARGE FROM THE LATERAL TILE LINE ADJACENT TO
AND PARALLEL WITH THE MAIN TILE LINE
C
16 IF (HMAIN(I) - ELEVMN(I) - TD(I) - TOELEV) 14, 14, 11
14 HT(I) = WATERT(I) - ELEVMN(I) - TD(I) - TOELEV
   GO TO 15
11 HT(I) = WATERT(I) - HMAIN(I)
15 N=0
   QTILE2(I) = QTILE1(I)
10 IF ( QTILE2(I) - HYDRCD) 150, 151, 150
151 QTILE2(I) = HYDRCD - 0.5
150 FQ = (QIN1 + QIN2 )/2. - (QTILE1(I) + QTILE2(I))*SPACNG/2. -
   1 UFACTR* QTILE2(I)/(1.- QTILE2(I)/HYDRCD) + DRNPO*CFCTR*SPACNG*
   2 HT(I)/DELT
   IF(ABS(FQ)-TESTDR) 25, 25, 13
13 N=N+1
   Q2FACT = 1. - QTILE2(I)/HYDRCD
   FPQ = 0.5 - UFACTR * (1./Q2FACT + QTILE2(I)/HYDRCD/Q2FACT/Q2FACT)
   FDPQ = - UFACTR * (2./HYDRCD/Q2FACT/Q2FACT +
   1 2.* QTILE2(I)/HYDRCD/Q2FACT/Q2FACT/Q2FACT)
   QTILE2(I) = QTILE2(I) - FQ/(FPQ - FQ*FDPQ/2./FPQ)
   IF (N- 8) 10, 10, 98
98 WRITE (6,100) N, SDELT(JKJ), HT2(I), I, JKJ, FQ
100 FORMAT(1 *,T30,I2,T53,F6.2,T88,E10.3,T116,I3,T2,'NO. OF ITERATION
   15 EXCEEDS'T34,' TIME EQUAL TO'T61,' WATER TABLE(FT)EQUAL TO'
   2T98,' PHOLE NUMBER' /T3,'ELEMENTAL WATERSHED',I5,T35,'DRNAGE
   2 ROUTINE PART 2 AND FPQ=',F10.5)
25 HT2(I) = SPACNG*FFCTN*QTILE2(I)/HYDRCD/(1.-QTILE2(I)/HYDRCD)
   IF(HT2(I)-6.) 75, 75, 48
48 WRITE (6,60) I, SDELT(JKJ), JKJ, HT2(I)
60 FORMAT(1 *,T64,I4,T85,F6.2,T2,' WATER TABLE ELEV. GREATER THAN T
   1 THE SOIL SURFACE FOR PHOLE'T68,' TIME EQUAL TO' /T3,'ELEMENTAL
   2 WATERSHED',I5,T35,'DRNAGE ROUTINE PART 2, HT= ',F4.1)

C
C COMPUTES THE SUBMAIN TILE DISCHARGE BASED ON A LINEAR LATERAL TILE
C DISCHARGE-DISTANCE FUNCTION BETWEEN THE LATERAL TILE LINE ADJACENT
C TO THE MAIN TILE LINE AND THE FIRST LATERAL NOT INFLUENCED BY THE
C MAIN TILE LINE HEAD
75 NTILES = CONVER / SPACNG + 1
5950
BNTILE = NTILES
5960
IF ( HMAIN(I) - ELEVMN(I) - TD(I) - TOELEV) 79, 79, 80
5970
79 QSUBMN(I) = BNTILE * QTILE9(I) * CONVER * SPACNG
6000
GO TO 84
6010
80 DSUBMN = (HMAIN(I) - ELEVMN(I) - TD(I) - TOELEV) / SLP SUB
6020
NTILE = DSUBMN / SPACNG + 1
6030
QSUBMN(I) = 0.
6040
76 DO 83 NN = 1, NTILES
6050
ANTILE = NTILE
6060
ANN = NN
6070
IF (NN - NTILE ) 77, 77, 78
6080
77 QSUBMN(I) = (QTILE9(I) - QTILE2(I)) * (ANN - 1.) * CONVER * SPACNG / ANTILE +
6090
1 QTILE2(I) * CONVER * SPACNG + QSUBMN(I)
6100
GO TO 83
6110
78 QSUBMN(I) = QSUBMN(I) + (BNTILE - ANTILE) * QTILE9(I) * CONVER *
6120
1 SPACNG
6130
GO TO 84
6140
83 CONTINUE
6150
84 QSUB = QSUBMN(I) / 24. / 3600.
6160
RETURN
6170
END
6180

FUNCTION VOLUME (DEPTH)

*********************************************************************

THESE FUNCTIONS COMPUTES THE VOLUME OF WATER STORED IN A DEPRESSION FOR A
GIVEN DEPTH OF WATER

FUNCTION VOLUME (DEPTH)
**Parameter Identification**

**Uses a Lagrangian Polynomial Approach**

This function computes the relative depth of flow in a circular conduit.

**Function**  

```
FUNCTION PFLOW(x)
END
```

```
RETURN
2 VOLUME = 43560*0.496*(DEPTH**2.424)
RETURN
1 VOLUME = 0.4
2800 IP(DPETH)**1.12
```

**Parameter Identification**
4 \[ (x-0.0) \times (x-0.2) \times (x-0.4) \times (x-0.6) \times (x-0.8)/0.0384 \]
RETURN
END

FUNCTION AREA (Q,RN,COEFBW)

*** THIS FUNCTION COMPUTES THE DRAINAGE DITCH CROSS-SECTIONAL FLOW AREA ***

PARAMETER IDENTIFICATION

AREA : DITCH CROSS-SECTIONAL AREA (SQUARE FEET)
COEFBW : TRAPEZOIDAL CHANNEL BOTTOM WIDTH COEFFICIENT : 2 TO 1 SIDE SLOPE
= 1.11 FOR 5 FOOT BOTTOM WIDTH
= 1.00 FOR 10 FOOT BOTTOM WIDTH
= 0.95 FOR 15 FOOT BOTTOM WIDTH
Q : DITCH DISCHARGE (CUBIC FEET/SECOND)
RN : MANNINGS ROUGHNESS COEFFICIENT FOR DITCH

2900 IF (Q) 1,2,3
1 WRITE (6,4) \( Q \)
4 FORMAT ('Q IS NEGATIVE ',1P10.4)
2 AREA=0.
RETURN
3 AREA=20.*((Q*RN/COEFBW)**.73)
RETURN
END
FUNCTION DSCHRG(A,RN,POWER,COEFBW)

******************************************************************************

This function computes the ditch discharge.

PARAMETER IDENTIFICATION

A : Ditch cross-sectional area (square feet)
COEFBW : Bottom width coefficient (see function area)
DSCHRG : Ditch discharge (cubic feet/second)
POWER : Parameter generated in function ASOL
RN : Mannings roughness coefficient for ditch

******************************************************************************

3000 IF(A) 1,2,3
1 WRITE(6,4) A
4 FORMAT(40X"IN FUNCTION DSCHRG A IS NEGATIVE \(F10.4")
2 DSCHRG =0.
RETURN
3 DSCHRG =(((A/20.)\(^POWER\)/RN)*COEFBW
RETURN
END

FUNCTION ASOL(LAMBDAL,ALPHAL,BETAL,A41,RN,COEFBW,TESTAS)

******************************************************************************

This function is used to compute the drainage ditch cross-sectional

8000
30 POWER = 1.73 - 1.

G0 TO 5

32 FORMAT (I) A M INCREASING TESTS TO .05.

WRITE (6, 32) TEST

TEST = TEST * 3.

31 N = 0

IF (N - 630, 31, 31)

6 N = N + 1

IF (ABS(PS) - ALPHA * TEST) (15, 15, 6)

PS = ALPHA + BETA - LAMBDA * PSI - AH/4.

Q4 = DSCPHR (AH, NH, POWER, COBDM)

5 POWER = 1.73

AH = AH + 1.

N = 0

IF (LAMBDA GT. 5000.) TEST = TEST * 3.

3100 TEST = TEST *

REAL LAMBDA

** 

************

************

TESTS = TEST : TOLERANCE FACTOR USED TO TERMINATE ITERATIVE PROCEDURE

04 = DIAM DISCHARGE (CUBIC FEET/SECOND)

LAMBDA = PARAMETER FROM MAIN PROGRAM

32 FORMAT (I)

PPZ = THIS FUNCTION EQUALS ZERO WHEN A ROOT (AH) IS DETERMINED

PPZ2 = SECOND DERIVATIVE OF FUNCTION, PPZ

PARAMETER FROM MAIN PROGRAM

BETA = PARAMETER FROM MAIN PROGRAM

PSI = CROSS-SECTIONAL AREA OF PITCH A1 END OF TIME INTERVAL (SQUARE FEET)

ALPHA = PARAMETER FROM MAIN PROGRAM

PARAMETER IDENTIFICATION

PARAMETER IDENTIFICATION

PARAMETER IDENTIFICATION

PARAMETER IDENTIFICATION

PARAMETER IDENTIFICATION

PARAMETER IDENTIFICATION

PARAMETER IDENTIFICATION

INTERVAL. (BALLET'S ITERATIVE METHOD IS USED)

POW AREA AT THE DOWNSTREAM END OF THE REACH AT THE END OF A TIME
Q4 = DSCHRG (A4, RN, POWER, COEFBW)
FPZ1 = -LAMBDA * (1./.73)*Q4 *0.05 - 0.5
POWER = 1./.73 -2.
Q4 = DSCHRG (A4, RN, POWER, COEFBW)
FPZ2 = -LAMBDA *(1./.73 -1.)*Q4*(1./.73)*0.05 *0.05
A4 = A4 - FZ/(FPZ1-FZ*FPZ2/(2.*FPZ1))
IF (A4) 14, 14.5
14 ASOL = 0.
RETURN
15 ASOL = A4
RETURN
END